Evaluating GHG Mitigation Potential from ESPC Projects

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Energy Technologies Area
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- Any errors are the responsibility of the authors.

Outline

Key Findings

Key Findings (1)

1. **Energy savings performance contracting (ESPC) delivers considerable greenhouse gas (GHG) emissions reductions, in addition to energy and water savings.**
   - Our analysis revealed that approximately two-thirds of the energy retrofit projects in eProject Builder (ePB) provided positive net benefits through cost savings and associated GHG reductions.
   - **Implication:** ESPCs are a valuable tool for agencies seeking cost savings and GHG reductions relating to energy and water efficiency gains.

2. **Multiple factors impact GHG emissions reductions for ESPCs, including the carbon intensity of the local grid.**
   - Our analysis finds that emissions reductions are affected by multiple factors, including the region of projects and carbon intensity of the local grid, the types of measures deployed, and the size of projects.
   - **Implication**: Government agencies with limited resources looking to maximize GHG reductions should consider the location of projects and the relative carbon intensity of the grid in their project portfolios alongside technology.

Key Findings (2)

3. **Some energy retrofit measures are more cost-effective than others in delivering GHG reductions.**
   - Our results indicate that individual measures provide a range of cost-benefit ratios but ESPC bundling of technologies and measures could help offset costs of higher measures and shorten payback periods.
   - **Implication:** ESPCs can effectively bundle efficiency measures to help ensure that projects can balance out overall in terms of achieving cost-effectiveness and GHG reductions.

4. **ESPCs contributed to substantial GHG reductions across market segments.**
   - Our analysis found that federal ESPCs were the most cost-effective across market segments. Projects deployed in the MUSH (municipalities, universities, schools, and hospitals) market also achieved emissions reductions and energy savings, but at a higher cost than in the federal market.
   - **Implication:** The MUSH market can target investments in ESPCs to maximize the cost savings while also ensuring GHG reduction.

Analysis Summary

Analysis Summary (1)

1. **The majority of energy retrofits measures in our analysis across all sectors delivered cost and/or GHG emissions reductions at a marginal abatement cost below $0, indicating that financial net benefits were greater than costs.**
    - The Marginal Abatement Cost (MAC) curve analysis revealed that approximately two-thirds of the energy retrofit projects in ePB provided positive net benefits through cost savings and GHG reductions.
    - Over half (58%) of energy retrofit measures had a lower cost per ton of carbon dioxide equivalent reduced ($/tCO2e) than the social cost of carbon (less than $51/tCO2e) (USWH 2021).
    - Lighting measures deployed in the West, Northeast, and Midwest regions had the lowest cost ($/CO2e reduced).
    - Technology categories and regions with the highest CO2e abatement potential include electric motors and drives in the Northeast and South regions and chilled/hot water/steam distribution systems in the Pacific region.

2. **Multiple factors can impact the GHG reduction of ESPCs**: The analysis finds that project emissions reductions are affected by multiple factors, including the region of projects and carbon intensity of the local grid, the types of measures deployed, and the size of projects.
    - For example, we found that technologies and regions with the highest GHG abatement potential (CO2e) include electric motors and drives in the Northeast and South, and chilled water, hot water and steam distribution systems in the Pacific.

Analysis Summary (2)

3. **Significant cost savings and emissions reductions can potentially be achieved with targeted and increased federal investments in performance contracting**
    - Federal ESPC investments can maximize their savings and emissions reductions impacts by targeting the most cost-effective highest impact projects, in terms of technologies deployed, location of deployment and project size.
    - Our analysis found that under a current business as usual (BAU) of ~$376 million/year in federal energy service performance contracting investment, the emissions reductions from these projects will achieve 1.4 million metric tons (MMT) of CO_2e annually through 2030.
    - If federal investments are targeted to cost-effective, higher impact projects, we find that a 66% **increase in annual federal investment** ($623M/year) between 2024 and 2030 could potentially achieve an annual reduction of 2.8 million metric tons with ESPC projects. However, a 308% ($1.54B/year) investment increase over the same period would be required to achieve those results if investment is not targeted.

4. **Bundling ESPC measures increases cost-effectiveness:** ESPC bundling of technologies and measures help offset costs of higher measures and shorten payback period. The MAC curve analysis focuses on individual technologies as opposed to bundled projects, while in ESPC projects, technologies and measures are bundled together, which results in greater overall project cost-effectiveness.

Background and Context

Overview

- This report explores the impact of implemented ESPC projects on GHG emissions reductions in the U.S. public buildings sector. While ESPC projects have historically been motivated by cost/energy savings and facility improvement needs, it is important to investigate the role that energy retrofits can play in achieving GHG emission reduction targets.
- The analysis draws from Lawrence Berkeley National Laboratory's (LBNL) ePB database, which contains approximately 3,000 energy retrofit projects implemented by energy service companies (ESCOs), mostly ESPC.
- This is the first report to empirically examine the GHG emissions impacts from ongoing ESPC projects in the U.S public sector. The analysis also provides the first publicly-available statistics about projects in ePB.
- The study summarizes:
  - GHG emissions reductions from energy retrofits for Scope 1—direct emissions generated from buildings, mostly from burning fossil fuels onsite (e.g. a gas furnace)—and Scope 2—indirect emissions from the power system that supplies electricity;
  - Project benefits in terms of net present value (NPV) and GHG emissions reductions, using a MAC curve analysis;
  - An analysis to answer how ESPC projects developed to-date (in the ePB database) have reduced GHG emissions from energy use in buildings; and
  - Estimates of the level of investment in ESPC projects needed to increase the rate of cost and energy savings and emissions reductions.
- This report examines how energy retrofit projects, including efficiency and renewable measures, can contribute to the decarbonization of the building sector. It is intended for policymakers, federal, state and local government officials and other potential ESPC customers, the ESCO industry, researchers, and other energy policy professionals.

Leveraging ESPC for Reducing Emissions from Buildings

- The buildings sector represents 34% of all U.S. GHG emissions (Walton 2022), while federal facilities—buildings, campuses, and installations—drive more than 80% of federal Scope 1 and 2 emissions from standard operations and are the largest contributing sector of emissions from standard federal operations (USCEQ 2016; DOE 2022; FEMP n.d. a).
- Since 1998, with the launch of indefinite-delivery, indefinite-quantity (IDIQ) ESPCs, the federal government has used ESPC contracting to "significantly reduce energy and operating costs and make progress toward meeting federal sustainability goals" (FEMP n.d. b).
- Several federal laws currently in effect support reducing energy use, costs and carbon emissions in buildings, including:
  - The Energy Policy Act of 1992 supported new buildings energy efficiency standards and directed the federal government to decrease energy consumption in federal buildings (Gov Info 1992).
  - The Energy Policy Act of 2005 supported deployment of renewable technologies that avoid GHG emissions; it also established federal building energy efficiency standards and enacted tax deductions for commercial building energy efficiency (Gov Info 2005).
  - The 2021 Infrastructure Investment and Jobs Act included $500M in funding for energy efficiency and renewable energy improvements in public schools (USCoC 2022).

Research on Decarbonization Benefits of Building Energy Retrofits

- Limited research has quantified the impact of energy retrofit projects on GHG emissions reductions using project data:
  - Ke et al. (2024) used system dynamic modeling of the impact of energy efficiency on decarbonization to meet net zero for residential buildings in China, and forecasted that improved building performance surpassed renewable energy systems and carbon sinks in terms of carbon emissions reductions, achieving a negative carbon state (Margini et al 2020).
  - Research by Nauclér and Enkvist (2009) and EDF (2021) modeled how energy retrofits contribute to decarbonization of buildings, but did not analyze actual project data.

- Many studies focus on cost savings, behavior and consumption change (Adan and Feurst 2016; Considine et al 2024; Scheer et al 2013), but few studies directly examine the impact that energy retrofit projects have on emissions reductions, even if reduced energy consumption results in GHG emissions reductions.

- This report aims to contribute to the existing literature by examining project-level data to empirically determine the contribution of building energy retrofits to decarbonization.

Methodology

Methodology Overview

- This study primarily uses data from LBNL's ePB database, along with additional sources mentioned below.
- After cleaning the data, we obtained a final dataset of 3,339 associated measure-level data points for the final analysis.
- Data Sources:
  - ePB database of ~3,000 [1] energy retrofit projects implemented by ESCOs.
  - U.S. Environmental Protection Agency (EPA) Emissions & Generation Resources Integrated Database (eGRID) of state-level emissions factors—used to develop GHG emissions reductions calculations (EPA 2024).
  - Construction inflation factors—Building Cost Index (BCI) compiled by Engineering News-Record (ENR) [2]—used to adjust project implementation prices and cost savings to 2022 dollars.
- Methodology
  - Using this dataset, the report examines GHG emissions reductions from electricity and natural gas, estimated net cost savings, and a MAC curve analysis.
  - See Technical Appendix for detailed overview of the methodology.

[1]While the original dataset used for this analysis has 2,365 projects which are in an pre-approved or approved status, the overall ePB database holds all projects statuses, including pending, which have no data or non-final data. We excluded the pending projects from the original dataset, but reference the total ePB projects in the database.
[2] Building cost Index (1929-2021). Available at: https://www.enr.com/economics/historical_indices

Calculations for the Analysis

NPV Calculation

To thoroughly explore the impact, we assess the GHG emissions alongside the NPV of projects and technology measures.

- The NPV of a project considers the project's lifetime (25 years) cost savings and subtracts the total implementation price. It is important to note that for this analysis, we will focus solely on the implementation cost and estimated annual cost savings. Financing costs and other associated recurring operating expenses (e.g., operations and maintenance costs) are excluded.

***See the Technical Appendix for a detailed explanation of these assumptions and calculations.**

MAC Curve Analysis Calculation

We calculated the NPV of projects and measure-level investments using the following steps:

1. **Total Benefits** were calculated using the total estimated annual cost savings—e.g. cost savings from electricity, natural gas, and other fuel sources—from the year of implementation for the next 25 years and adjusted to the present value of 2022.
2. **Implementation Price** was adjusted to the present value of 2022 [1].
3. **NPV** = Total Benefits - Implementation Price
4. **Total GHG emissions reductions**: Calculated using the sum of the total GHG emissions reductions for electricity, natural gas, and other GHG emissions reductions (kg CO_2e) and adjusted for the location of the project and relative avoided GHG emissions on the grid using the eGRID dataset.
5. **Marginal Abatement Cost:** We then divided the NPV by the Total GHG emissions reductions to calculate the marginal abatement cost of the project.

[1] We adopted a standardized approach by adjusting all implementation prices and their estimated annual savings as expressed in real $ for 2022 using two approaches: past values were inflated to 2022 values based on the BCI, whereas the future values have been discounted to 2022 values using a 3.7% rate, reflecting the average annual change in the BCI from 2005 to 2022.

GHG Emissions Reduction Analysis and Findings

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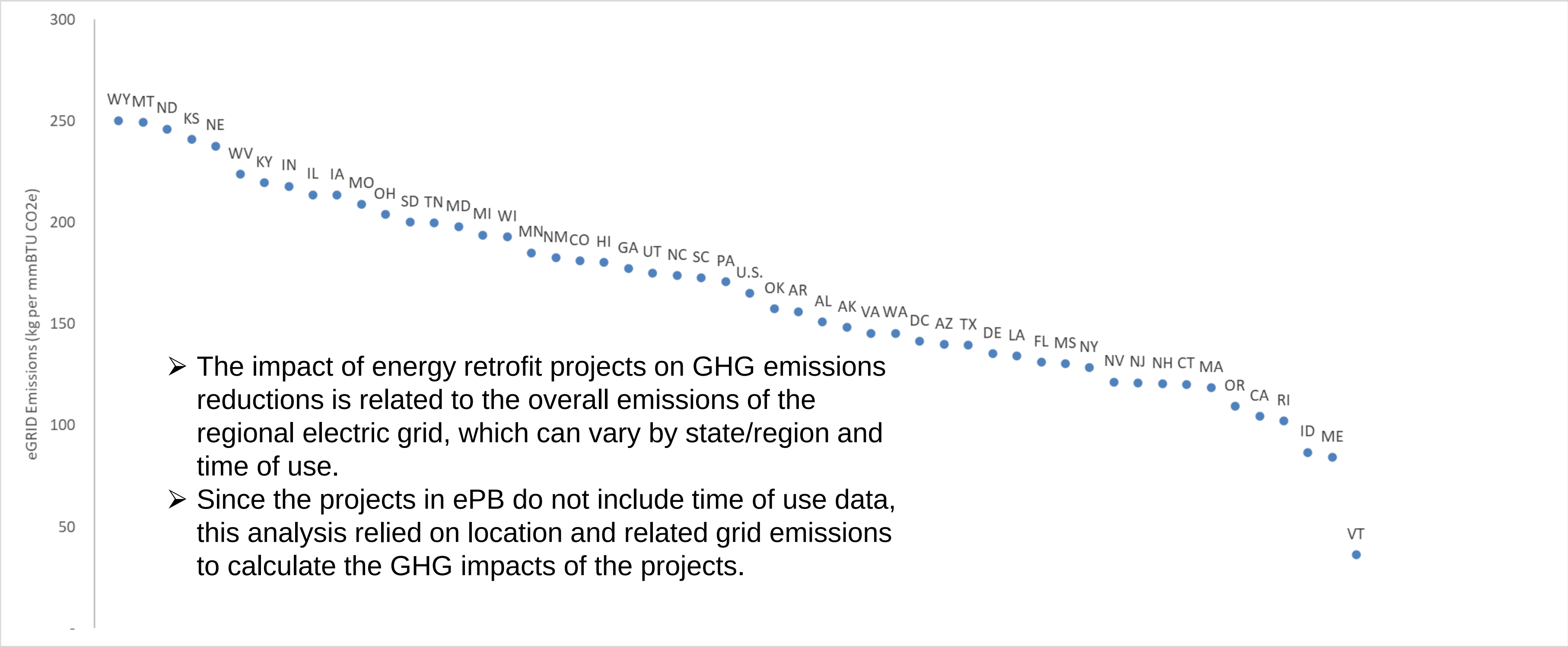
Analysis Findings on GHG Emissions Reduction Across Measures

- We conducted an analysis of the GHG emissions reductions of different energy retrofit measures across market segments and across U.S. states to compare how deployment levels and location affect the measures' relative impacts.

- The first set of figures on the following slides, Figures 1 - 3, show the relative emissions of the electric grid across U.S. states. In particular, Figure 3, illustrates how location affects the GHG emissions reductions impacts of energy efficiency measures, by focusing on one technology in particular—lighting—as deployed across the U.S.

- Figures 4a and 4b illustrate the total GHG emissions reductions of efficiency measures for the federal and MUSH market segments.

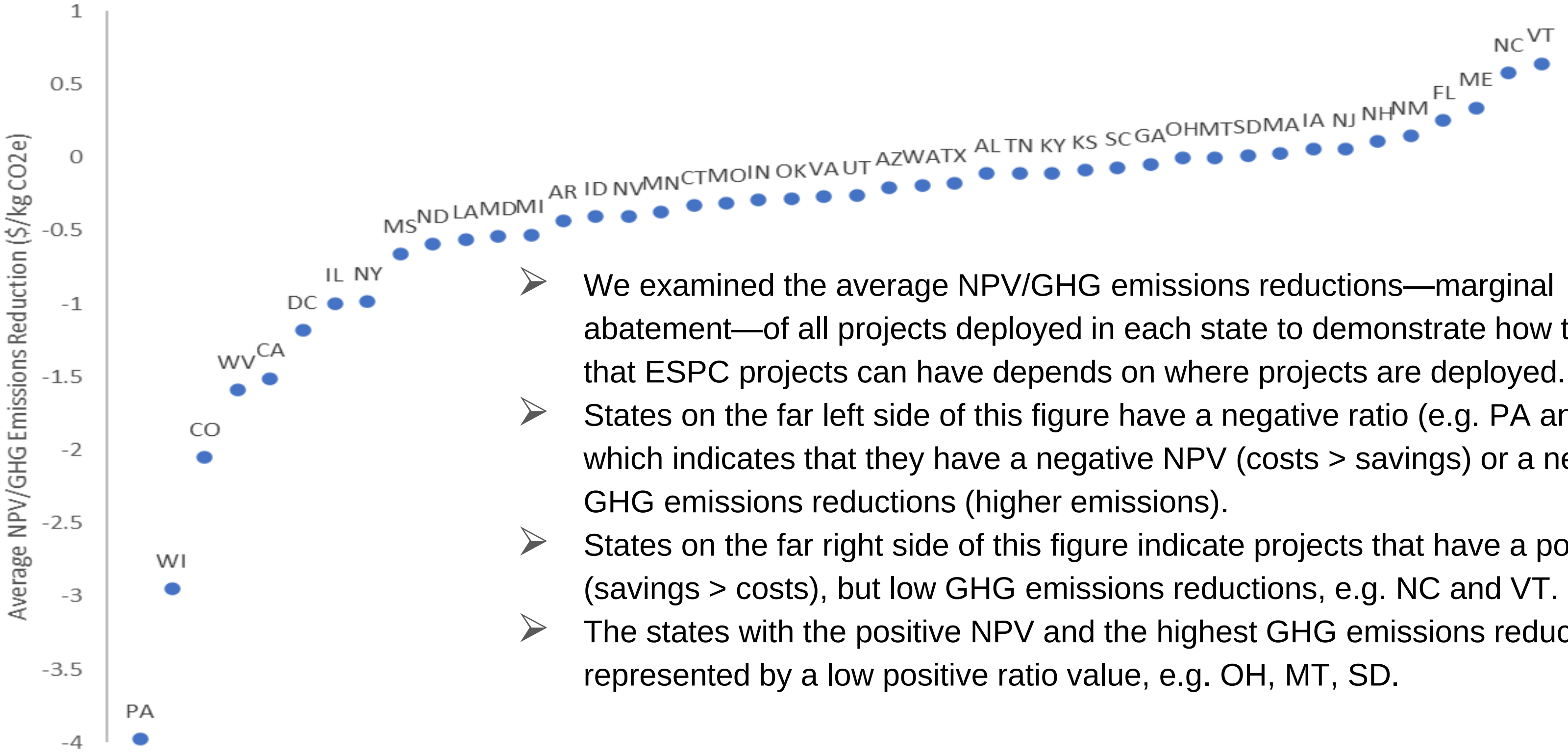
Figure 1. Average Annual Emissions of the Electricity Grid Across U.S. States



- The impact of energy retrofit projects on GHG emissions reductions is related to the overall emissions of the regional electric grid, which can vary by state/region and time of use.
- Since the projects in ePB do not include time of use data, this analysis relied on location and related grid emissions to calculate the GHG impacts of the projects.

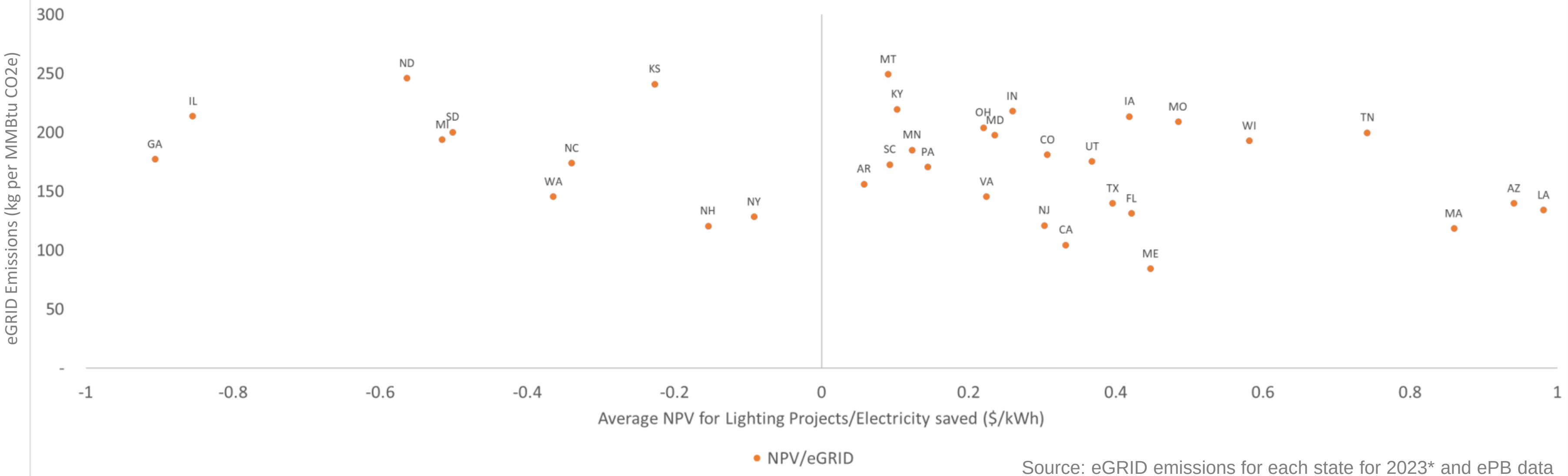
Source: EPA 2024

Figure 2: Average NPV per GHG Emissions Reduction by State for All Measures



- We examined the average NPV/GHG emissions reductions—marginal abatement—of all projects deployed in each state to demonstrate how the impact that ESPC projects can have depends on where projects are deployed.
- States on the far left side of this figure have a negative ratio (e.g. PA and WI), which indicates that they have a negative NPV (costs > savings) or a negative GHG emissions reductions (higher emissions).
- States on the far right side of this figure indicate projects that have a positive NPV (savings > costs), but low GHG emissions reductions, e.g. NC and VT.
- The states with the positive NPV and the highest GHG emissions reductions are represented by a low positive ratio value, e.g. OH, MT, SD.

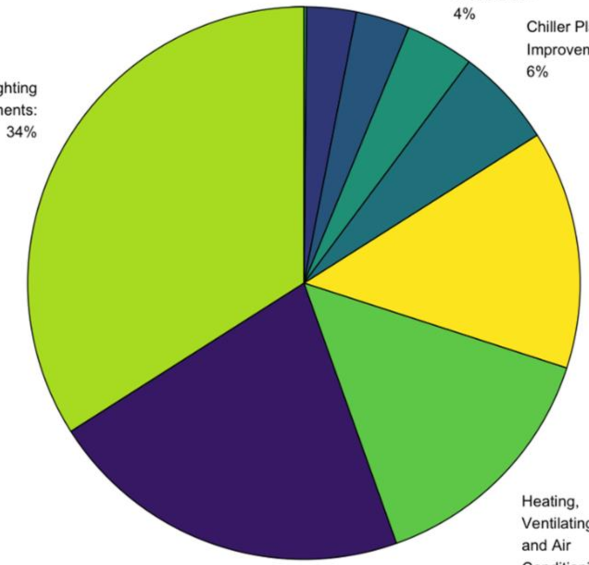
Figure 3: The Role of Geography on Lighting Measures GHG Emissions Reduction Impact



Source: eGRID emissions for each state for 2023* and ePB data

- The impact of geography, namely local grid emissions, is even more evident when focusing on the relative NPV/electricity savings for a particular technology deployed across the U.S. We take lighting as an example to demonstrate the variable GHG emissions reductions impact across states.
- The figure depicts the average NPV ($) for lighting projects over the electricity saved (kWh) across states and the relative grid emissions (eGRID) for that state.
- States all the way to the left along the Y axis have negative NPV, meaning lighting projects have higher costs than benefits, including NY and NH.
- Projects deployed in states on the bottom right quadrant are NPV positive, but a relatively cleaner grid—so less impact of lighting projects (e.g. in ME or CA).

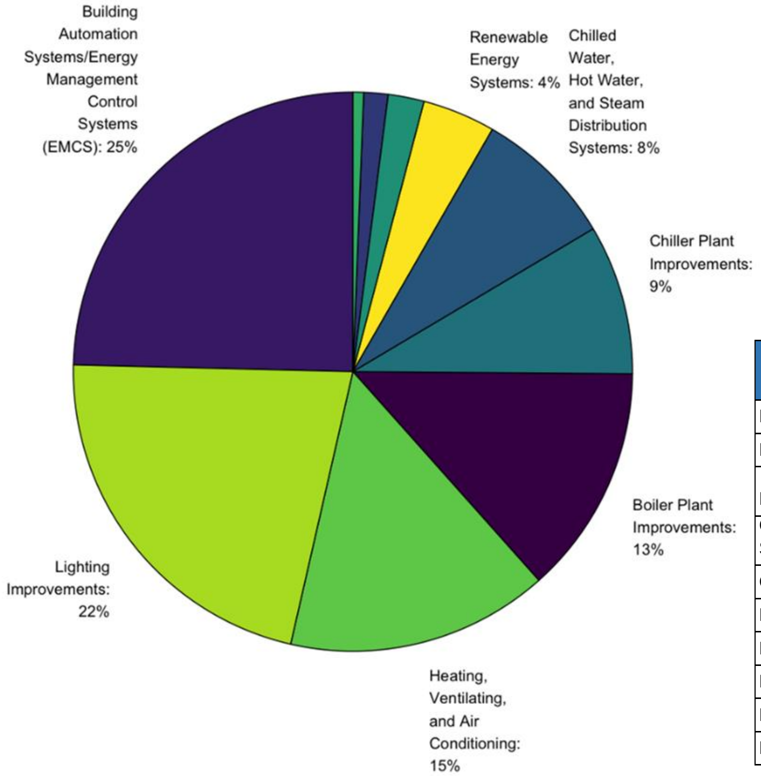
Figure 4a: Share of GHG Emissions Reduction by Measure Category for MUSH Projects



Measure	Total Measure Count MUSH	GHG Reduction (MMT CO2)
Boiler Plant Improvements	31	0.0
Building Automation/EMCS	106	0.6
Building Envelope Modifications	82	0.1
Chilled Water, Hot Water, and Steam Distr.	52	0.1
Chiller Plant Improvements	19	0.2
Distributed Generation	1	0.1
Electric Motors and Drives	38	0.0
HVAC	198	0.4
Lighting Improvements	444	1.0
Renewable Energy Systems	143	0.4

- We report the share of GHG emissions reductions in MUSH market projects by measure category.
- The share of GHG emissions are calculated as percentage share of GHG savings across the MUSH market by specific measure deployed across projects, assuming the full project life (25 years).
- The table displays the count of measures deployed in the MUSH market segment and the total GHG reduction in metric tons CO2e
- For the MUSH market segment, measure categories that make up the highest share of GHG emissions reductions are: 1) lighting improvements (34% of all savings), followed by 2) building automation/energy management control systems (EMCS) (21%), and 3) heating, ventilation, and air conditioning (HVAC) (15%).

Figure 4b: Share of GHG Emissions Reduction by Measure Category for Federal Projects



Measure	Total Measure Count Federal	GHG Reduction (MMT CO2)
Boiler Plant Improvements	123	3.6
Building Automation/EMCS	372	6.7
Building Envelope Modifications	95	0.4
Chilled Water, Hot Water, and Steam Distr.	174	2.2
Chiller Plant Improvements	199	2.4
Distributed Generation	20	0.6
Electric Motors and Drives	77	0.2
HVAC	336	4.1
Lighting Improvements	474	5.9
Renewable Energy Systems	123	1.2

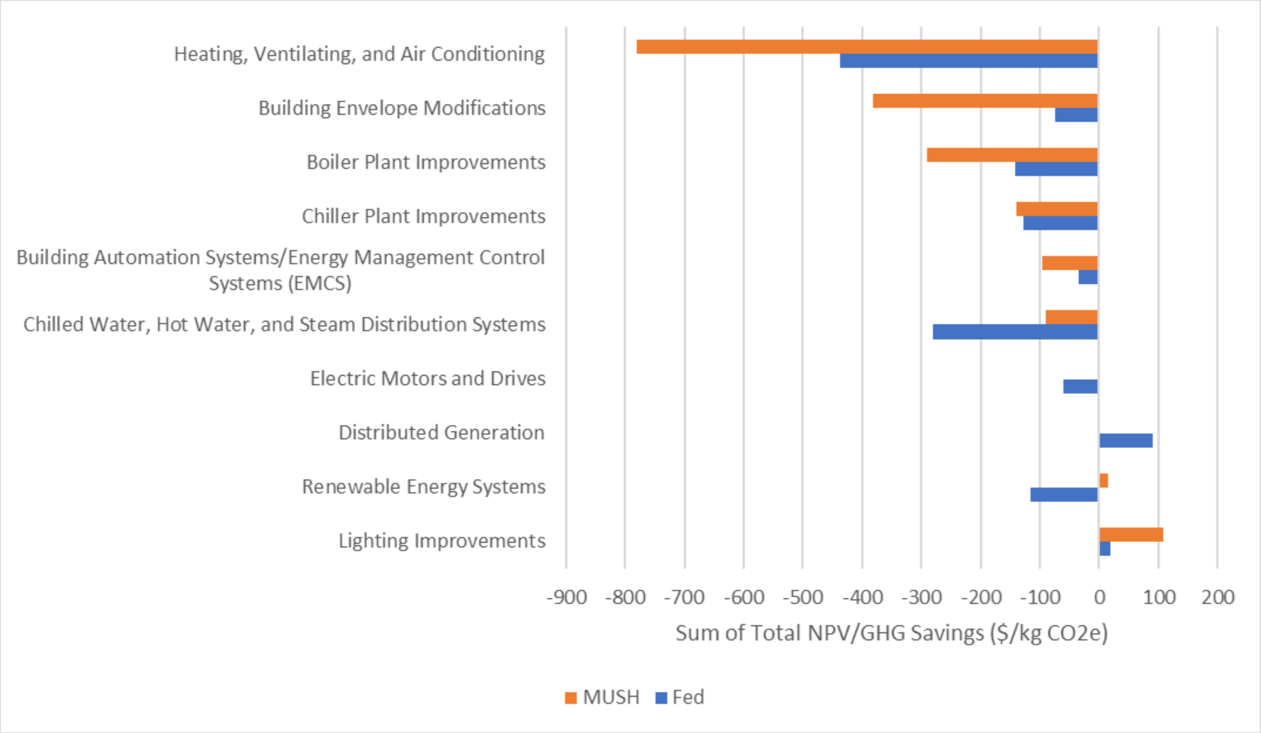
- We report the share of GHG emissions reductions in federal projects by measure category.
- The share of GHG emissions are calculated as percentage share of GHG savings across the federal market by specific measure deployed across projects, assuming the full project life (25 years).
- The table displays the count of measures deployed in the federal market segment and the total GHG reduction in MMTCO2e.
- In the federal market sector, the measure categories that make up the highest share of total GHG emissions reductions are: 1) building automation/ EMCS (25%), 2) lighting improvements (22%), and 3) HVAC (15%).

NPV and GHG Emissions Reduction Findings

NPV and GHG Emissions Reduction

- The following figures in this section examine a ratio of NPV over GHG emissions reduction to determine which projects have the best outcome in terms of cost savings (or low implementation price) combined with GHG emissions reductions.
- Figures 5 introduces the MAC curve analysis, which calculates the marginal abatement cost ($/CO2e) and abatement potential in giga-tons of CO2e (Gt CO2e) to depict which measures and geographic region have the best impact in terms of cost savings and GHG emissions reductions.

Figure 5: Sum of NPV/Total GHG Emissions Reduction Across MUSH and Federal Projects

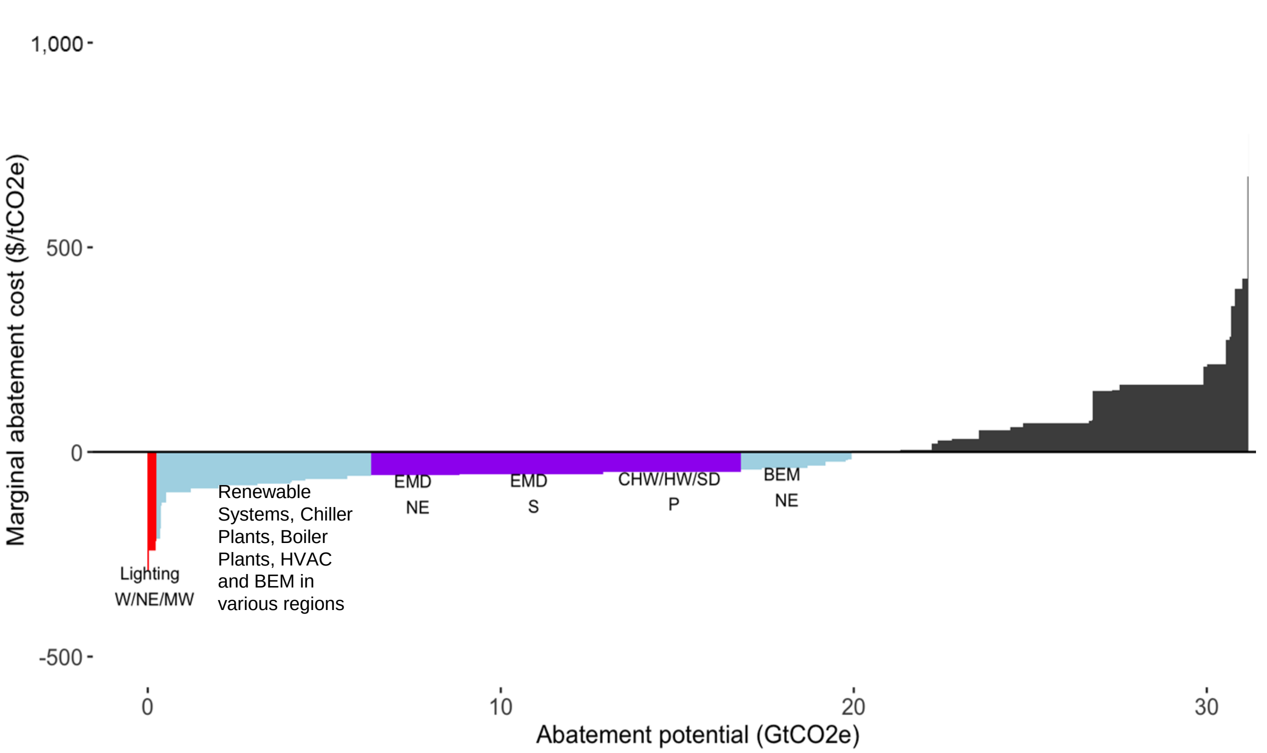


- When analyzing the NPV of projects for federal projects, the lowest cost projects with the highest GHG emissions reductions were lighting and distributed generation.
- In the MUSH market, the lowest cost projects with the highest GHG emissions reductions were also lighting projects, followed by renewable energy systems.
- The negative NPV/GHG emissions reductions are mainly due to costs being larger than net benefits, as most of the ongoing maintenance benefits are not captured in this analysis.

Measure-level Abatement Potential and Abatement Cost by Technology

- The MAC curve analysis calculates NPV as net benefits minus implementation price, indicating that a positive NPV is a good signal of overall cost-effectiveness (benefits > costs). When evaluating the ratio of NPV to GHG emissions reductions, a lower positive ratio signifies greater effectiveness—indicating that better GHG emissions reductions correspond to a lower ratio. However, for the MAC curve analysis, we note that the common practice for MAC curves is to display the positive NPV (NPV>0) as a negative value; thus, the negative value is a positive indicator.
- Figure 6 depicts both the scope of cost-effectiveness (y-axis) as well as abatement potential (x-axis) by technology and region.
- The major findings from the MAC curve analysis show:
  - Approximately two-thirds of the abatement potential (~20 GTCO2e) was achieved with a marginal abatement cost below $0, indicating that benefits surpassed costs; these benefits internalize monetized emission reductions.
  - 36% measure-level investments with positive marginal abatement cost (negative NPV with net GHG emission reductions) contributed to one-third of the overall potential reductions, amounting to ~11 GTCO2e reduced.
  - The majority of energy retrofits measures in our analysis across all sectors delivered cost and/or GHG emissions reductions at a cost less than the U.S. social cost of carbon ($51/tCO2e) (USWH 2021).
  - ESPC projects bundling of technologies and measures help offset costs of higher measures and shorten payback period. As the MAC curve analysis focuses on individual technologies as opposed to bundled projects some individual measures are depicted as more cost-effective than others, but in practice ESPC projects bundle technologies and measures together, which improves the overall cost-effectiveness of the project.

Figure 6: Measure-level MAC Curve Depicting the Efficacy of Investments in GHG Emissions Reduction Across Measure Technologies

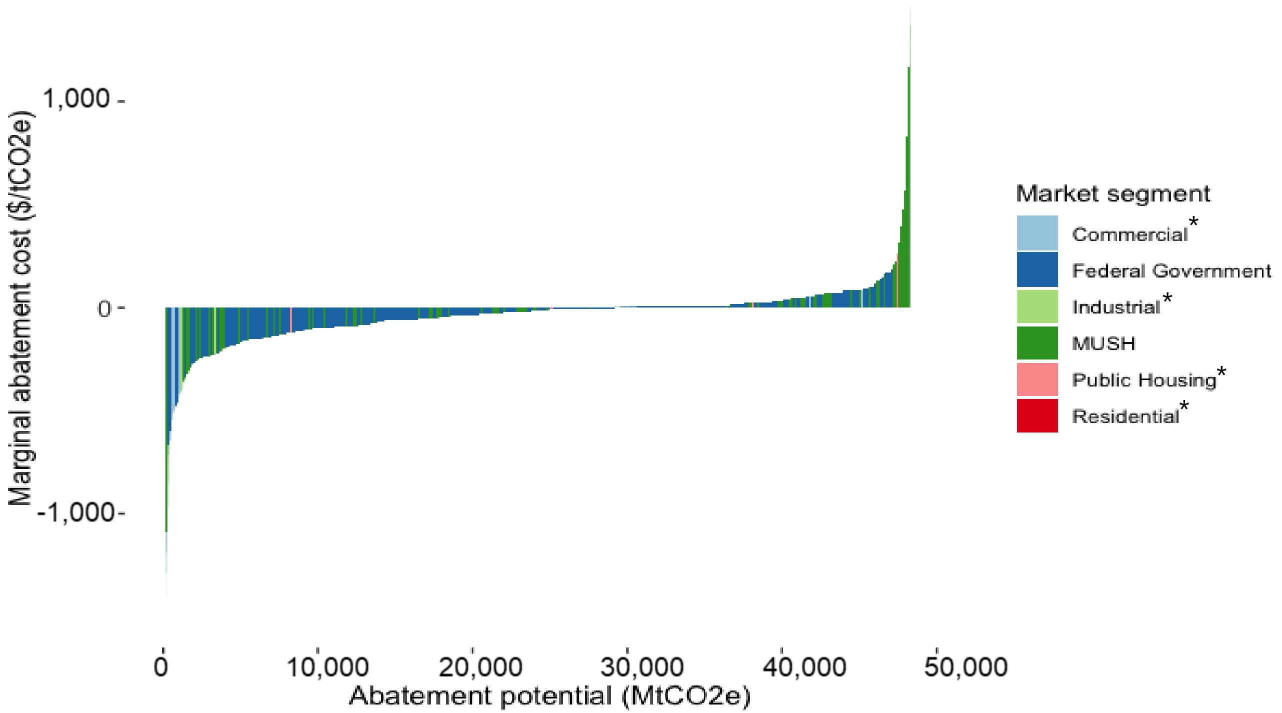


- In Figure 6, the y-axis indicates measures ranked by cost from lowest to highest according to height. Boxes below the x-axis reflect net savings (lower/deeper boxes indicate greater net savings), while black boxes above the axis represent emissions reductions garnered at a higher cost. The width of each box corresponds to the volume of emissions reduction potential (CO2e reduced). These factors together provide an initial assessment of the cost-effectiveness of mitigation opportunities, forming a basis for policy and investment decisions.
- **Marginal abatement cost:** Lighting measures deployed in: (1) West, (2) Northeast, and (3) Midwest regions had the lowest abatement cost ($/CO2e reduced).
- **Abatement potential:** The technology categories and regions with the highest abatement potential (CO2e reduced) include: (1) Electric Motors & Drives (EMD) in the Northeast and South regions, and (2) Chilled Water, Hot Water, and Steam Distribution Systems in the Pacific region. Building envelope modifications in the Northeast came in fourth in terms of technologies with high abatement potential and net benefits.

Key: Region acronyms: W (West), MW (Midwest), NE (Northeast), P (Pacific), and S (South) regions are categorized according the Census geographic regions. **Measure acronyms:** Lighting (Lighting improvements), EMD (Electric Motors and Drives), BEM (Building Envelope Modifications), and CHW/HW/SD (Chilled Water, Hot Water, and Steam Distribution Systems).

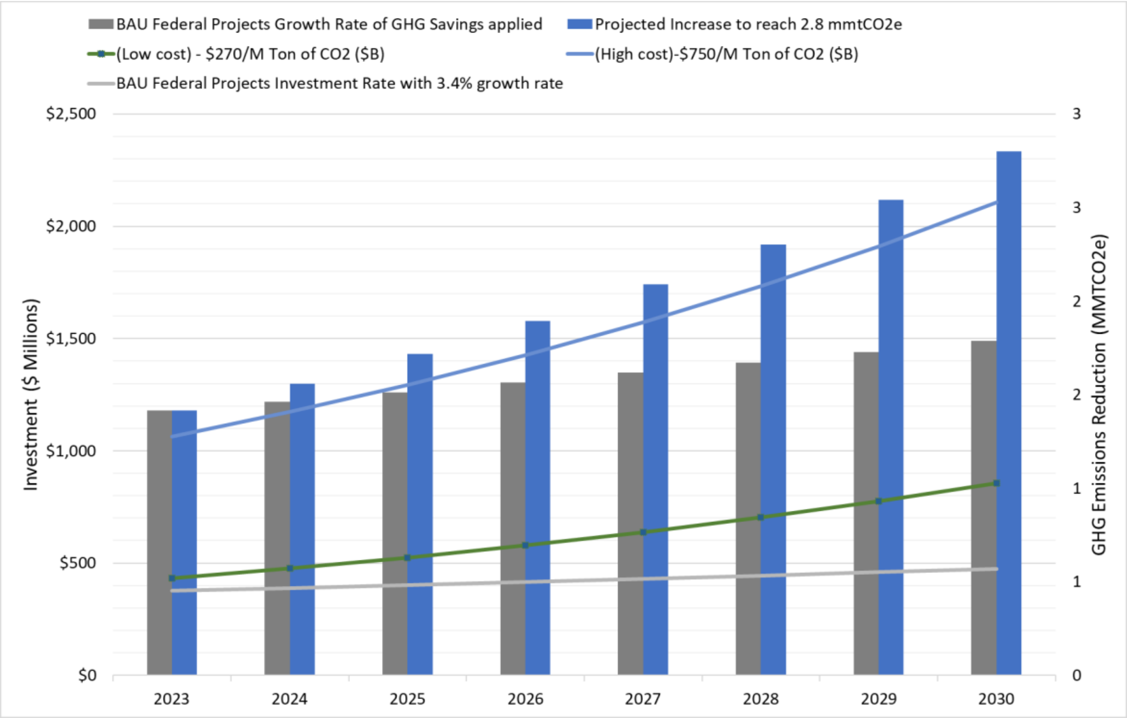
Figure 7: Project-level MAC Curve Depicting the Efficacy of Investments in GHG Emissions Reduction Across Market Segments

- This figure summarizes the abatement potential and costs for projects with GHG emission reductions across market segments using a MAC curve analysis.
- Approximately 61% of the abatement potential achieved net benefits with positive cost savings (i.e., marginal abatement cost < 0).
- Among projects with a the lowest costs to achieve emissions reduction (below $0/tCO2e), many are federal government projects. This finding may be partly attributed to the larger scale of federal government investments and the resulting economies of scale in GHG emissions reduction effectiveness.
- While MUSH projects also contributed to abatement potential with net benefits, some projects resulted in GHG emissions reductions but at higher marginal abatement costs than those of federal projects.



The limited number of projects within these segments (C&I, Public housing, Residential) leads to a very low overall abatement potential, meaning the total annual GHG emissions reduction is minimal.

Figure 8: Federal GHG Emissions Reduction Scenarios, 2023-2030



- As depicted in Figure 8, our analysis of the current BAU annual investment in ESPC reveals that it stands at approximately $376 million per year [1], with forecasted annual emissions reductions of only 1.41 MMTCO2e.
- Using a 95% confidence interval, we compare the BAU scenario to both a lower marginal cost investment case and a higher marginal cost investment case, with costs of $5.80 per kg CO2e and $14.34 per kg CO2e, respectively. This comparison helps us determine the investment required to achieving 2.8 MMTCO2e in annual emissions reductions, assuming a standard industry growth rate of 3.4% [2].
- The lower marginal cost investment case focuses on projects that achieve CO2e reductions at the lowest expense, while the higher marginal cost investment case represents projects that achieve the same reductions but at a higher cost.
- Our findings indicate that to double the emissions reductions to reach a goal of 2.8 MMTCO2e annually, federal ESPC investments will need to increase, but the percentage increase depends on how targeted the investments are.
  - **If federal ESPC investments are more targeted to the lower marginal abatement cost case– in terms of type of measure, location of deployment, and size of projects – a 66% increase in annual investment** ($623M/year) between 2024 and 2030 can achieve an annual reduction of 2.8 MMTCO2e with ESPC projects.
  - **If federal ESPC investments are less targeted, it could require an up to 308% increase in annual investment** ($1.54B/year) over the same period to achieve the same level of emissions reductions.

[1] $376 million/year in federal ESPC in the ePB database does not capture all federal ESPC activity; however, it exceeds the FEMP IDIQ program annual investment ($320 million/year for past 25 years), so is a reasonable proxy for BAU federal investment levels (FEMP n.d. c)
[2] We incorporated a 3.4% growth rate based on historic ESCO industry growth rates (Stuart et al. 2021).

Conclusions

Main Findings of the Analysis

- Overall, the MAC curve analysis found that the majority (two-thirds) of the abatement potential (~20 GtCO2e) was achieved with benefits that surpassed costs; these benefits internalize monetized emission reductions. These findings indicate that ESPC with net benefits contribute to GHG mitigation.
- This analysis estimates that energy retrofit projects have a measurable impact on reducing GHGs in addition to cost savings, particularly in the MUSH and federal markets; nevertheless, the impacts depend on the location of projects, the types of measures deployed, baseline conditions, and the size of projects (Scope 2 emissions).
- Federal projects include higher annual GHG emissions reduction potential at a lower cost compared to MUSH projects.
  - While MUSH projects also contributed to abatement potential with net benefits, some resulted in GHG emissions reductions, but at a higher cost.
- Our analysis of scenarios for federal ESPC investment revealed that if future federal ESPC investments are targeted (least marginal cost with highest emissions reduction impact based on type of measure, location of deployment, and size of projects), the federal government could double emission reduction rates over BAU activity to date to 2.8 MMTCO2e annually with an increase of 66% in investment (between 2024-2030). Absent targeted investment, an increase of over 300% may be required to achieve the same emission reduction rates.

Policy Implications and Additional Research

- The relative emissions of the grid and locations of deployment have a large impact on the efficacy of a particular ESPC measure on Scope 2 GHG emissions. The relative impacts on emissions and cost savings of ESPC projects vary by measure and the baseline conditions of the project.
- The relative abatement costs versus abatement potential should be a strong consideration, as there is evidence that certain ESPC measures have a higher cost savings combined with abatement, such as building automation/EMCS or lighting systems.
- ESPC projects can play a key role in emissions reduction, but this requires addressing barriers to ESPC deployment and promoting decarbonization measures by incentivizing GHG measures through appropriated dollars (e.g. the Assisting Federal Facilities with Energy Conservation Technologies (AFFECT) program).
- Further research can expand upon this analysis by exploring the impacts of various combinations of measure mixes and geographic locations. This investigation will help identify project strategies that could maximize the impact on achieving GHG emissions reduction targets while minimizing investment costs. By analyzing different combinations, researchers can uncover insights into which strategies are most effective in specific contexts, ultimately informing decision-making and optimizing resource allocation for future energy retrofit projects.
- Future analysis can also assist in evaluating AFFECT, ESPC, and other energy projects for the highest GHG impact and positive NPV over the entire project lifecycle. Such analysis would consider factors such as location, baseline conditions, the types of proposed measures, and expected future emission profiles of the grid.

Technical Appendix: Data Preparation

Data Cleaning Overview

- We conducted a rigorous analysis of relative GHG emissions reduction normalized by cost savings. We analyzed projects that started their performance period between 2005 and 2023 in the contiguous U.S.
- We focused on projects using the following categories: lighting improvements; HVAC; EMCS; renewable energy systems; chilled water, hot water, and steam distribution systems; chiller plant improvements; building envelope modifications; boiler plant improvements; electric motors and drives; commissioning; energy-related process improvements; distribution generation; appliance/plug load; and refrigeration.
- In the case of the measure-level investment data, we developed criteria for outlier detection and excluded measures that were considered outliers. From an initial dataset of 2,365 projects, we narrowed down the final dataset as follows:
  - Out of the initial pool, we excluded projects based on the criteria outlined in Table TA1 and set thresholds to identify and exclude projects with erroneous values, outliers, and/or out of scope.*
- The following slides provide further details on data cleaning.

Table TA1: Criteria for Outlier Removal

Category removed	Projects removed	Measures removed
Date (pre- 2005)	104	79
Location (outside U.S.)	3	
Electricity savings out of scope	92	
NG savings out of scope	71	
Other energy cost savings out of scope	43	
Implementation price (<$10K)	15	12,345
Total energy cst savings (<$400)	317	13,487
Too high cost savings	65	

*The projects and measures removed have been removed for multiple factors, such as both location and date, or date and implementation price, therefore the totals cannot be summed from this table

Data Cleaning: Project-Level Data

Out of the initial pool of 2,365 projects, we excluded projects based on the following criteria and thresholds to identify and exclude projects with erroneous values, as defined as follows (multiple criteria could be applied to a single project):

- Implemented before 2005 to focus more on more recent and potentially relevant practices (removed 104 projects).
- Located outside of the contiguous U.S. (removed 3 projects).
- Electricity Cost Savings per kWh Savings: Exclusion criteria were defined by estimated energy savings from electricity usage and the corresponding cost savings from electricity consumption. The thresholds were set at a lower limit of $0/kWh and an upper limit of $0.3/kWh, based on the unadjusted historical average price of electricity (removed 92 projects).
- Natural Gas Cost Savings per MMBtu Savings: Projects were excluded if the estimated cost savings from reduced natural gas usage divided by the estimated savings in natural gas consumption fell below $0/MMBtu (lower threshold) or exceeded $20/MMBtu (upper threshold, based on the historical price of natural gas) (removed 71 projects).
- Cost Savings from Other Energy Sources per MMBtu Savings: Exclusion criteria were defined by estimated cost savings from other energy sources divided by the estimated savings in other energy source consumptions. The lower threshold was set at $0/MMBtu, while the upper bound was set at $35/MMBtu (removed 43 projects).

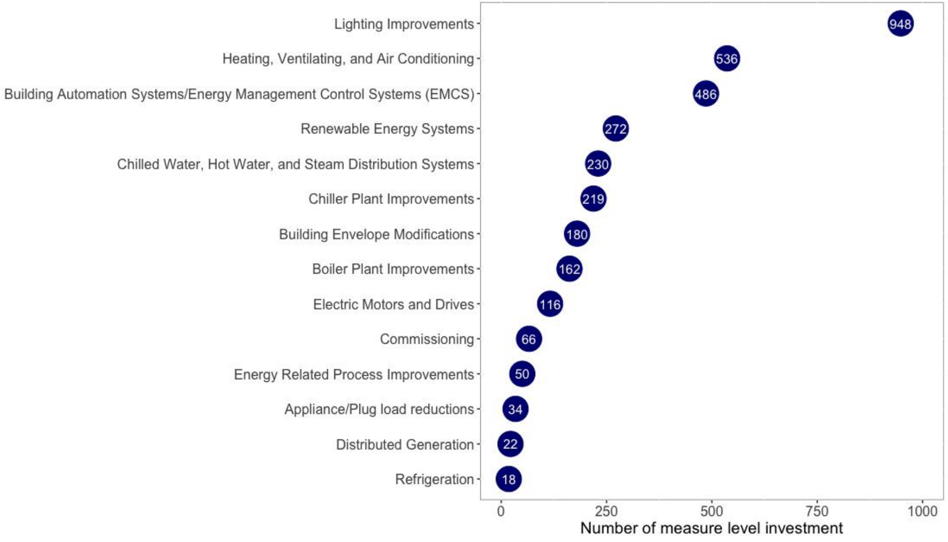
Beyond these constraints, we further refined the project-level investment data selection by excluding those that met any of the following criteria:

- Total implementation cost of less than $10,000 (removed 15 projects) and annual estimated savings of less than $400 at the project-level (removed 317 projects).
- Estimated cost savings deviated significantly from other projects, which are defined as projects with cost savings more than three standard deviations away from the mean, to avoid skewing the results (removed 65 projects).
- Projects with missing total implementation prices or estimated cost savings (removed 713 projects).

Data Cleaning: Measure-Level Data

- In the case of the measure-level investment data, we developed criteria for outlier detection and excluded measures that were considered outliers as out of scope. From an initial dataset, we narrowed down the final dataset as follows:
  - We excluded projects implemented before 2005 to focus more on more recent and potentially relevant practices (removed 749 measure-level investments).
  - We excluded investments with electricity cost savings outside the range of $0 to $0.3 per kWh, natural gas savings outside $0 to $20 per MMBtu, and savings from other energy sources outside $0 to $35 per MMBtu (removed 269 measure-level investments).
  - Measures that included a Total Implementation Price or Total Energy Cost Savings that were either missing or included a value that was $0 or less were also excluded from the dataset (removed 12,345 measure-level investments from total implementation price, 13,487 measure-level investments from total energy cost savings).
  - We excluded these projects with higher costs as outside of the scope of this analysis.
- Following the dataset cleaning, we obtained a final dataset of 3,339 measure-level data points.

Figure TA1. Distribution of measure-level data points by technology type.



Calculating GHG Emissions Reductions from Energy Savings

To compute GHG emissions reductions from electricity, natural gas, and other energy sources throughout the entire performance period, we employed the following calculations.

- **Natural gas GHG emissions reductions:** We multiplied the estimated natural gas energy savings by the EPA's emission factors. Specifically, we used CO2 factors, CH4 factors multiplied by CH4's global warming potential (GWP), and N2O factors multiplied by N2O's GWP.
- **GHG emissions reductions from other sources:** Some energy savings in ePB are categorized as 'Other' resources. This category includes coal, diesel, gasoline, heating oil, jet fuel, chilled water, purchased steam, or propane. Users often do not specify the exact resource type when entering data, so we estimate the GHG emissions reductions from these 'Other' sources by multiplying the total energy savings by a factor of 72.67 kg CO2/MMBtu obtained based on simple averages for GHG emissions factors for all the possible options for Other.
- Assumed no changes in emission factors from stationary combustion fuel sources in the future, we applied these factors consistently across the analysis.
- **Electricity GHG emissions reductions:** Electricity GHG emissions reductions were calculated by multiplying estimated electricity savings by state-level non-baseload emission factors from EPA's Master Non-Baseload eGRID Factors (2005-2022). To account for future grid greening, a multiplier based on the forecasted North America CO2 intensity trend for electricity generation (2000-2050) was applied to the 2022 North American eGRID data, reflecting the projected decline in CO2 intensity [1] [2].
- The total GHG emissions reductions were calculated by summing up the GHG emissions reduction from electricity, natural gas, and other energy sources and then multiplied by the duration of the term, which is assumed to 25 years for all the projects.
- Some projects resulted in GHG emissions reductions from only one source, while others exhibited substantial savings from one source and substantial emissions from others. Given the plausible occurrence of both scenarios, no additional outlier detection based on GHG saving was applied.

[1] https://www.epa.gov/egrid/data-explorer
[2] We did not incorporate time sensitivity of savings into our analysis. This would require hourly intensity factors to accurately capture the actual marginal contribution of a given measure. A single annual value masks variation in emissions reduction through the year. While out of the scope of this project, this is an area for future research.

Net Present Value Calculation

- A key objective of this paper is to assess the GHG emission reductions from ESPC projects that have been implemented.
- To thoroughly explore the impact, we assess the GHG impact alongside the NPV of projects and efficiency measures. The NPV of a project considers the project's lifetime (25 years)[1] cost savings and subtracts the total implementation price. It is important to note that for this analysis, we will focus solely on the implementation cost and estimated annual cost savings. Financing costs and other associated recurring expenses line costs are excluded.
- **Standardized Price and Savings Adjustments to 2022 Values:** We adopted a standardized approach by adjusting all implementation prices and their estimated annual savings as expressed in real U.S. $ for 2022 using two approaches: past values were inflated to 2022 values based on the BCI [2], whereas the future values have been discounted to 2022 values using a 3.7% rate, reflecting the average annual change in the BCI from 2005 to 2022.
- **NPV Calculation Over 25 Years**: Even though each of the projects has a set contract term over which the loan is amortized, it is assumed that these projects will continue to yield benefits even after this contract term ends. Therefore, a standardized 25-year timeframe was used for all projects to observe their accrued lifetime NPVs.

[1] Not all ESPC projects have a 25-year lifetime, but 25 years is held to be a standard contract term length by the industry and regulators. See: https://www.energy.gov/femp/about-federal-energy-savings-performance-contracts
[2] Inflation adjustments were made using the BCI, a comprehensive index compiled by ENR. It tracks changes in the prices of various factors of production relevant to the building trade, including materials, wages, salaries, and other inputs, relative to a base-year average.

MAC Curve Analysis Calculation

We calculated the NPV of projects and measure-level investments using the following steps:

1. **Total Net Benefits** were calculated using the total estimated annual cost savings from the year of implementation over the next 25 years and adjusted to the present value of 2022.

2. **Implementation Price** was adjusted for regional variations in labor costs across different states using the Cost of Living Index (COLI) published by the Economic Policy Institute and the Council for Community and Economic Research, and then adjusted to the present value of 2022.

3. **Net Present Value (NPV)** = Total Net Benefits - Implementation Price

4. **Total GHG Emissions Reduction**= Calculated using the sum of the total electricity GHG emissions reduction, total natural gas GHG emissions reduction, and total other GHG emissions reduction (kg CO2e) and adjusted for the location of the project and relative avoided GHG emissions on the grid using the eGRID dataset.

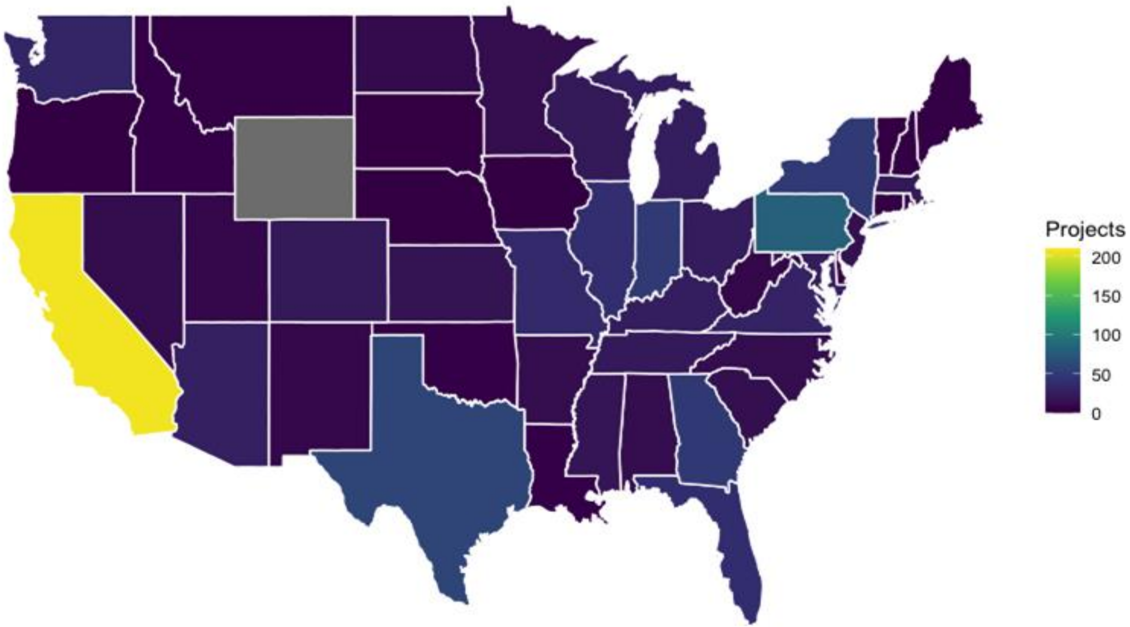
5. **Marginal Abatement Cost:** We then divided the NPV by the total GHG emissions reduction to calculate the marginal abatement cost of the project.

The Benefits of Using Marginal Abatement Cost Curve

- We decided to use the MAC curve analysis owing to their use as a prominent tool to illustrate the economic and technological feasibility of climate change mitigation. A MAC curve is a graphical representation depicting the marginal cost (the cost of the last unit) of emission abatement across varying levels of emission reduction.
- MAC curves have gained prominence among researchers and policymakers engaged in climate change mitigation, largely influenced by the efforts of LBNL and McKinsey & Company (see McKinsey 2022 and Nauclér and Enkvist 2009).
- Nauclér and Enkvist proposed that the curve should initiate "a global discussion about how to reduce GHG emissions, showing the relative importance of different sectors, regions, and abatement measures, and providing a factual basis on the costs of reducing emissions" (Nauclér and Enkvist 2009: 20).
- Existing research using MAC curves developed by Evolved Energy Research in partnership with EDF, showed that electricity measures are found to be the major driver of emission reductions through 2030 (EDF 2021). They further found that a number of factors could lead to lower marginal abatement costs by 2030, including: a broader set of measures than considered in this analysis, innovation that lowers technology cost or improves performance, or faster market adoption (EDF 2021).
- Limitations of this methodology: MAC curves are typically used for measuring the positive costs and net reduction of GHGs. Using MAC curves for energy retrofit projects with net negative costs can lead to “perverse and incorrect outcomes” (Ward 2014: 820).
    - The MAC curve results must be reviewed carefully.
- Building off of this research, we use a MAC curve to measure the relative cost and benefits associated with particular ESPC measures, including GHG emissions reduction respective to NPV of the measure.

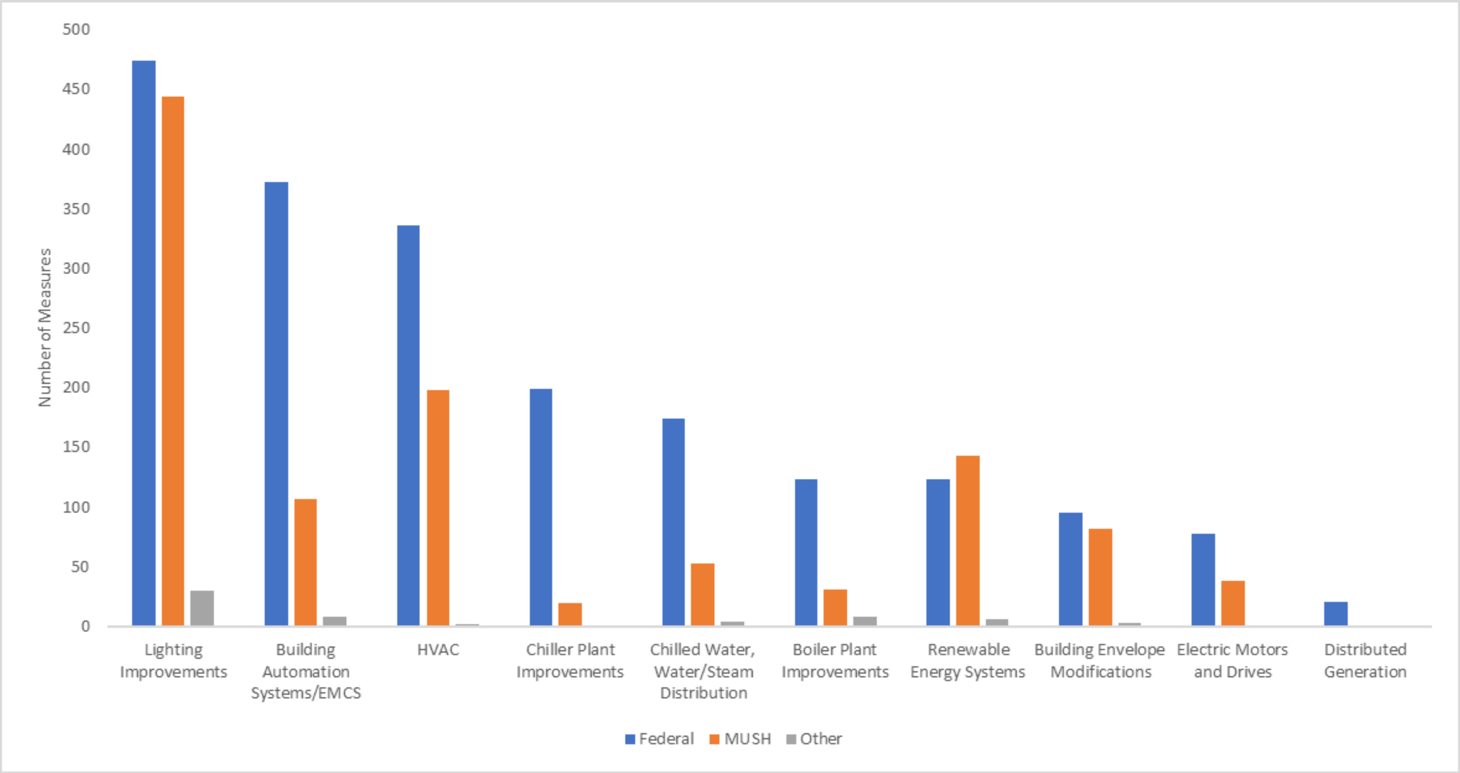
Technical Appendix: Data Analysis and Database Descriptive Statistics

Figure TA2: Total Projects by State



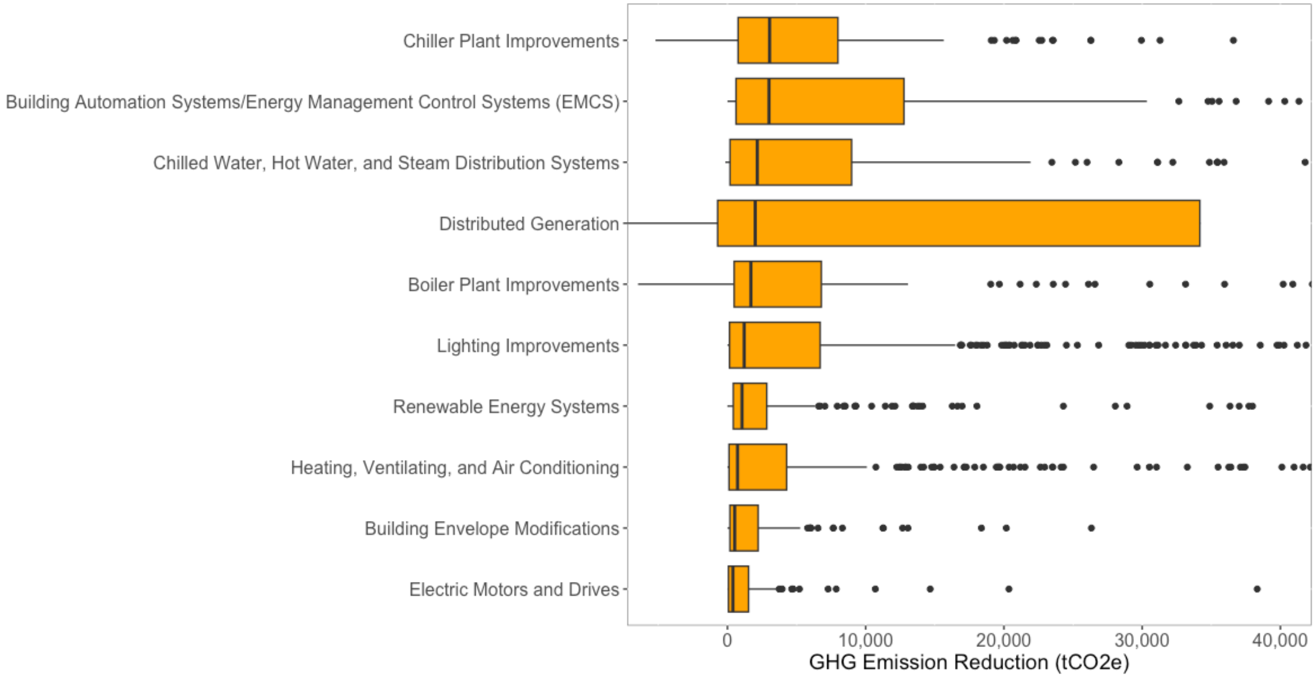
- Figure TA2 displays the number of projects in the dataset by state included in the final analysis after removing outliers.
- Following the application of data cleaning criteria, we obtained a final dataset of 2,365 projects.
- California contains the highest number of projects (208), followed by Pennsylvania (80), Texas (59), New York (49), Indiana (49), and Georgia (48).
- 17 states had fewer than 10 projects. Wyoming had no projects and was therefore excluded from the analysis.

Figure TA3: Deployment Measure Types by Market Segment



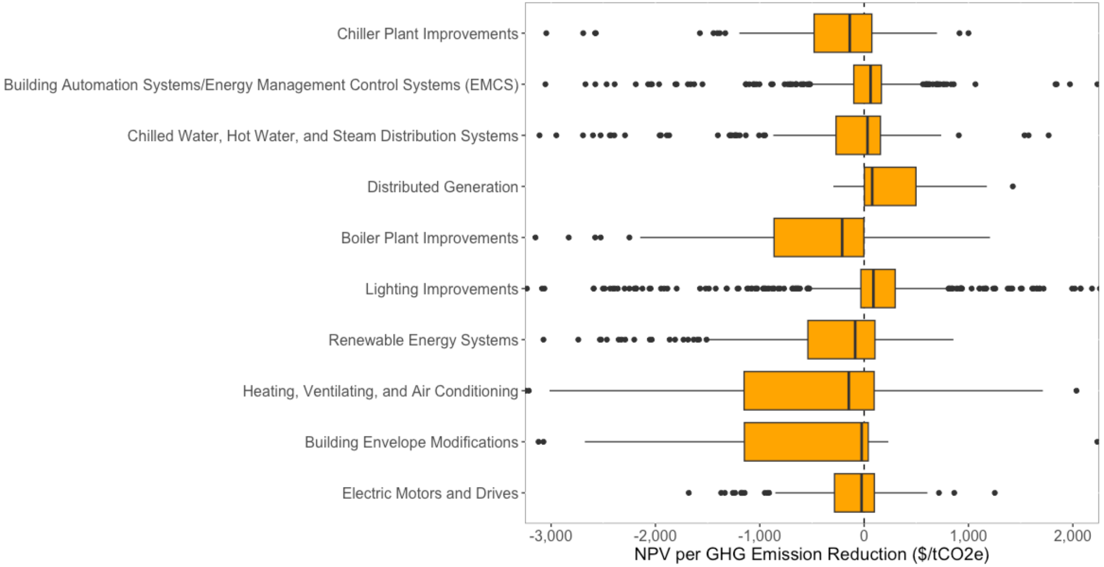
- This figure shows the deployment of measure types by market segment.
- The highest deployment of measures in the ePB database for the federal market is lighting, followed by building automation and HVAC.
- For the MUSH market, lighting improvements, followed by HVAC and renewables had the highest deployment.

Figure TA4: Distributions of GHG Emission Reduction by Technology Type



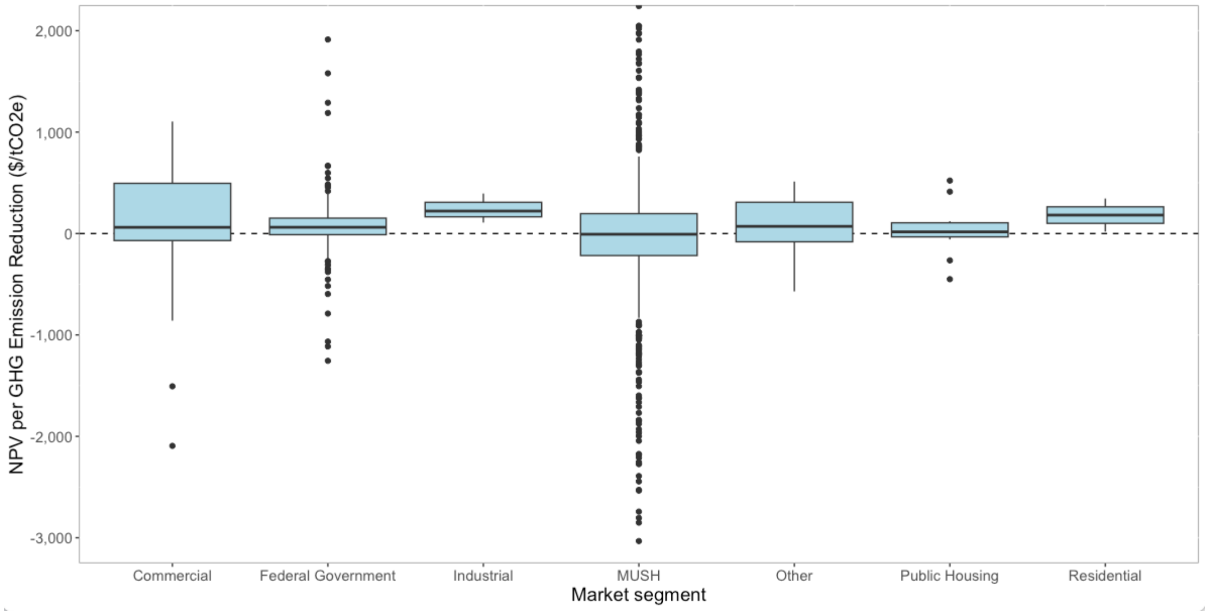
- Large-scale investments such as distributed generation, chiller plant upgrades, building automation systems, and EMCS often deliver significant GHG emission reductions. However, technologies such as boiler plant improvements can show more variability in their impact.
- While EMCS, chilled water, hot water, and steam distribution system investments consistently reduce emissions, large-scale technologies may lead to both savings and increased emissions. This variability creates "long tails" in the emission reduction distribution.
- Lighting improvements, though generally effective, also vary, with some projects achieving significant reductions.
- Other technologies tend to offer more consistent GHG emissions reductions, with fewer outliers.

Figure TA5: Distributions of NPV per GHG Emission Reductions Across Different Technology Categories



- The distributions depicted in Figure TA6 summarize the normalization of NPV by GHG emission reductions.
- 53% of the investments at the measure level (1,688 investments) achieved a positive NPV, while 99% (3,136 investments) led to GHG emission reductions.
- Projects with very high or very low NPVs per GHG emission reduction create long-tailed distributions, influencing overall impact assessment.
- Lighting improvements ($88/tCO2e), distributed generation ($77/tCO2e), chilled water, hot water, steam distribution systems ($32/tCO2e), and EMCS ($62/tCO2e) yield positive median NPV per GHG emission reduction indicating net benefits, while all others show negative median NPV per GHG emissions reduction, showing that overall implementation costs were higher than cost savings.
- Average NPVs per GHG emissions reduction are skewed by a few projects with extreme values, distorting the distribution and causing average values to differ significantly from medians.
- The average NPV per GHG emission reduction values ranged from -$2,780/tCO2e for boiler plant improvements to $4,330/tCO2e for distributed generation.

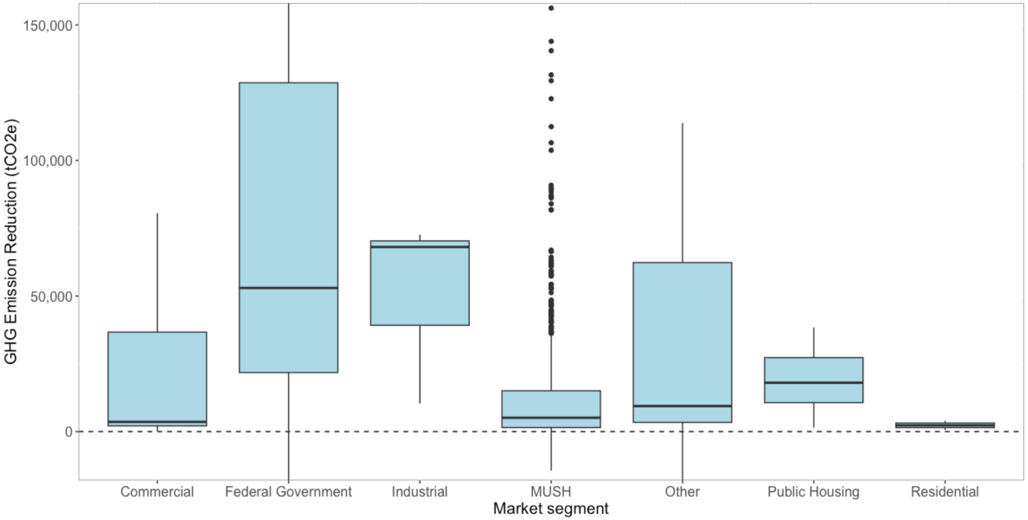
Figure TA6: Distributions of NPV per Ton of GHG Emission Reduction Across Market Segments



- Figure TA6 depicts our examination of the NPV per ton of CO2e saved across various market segments. Approximately 45% of projects yielded negative NPV.
- It is important to note that 95% of the projects comprised MUSH and federal government sectors (28% and 27% each), with only 5% distributed across other sectors, indicating that some sectors had a limited number of projects, thus potentially providing limited insights.
- In the box and whisker plot, the line is the mean, while top and bottom tails represent outliers, and the top and bottom of the box represent the 25th and 75th percentile.

Figure TA7: Distributions of Project-Level GHG Emission Reduction Across Market Segments

- The federal government projects delivered significant GHG emission reductions. Nearly all projects (99%) resulted in emissions reductions, resulting in saving 120,000 tCO2e with a median of 53,000 tCO2e.
- MUSH projects, though undertaken three times more frequently than federal government projects, tend to be smaller in scale. This consequently leads to lower average reductions in GHG emissions.
- MUSH projects achieved an average of 4,800 tCO2e and a median of 5,100 tCO2e GHG emissions reductions. Outliers with significant GHG emissions and savings exist for both the federal government and MUSH.



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