Building Energy Performance Standards: Impacts on Building Energy Efficiency and GHG Emissions in Washington, DC

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Abstract

This study evaluates the causal impact of Washington, DC's Building Energy Performance Standards (BEPS) on building-level energy efficiency and GHG emissions. Using panel data (2012–2023) and a two-way fixed effects (TWFE) framework with continuous treatment intensity defined by compliance gaps, the analysis examines whether BEPS has led to measurable improvements in energy and environmental outcomes. Results show that BEPS significantly improved energy and emissions outcomes, with stronger effects among underperforming buildings. Each additional unit of pre-policy gap reduced Site and Source EUI by up to 0.47 kWh/ft^2 and lowered emissions intensity by 0.70 $kgCO_2e/ft^2$. Event-study models show effects emerging after 2019 and intensifying post-2021. Public buildings achieved greater emissions gains, while private buildings improved efficiency more sharply, confirming BEPS as an effective policy for urban decarbonization.

1.0 Introduction

The accelerating urgency of climate change and the need to reduce carbon emissions have driven the development of ambitious energy policies aimed at improving efficiency and sustainability in the built environment. Buildings are at the center of this challenge—accounting for over 40% of total energy use and greenhouse gas (GHG) emissions in Europe and roughly 40% of total energy consumption and 30% of emissions in the United States (European Commission 2024; U.S. Department of Energy 2021). In response, governments worldwide have increasingly adopted performance-based standards and building codes to decarbonize the sector. Yet, while these policies aim to reduce emissions and enhance energy efficiency, their actual ex post impacts remain under studies, especially in the context of existing building stock, which accounts for most urban energy use and emissions.

This study seeks to evaluate the causal impacts of the District of Columbia's Building Energy Performance Standards (BEPS) on building-level energy efficiency and environmental outcomes, with particular attention to how compliance shortfalls shape responses across ownership categories. Specifically, the analysis pursues three objectives: to estimate the causal effect of BEPS on building-level energy efficiency outcomes; to assess its environmental impact on total GHG emissions and emissions intensity; and to examine heterogeneity in BEPS impacts across public and private buildings to identify differences in mechanisms of response. By addressing these objectives, the study provides evidence on whether mandatory performance standards deliver measurable energy and emissions reductions and how these outcomes vary across institutional contexts.

Across the globe, governments have implemented diverse regulatory frameworks to promote low-carbon buildings. In the European Union (EU), the Energy Performance of Buildings Directive mandates "nearly-zero energy buildings" for all new construction since 2020, with stricter requirements for public buildings beginning in 2028 and for all other buildings by 2030. These rules aim to support the EU's 2050 climate-neutrality goal and are supported by Minimum Energy Performance Standards that target the worst-performing structures for renovation or retrofit (Sunderland and Santini 2020). Other international initiatives, such as Energiesprong in the Netherlands, Building Research Establishment Environmental Assessment Method in the United

Kingdom, and Global Sustainability Assessment System in Qatar, similarly highlight how performance standards and certifications are being used to transform the building sector (Madigan 2025).

In the United States, most early efforts focused on benchmarking and disclosure laws rather than mandatory performance thresholds. Benchmarking policies, such as New York City's Local Law 84 and Chicago's energy rating system, have been associated with modest reductions in energy consumption and improvements in market valuation for efficient buildings (Kontokosta 2013; Hsu 2014a). However, evidence suggests that while informational policies can deliver moderate savings of 3–8% over two to four years, they do not always overcome structural or behavioral barriers to efficiency (Hsu 2014b; Mims et al. 2017). This realization has prompted a transition toward mandatory performance-based regulation.

Washington, DC has been at the forefront of this shift. The Clean and Affordable Energy Act (CAEA) of 2008 established mandatory benchmarking and public disclosure for large private (≥50,000 ft²) and public (≥10,000 ft²) buildings (District of Columbia Council 2008). While this improved market transparency, it lacked enforceable efficiency requirements. Recognizing these limitations, the Clean Energy DC Omnibus Act (CEOA) of 2018 created the Building Energy Performance Standards (BEPS), the policy requires existing buildings to meet minimum energy performance thresholds based on benchmarking data (District of Columbia Council 2018; DOEE 2019). Unlike benchmarking, BEPS mandates compliance, underperforming buildings must either improve their energy performance or pursue prescriptive pathways within multi-year compliance cycles (DOEE 2021a).

The BEPS framework is implemented in three sequential cycles that gradually expand coverage based on building size. BEPS 1 (Cycle 1) began in 2021, covering private buildings of 50,000 square feet or larger and public buildings of 10,000 square feet or larger. BEPS 2 (Cycle 2) will take effect in 2027, lowering the threshold to include private buildings of 25,000 square feet or larger, while the public building requirement remains unchanged. BEPS 3 (Cycle 3) will commence in 2033, extending the standard to all private and public buildings of 10,000 square feet or larger, effectively encompassing nearly the entire large-building stock in the District. Each

BEPS phase operates within a multi-year compliance cycle, during which owners of underperforming buildings must demonstrate energy performance improvements relative to the standard or pursue prescriptive compliance pathways (DOEE 2021a). By mandating measurable performance outcomes, BEPS represents a paradigm shift from voluntary transparency to enforceable regulation designed to accelerate retrofits, promote clean technologies, and reduce carbon emissions (DOEE 2021b).

Following this policy evolution, the analysis applies a two-way fixed effects (TWFE) framework with continuous treatment intensity defined by compliance gaps, addressing potential attrition bias through inverse probability weighting and testing robustness across alternative gap definitions (property-type mean, percentile, and citywide). While modeling studies have examined potential decarbonization pathways (e.g., Andrews and Jain 2023; Webb and McConnell 2023; Palmer and Walls 2017; Asensio and Delmas 2017), actual ex post effects remain under-investigated. To address this gap, event-study models are employed to test the parallel trends assumption and to trace the dynamic effects of BEPS over time. Results are further disaggregated by ownership type (public vs. private) to assess institutional heterogeneity. Together, these methods provide robust causal evidence on BEPS effectiveness and generate policy-relevant insights for cities adopting similar performance-based building standards.

The remainder of the paper is organized as follows. Section 2 reviews the theoretical and empirical literature on benchmarking and performance standards in the building sector. Section 3 describes the data sources and outlines the empirical methodology, including the TWFE and event-study specifications. Section 4 presents and discusses the empirical results, highlighting distributional and ownership-based differences in BEPS impacts. Section 5 concludes by summarizing the main findings and discussing their implications for urban decarbonization and future research directions.

2.0 Literature Review

Benchmarking and performance-based standards have emerged as central tools for improving energy efficiency in the building sector. Benchmarking policies require building owners to measure and disclose energy use, operating on the premise that increased transparency reduces information asymmetry and motivates market-driven efficiency improvements (Palmer & Walls

2015). However, while disclosure policies have achieved modest savings through voluntary compliance, their effectiveness is limited by behavioral and structural barriers (Hsu 2014b; Mims et al. 2017). In contrast, performance-based standards such as Washington, DC's Building Energy Performance Standards (BEPS) introduce enforceable thresholds that compel low-performing buildings to implement energy-saving measures (Palmer & Walls 2017). This literature review examines the theoretical foundations of benchmarking and performance regulation, synthesizes empirical evidence on their impacts, and evaluates how mandatory standards can accelerate decarbonization and energy efficiency in the building sector.

2.1 Theoretical Foundation of Benchmarking and BEPS

A core motivation for benchmarking policies lies in closing the energy efficiency gap, defined as the under-adoption of cost-effective energy-saving measures (Palmer & Walls, 2015). Several factors contribute to this gap, including split incentives (where building owners do not benefit from tenants' reduced utility bills) and information asymmetry (where energy consumption data are not transparent to prospective tenants, buyers, or investors). By requiring building owners to collect and disclose energy performance information, benchmarking policies aim to correct these market failures (Palmer & Walls 2017).

The theoretical foundation rests on information economics and behavioral response theory. When credible information on building performance becomes publicly available, market participants adjust their choices, generating reputational and financial incentives for energy efficiency (Allcott and Greenstone 2012). Benchmarking thus serves both as a transparency mechanism and a behavioral nudge, encouraging building owners to invest in energy-saving measures even without direct mandates. Over time, greater transparency can also promote competitive differentiation, allowing efficient buildings to command higher rents, improved occupancy rates, and stronger investor interest (Palmer and Walls 2015).

Such transparency can theoretically lead to market-based rewards for efficient buildings through higher occupancy rates, increased property values, and stronger investor interest (Palmer & Walls, 2015). In parallel, policy frameworks such as building codes, labeling programs, and performance standards help ensure that minimum efficiency requirements are met (Laustsen 2008). Building codes typically apply to new construction, but older structures remain a challenge because of their high energy consumption and the lack of enforceable requirements for retrofits (EPA 2014). The introduction of Building Energy Performance Standards (BEPS) addresses this gap by mandating improvements in underperforming existing buildings, effectively complementing the informational function of benchmarking with a regulatory "stick" (Palmer & Walls 2017).

Conceptually, BEPS can be viewed as a hybrid policy instrument that bridges informational and command-and-control approaches. It internalizes energy externalities by imposing quantifiable performance thresholds while preserving flexibility in compliance—allowing owners to choose between operational upgrades and prescriptive pathways (Gillingham and Palmer 2014). This framework aligns with broader insights from building energy performance research emphasizing the need for robust assessments that account for dynamic thermal properties and regional climates (Vollaro et al. 2015; Lam et al. 2008). Ultimately, benchmarking and BEPS policies enhance social welfare by mitigating informational inefficiencies, stimulating retrofit investments, and aligning private incentives with public climate and decarbonization goals (Aldy and Stavins 2012).

2.2 Empirical Evidence on Benchmarking Policies and BEPS

A number of studies provide empirical support for the effectiveness of benchmarking and disclosure laws in driving moderate energy savings. For example, Palmer and Walls (2015) note that U.S. cities with benchmarking ordinances observe 3–8% reductions in building energy use over a two- to four-year period, attributable to increased awareness and the reputational effects of public disclosure. New York City's Local Law 84 offers a notable case study, where buildings subject to benchmarking requirements realized 5.7% lower weather-normalized source energy use within three years, coupled with an 8.3% reduction in GHG emissions (Kontokosta 2014).

Despite these gains, studies caution that benchmarking alone may not deliver the deep energy savings necessary to meet aggressive climate goals (Palmer & Walls, 2017). Buildings often exhibit complex, climate-dependent energy demands (Lam et al. 2008), and a voluntary or informational approach may not overcome persistent financial, technical, or behavioral barriers. As a result, the shift toward BEPS in Washington, DC and other jurisdictions represents a more directive policy mechanism that can spur retrofits in the least-efficient segment of the building stock (Palmer & Walls, 2015). The expectation is that by coupling benchmarking data with mandatory performance thresholds, BEPS policies can achieve significantly larger energy reductions compared to transparency measures alone (Palmer & Walls, 2017).

BEPS programs extend the logic of benchmarking by requiring buildings that fall below a designated energy performance threshold to undertake upgrades or face penalties (Palmer & Walls, 2017). In Washington, DC, for instance, buildings that fail to meet these standards are placed on a compliance pathway, during which they must implement efficiency measures or otherwise demonstrate improvement. This approach seeks to accelerate the rate of energy retrofits across a large share of the building stock, addressing the older, more energy-intensive structures that often dominate urban environments (EPA 2014; CBI 2012).

Comparative studies emphasize that building energy performance is influenced by a variety of factors, including construction practices, climatic conditions, and building age (Lam et al. 2008; Vollaro et al., 2015). Hence, successful BEPS implementation often requires flexibility to accommodate different property types and local conditions. In line with this, the Clean Energy Omnibus Act of 2018 includes compliance pathways such as prescriptive upgrades or a target percentage reduction in energy use to account for the unique circumstances of each building (Palmer & Walls, 2017). By integrating benchmarking data with dynamic performance requirements, Washington, DC's BEPS framework exemplifies a policy design that is responsive to diverse building conditions, while ensuring tangible progress toward efficiency goals.

Recent research highlights the growing interplay between performance standards and building energy labeling programs worldwide. In the European Union, Energy Performance Certificate (EPC) schemes have become instrumental in driving demand for energy-efficient properties, although challenges persist regarding data quality and uniform implementation (Li et al. 2019). Similar labeling efforts in Singapore emphasize a rigorous benchmarking database and independent audits by accredited Energy Service Companies, resulting in the Energy Smart Office Label for top-performing buildings (Lee & Rajagopalan 2008). In Brazil, voluntary labeling schemes were introduced for residential, commercial, and service buildings, aiming to inform consumer choice and encourage more efficient design (Fossati et al. 2016).

Alongside these national programs, studies including Goldstein & Eley (2014) have examined how performance indices (e.g., asset versus operational ratings) can better inform building owners, operators, and policymakers about both the intrinsic efficiency of a structure and its real-world operational management. These initiatives often operate within a broader policy environment that mixes regulatory mandates and voluntary measures, where cost-effectiveness, enforcement, and stakeholder engagement remain central considerations (Lee & Yik 2004; Sun et al. 2016). Furthermore, the advent of big data approaches, such as the consolidation of large-scale building energy datasets, is enhancing peer group analysis and empirical methods for evaluating retrofit impacts and performance outcomes (Mathew et al. 2015).

Beyond demonstrating the potential for energy savings in the short term, recent literature has underscored the importance of standardizing methods for data collection, reporting, and evaluation to strengthen the long-term efficacy of BEPS. In a review of 24 state and local jurisdictions, Mims et al. (2017) find that most benchmarking and transparency programs yield energy reductions between 3% and 8% over a two- to four-year period, yet the diversity of data collection practices and analytical methods complicates definitive comparisons of policy outcomes. Similar challenges appear in jurisdictions like China and Europe, where divergent building standards and limited data accessibility hamper rigorous cross-study evaluations (Zhang et al. 2017). Additionally, the question of how much information is necessary to spur meaningful energy improvements remains pivotal, with Hsu (2014b) arguing that building-level benchmarking data alone often outperforms more detailed engineering audits in predicting energy use intensity.

Recent analyses also highlight the emerging role of emissions-based performance standards, showing that combining annual GHG targets with peak-load flexibility requirements can drive 89% overall reductions in building emissions for certain U.S. cities (Andrews & Jain, 2023). Studies of building energy data further demonstrate that performance improvements vary by building size, type, and operational patterns (Papadopoulos et al. 2018), underscoring the necessity for tailored compliance pathways and robust enforcement to achieve substantial and enduring emissions cuts (Hicks & Clough 1998; Webb & McConnell 2023). Asensio and Delmas (2017) also show that even high-profile labeling and certification programs may fail to capture significant savings in small and medium buildings, underscoring a gap that BEPS policies must address through carefully structured mandates and incentives. Lastly, Cohen and Bordass (2015) advocate for operational ratings that focus on actual in-use performance rather than purely asset-based assessments, a perspective that aligns with the push toward standardized operational data (Mims et al. 2017) and highlights how BEPS can evolve from static benchmarks to dynamic, outcome-focused regulation.

Scholarly evidence underscores the critical role of occupant behavior and actual operating conditions in achieving modeled energy savings, suggesting that BEPS must account for these real-world dynamics. McCoy et al. (2018) find that simulated energy usage often overestimates actual consumption in newly constructed green homes, while being less accurate for renovated properties, highlighting the complexity of existing building stock retrofits and the need for more occupant-centric modeling. Similarly, Li et al. (2014) demonstrate that high-performance buildings do not always deliver low EUIs in practice, due in part to occupant-driven loads and operational factors. These findings align with Parker (2009) observation that very low energy designs can achieve near net-zero outcomes only when users engage in energy-conscious practices. Indeed, occupant heterogeneity and building usage patterns contribute to wide variance in measured outcomes, even for buildings employing similar technologies (Wang et al. 2012; Chung et al. 2006).

In addition to these operational and occupant-driven dynamics, another strand of research highlights the informational and behavioral channels through which building performance policies can generate impact. Stavins et al. (2013) emphasize that labeling, scoring, and benchmarking policies serve a similar role to consumer product efficiency labels, providing transparent information to buyers, renters, and investors and thereby shifting market demand toward higher-performing buildings. This informational effect complements physical retrofits by shaping expectations and investment behavior. Evidence from residential energy conservation programs reinforces the importance of behavioral responses: Allcott (2011) shows that peer comparison reports reduce household electricity use by an average of 2%, with much larger effects for high-use households, while Costa and Kahn (2013) find that ideological orientation conditions the effectiveness of such “nudges,” with liberals more responsive than conservatives.

Building on this, Papadopoulos and Kontokosta (2019) show that machine learning approaches can enhance building grading by incorporating occupancy and operational data, underscoring the need for BEPS to integrate more granular metrics beyond static design parameters. Collectively, this body of work echoes Ruparathna et al. (2016) and Foroushani et al. (2022) in suggesting that performance-based regulations must adopt flexible, context-specific strategies, addressing occupant behavior, building typology, and local climate to maximize real-world energy savings and effectively drive the net-zero carbon transition.

While the theoretical rationale for benchmarking and BEPS is well-established, empirical evidence on their realized effectiveness remains comparatively limited. The literature shows that benchmarking and performance-based standards can generate measurable but heterogeneous improvements in building energy efficiency and emissions. Benchmarking programs promote transparency and modest voluntary reductions, while BEPS and related performance mandates offer greater potential for deep decarbonization when supported by robust enforcement, flexible compliance pathways, and high-quality data. Yet, key empirical gaps persist. Most studies remain ex ante or descriptive, rely on limited or short time-series data, and rarely quantify realized efficiency or emissions outcomes at the building level. Moreover, behavioral, operational, and climatic heterogeneity remain underexplored—particularly regarding how policy stringency and compliance shortfalls shape responses across building types and ownership categories. Addressing these limitations, the present study provides an ex post causal evaluation of Washington, DC's BEPS, using building-level longitudinal data to assess its realized energy efficiency and environmental impacts.

3.0 Methodology

3.1 Data and Cleaning Procedures

The data used in this study are drawn from Open Data DC, which provides building-level benchmarking records reported under the District of Columbia's Building Energy Performance Standards (BEPS). These records constitute an unbalanced panel spanning 2012–2024, capturing year-to-year variation in energy consumption, emissions, and compliance behavior across buildings. Climate-related variables, cooling degree days (CDD) and heating degree days (HDD), calculated at a 65°F base temperature is obtained from Bizee Degree Days (degreedays.net) and mapped by year since they vary over time but not across buildings. Together, these sources form the empirical foundation for assessing the impacts of BEPS on building energy efficiency and greenhouse gas performance in the District of Columbia.

Extensive data cleaning procedures are implemented to ensure accuracy, consistency, and reliability. First, only properties with a reporting status of "In Compliance" are retained, since compliance indicates adherence to DC's benchmarking standards. Second, buildings with missing or zero values for electricity consumption or weather-normalized site energy use intensity are excluded to avoid incomplete records. Third, only standalone buildings or the primary property within a campus are retained, eliminating partial or nested structures. Fourth, outliers are identified and removed by excluding properties whose log-transformed, weather-normalized site energy intensity deviate by more than two standard deviations from their property-type mean.

Further refinements improve classification consistency: property type categories are collapsed by grouping all "Other" labels into a single "Others" category, and targeted recoding harmonizes related categories (e.g., "Food Sales" mapped to "Supermarket/Grocery Store," "Warehouse (Unrefrigerated)" mapped to "Non-Refrigerated Warehouse," "Vocational School" mapped to "Adult Education"), ensuring comparability while reducing noise from inconsistent classifications.

To identify publicly owned buildings, benchmarking records are matched to the District Government Owned Structures dataset using normalized SSL identifiers. Properties that match are coded as "Public," while others are assigned to "Private" ownership, enabling replication of the analysis on ownership-based subsets. Additional cleaning steps address measurement and missingness. A dummy variable flags property with missing Energy Star scores for robustness checks, and buildings reporting zero GHG emissions are removed, as such entries likely reflect reporting errors or incomparable structures. Finally, energy variables originally reported in thousand British thermal units (kBtu) are converted to kilowatt-hours (kWh) using the standard factor 1 kBtu = 0.293 kWh. After all cleaning steps, the dataset is reduced from 26,689 building-year observations to a final sample of 15,828 observations.

3.2 Descriptive Statistics

Table 2.1 reports descriptive statistics for the main variables in the analysis. The average Site EUI is 18.8 kWh/ft^2, while Source EUI averages 42.3 kWh/ft^2, both with substantial variation across buildings. The mean Energy Star score is 65.7, with wide dispersion (standard deviation of 24.1) and coverage across the full 1–100 range. Average annual GHG emissions amount to about 1.09 million $kgCO_2e$ per building, though the highly skewed distribution is evident in the maximum value of nearly 68 million $kgCO_2e$. On an intensity basis, emissions average 5.6 $kgCO_2e/ft^2$. The mean building size is 185,580 ft^2, with significant heterogeneity ranging from small structures just over 10,000 ft^2 to large complexes exceeding 5.6 million ft^2. Climate controls reflect stable annual variation, with average annual cooling degree days of 1,829 and heating degree days of 3,714 during the study period.

Table 3.1: Summary statistics of key variables

Variable	Count	Mean	Std	Min	25%	50%	75%	Max
Site EUI (kWh/ft^2)	15828	18.76	7.54	5.69	13.42	17.53	22.42	51.11
Source EUI (kWh/ft^2)	15828	42.27	17.71	6.62	29.60	38.16	51.40	152.19
Energy Star Score	13813	65.72	24.07	1.00	51.00	72.00	84.00	100.00
GHG Emissions ($KgCO_2e$)	15828	1090150.67	1961750.37	4300.00	326575.00	639250.00	1288525.00	67780000.00
GHG Emissions Intensity ($kgCO_2e/ft^2$)	15828	5.55	2.94	0.05	3.69	4.83	6.67	85.33
Building Size (floor area, ft^2)	15828	185579.89	218918.86	10171.00	69600.00	122062.00	236646.00	5634890.00
Cooling degree days	15828	1829.07	111.94	1680.60	1728.80	1835.70	1951.30	1993.70
Heating degree days	15828	3713.56	280.24	3216.70	3480.90	3759.30	3925.00	4163.20

3.3 Outcome Variables of Interest

The empirical analysis focuses on five outcome variables that capture the energy efficiency and environmental performance of buildings, each of which is directly tied to the objectives of the BEPS. Together, these measures allow the study to assess whether BEPS has reduced energy use and emissions while improving performance relative to industry benchmarks.

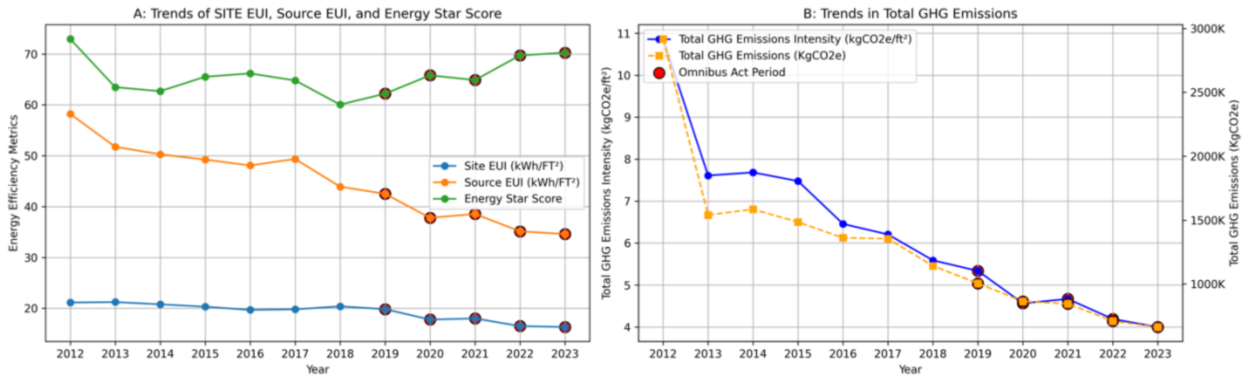
The first two outcomes are Weather-Normalized Site Energy Use Intensity (Site EUI, kWh/ft^2) and Weather-Normalized Source Energy Use Intensity (Source EUI, kWh/ft^2). Site EUI measures the amount of energy consumed per square foot of floor area at the property level, reflecting operational efficiency. Source EUI expands this measure to account for the total upstream energy required to deliver energy to the building, including generation and transmission losses. Both Site and Source EUI are normalized for weather, meaning they are adjusted to reflect what energy consumption would have been under 30-year average climate conditions. This adjustment allows for more consistent year-to-year comparisons within buildings and across regions by correcting for unusually hot or cold years, while not altering differences between distinct climate zones (NEEP 2020; DOEE 2021a).

The third outcome is the Energy Star Score (1–100), a standardized performance rating calculated by the Energy Star Portfolio Manager. This metric evaluates how efficiently a building operates relative to comparable properties nationwide, adjusting for climate and operational characteristics. A score of 50 represents the national median, while a score of 75 or higher indicates high efficiency and potential eligibility for Energy Star Certification. This outcome provides an intuitive benchmark of relative performance and allows evaluation of whether BEPS has shifted buildings toward higher levels of efficiency recognized in national certification programs (U.S. EPA 2022).

The final two outcomes capture the environmental dimension of BEPS. Total GHG Emissions (kgCO_2e) measure the aggregate amount of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) released into the atmosphere due to a building's energy consumption. This measure accounts for the varying global warming potentials of these gases and includes both direct emissions from on-site fuel use and indirect emissions from purchased energy produced off-site. To standardize across buildings of different sizes, GHG Emissions Intensity (kgCO_2e/ft^2) divides total emissions by floor area, providing a comparable measure of how efficiently a building manages emissions relative to its operational scale (NEEP 2020; DOEE 2021a).

Figure 3.1 illustrates temporal trends in the key outcome variables over the 2012–2023 period. Panel A shows gradual improvements in energy efficiency metrics, with weather-normalized Site EUI and Source EUI steadily declining, while Energy Star scores generally rising, indicating enhanced performance relative to national benchmarks. Panel B highlights notable reductions in environmental outcomes, with both total GHG emissions and emissions intensity (kgCO_2e/ft^2) exhibiting a clear downward trajectory over time. The implementation of the Clean Energy Omnibus Act in 2019, which introduced BEPS, coincides with an acceleration in these improvements, suggesting that policy adoption may have reinforced pre-existing efficiency trends.

Figure 3.1: Trends in Building Energy Efficiency Metrics and GHG Emissions



3.4 Policy Variable Construction

The treatment variable in this study is defined through the concept of a 'gap', which measures the difference between each building's baseline energy performance and the applicable BEPS threshold. The baseline is calculated as the building's average performance during the pre-policy period (2012–2018), prior to the implementation of the Clean Energy Omnibus Act. The gap represents the degree of underperformance relative to the BEPS standard: buildings performing below the threshold have a positive gap, reflecting the magnitude of required compliance, while buildings at or above the threshold have a gap of zero. Importantly, among the outcome variables, only the Energy Star score is a higher-is-better metric; all others (Site EUI, Source EUI, total GHG emissions, and GHG intensity) are lower-is-better. This distinction ensures that a positive gap always represents underperformance, regardless of the outcome.

Formally, for building i and outcome v, under Method A (type-average threshold), the gap is defined as:

$$Gap_{i,v}^{A} = \begin{cases} \max\{0,\ \ Baseline_{i,v} - Threshold_{s,v}^{A}\}, if\ lower\ is\ better \\ \max\{0, Threshold_{s,v}^{A} - Baseline_{i,v}\}, if\ higher\ is\ better \end{cases}$$

where $Baseline_{i,v}$ is the 2012–2018 pre-policy mean for building i, outcome v, and $Threshold_{s,v}^{A}$ is the pre-policy mean for property type s.

For Method B (type-percentile benchmark), the gap is instead defined relative to the efficient end of the property type distribution:

$$Gap_{i,v}^{B} = \begin{cases} max\{0,\ \ Baseline_{i,v} - Q_{0.25}(Threshold_{j,v} |\ j\ \in s)\}, if\ lower\ is\ better \\ max\{0, Q_{0.75}(Threshold_{j,v} |\ j \in s\ ) - Baseline_{i,v}\}, if\ higher\ is\ better \end{cases}$$

where $Q_{0.25}$ and $Q_{0.75}$ denote the 25th and 75th percentiles of pre-policy performance within property type s.

For Method C (citywide benchmark), the gap is constructed relative to the citywide average:

$$Gap_{i,v}^{c} = \begin{cases} max\{0,\ Baseline_{i,v} - Threshold_{s,v}^{c}\}, if\ lower\ is\ better \\ max\{0, Threshold_{s,v}^{c} - Baseline_{i,v}\}, if\ higher\ is\ better \end{cases}$$

where $Threshold_{s,v}^{c}$ is the overall pre-policy mean across all buildings for outcome v.

Because the dataset is unbalanced, attrition may bias estimates if exiters systematically differ from stayers. To address this, a logit model is estimated predicting the probability of exit, defined as a building that has no observations at or after 2021. Formally, let R_i^{max} denote the maximum reporting year observed for building i. The stayer and exit buildings are defined as:

$$Stayer_i = \begin{cases} 1, if R_i^{max} \geq 2021, \\ 0, if R_i^{max} < 2021, \end{cases} \qquad Exit_i = 1 - Stayer_i$$

Thus, buildings with observations in or after 2021 are classified as *stayers* ($Stayer_i = 1$), while those with no post-2020 records are classified as *exiters* ($Exit_i = 1$). This variable ($Exit_i = 1$) is used as the dependent variable in the attrition logit model used to generate inverse probability weights.

The model uses the last available pre-policy (≤ 2018) record for each building and includes baseline performance measures—Site EUI, Source EUI, Energy Star score, total GHG emissions, and GHG emissions per sqft—alongside building size, ownership type (public vs. private), and climate variables (HDD, CDD). The specification is:

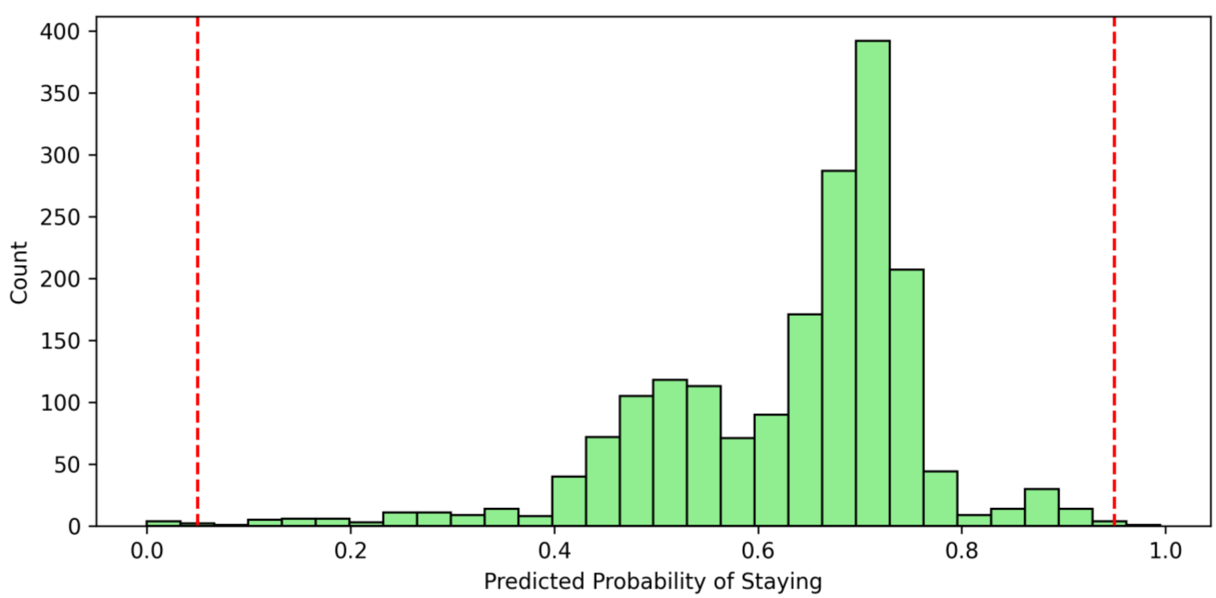
$$Pr(Exit_i = 1|X_i) = \Lambda(\gamma_0 + \gamma' X_i)$$

where Λ(·) is the logistic function and X_i is the vector of baseline predictors. To ensure a well-specified model, near-zero variance predictors and collinear variables are dropped, and clustered standard errors are calculated at the building level.

From this model, predicted probabilities of staying, $\widehat{p_i} = 1 - Pr(Exit_i = 1)$, are used to construct inverse probability weights, $w_i = {}^{1}/_{\widehat{p_i}}$.

These weights are applied in robustness checks of the TWFE models to mitigate potential attrition bias. The overlap (positivity) assumption is examined to ensure the validity of inverse probability weighting. This assumption requires that all buildings, regardless of their covariate profiles, retain a non-zero probability of staying in the sample. Figure 2.2 displays the distribution of predicted probabilities of staying from the attrition logit model, with red dashed lines marking the [0.05, 0.95] range typically used to assess common support. The distribution is concentrated between 0.4 and 0.8, with most buildings clustering around 0.6–0.7. Only 0.3% of observations fall below 0.05 and 0.1% exceed 0.95, leaving 99.7% of the sample. These results indicate substantial overlap between exiters and stayers, with no subset of buildings deterministically predicted to remain or exit. The overlap condition is therefore satisfied, supporting the application of inverse probability weighting without concerns of instability from extreme weights.

Figure 2.2: Distribution of predicted probabilities of staying



3.5 Identification Strategy and Estimation of Causal Effects

The primary empirical challenge in evaluating the impact of BEPS is that nearly all large private and public buildings in the dataset are subject to the policy. This context rules out the conventional binary treatment framework, in which treated and untreated units are directly compared. Instead, the intensity of treatment varies continuously according to the magnitude of each building's gap—the distance between its pre-policy baseline performance and the BEPS threshold. Buildings with larger gaps face stricter compliance obligations, while those with small or zero gaps face weaker or no obligations. To capture this structure, the analysis adopts a continuous-treatment framework with TWFE. The baseline specification is:

$$Y_{it} = \beta_0\left(Post_t \ x \ Gap_{i,v}\right) + \alpha_i + \tau_t + \varepsilon_{it}$$

where Y_{it} denotes the outcome of interest for building i in year t (Site EUI, Source EUI, Energy Star Score, GHG emissions, or GHG emissions intensity). The variable $Gap_{i,v}$ measures the pre-policy shortfall relative to the BEPS threshold, and $Post_t$ is the policy indicator, building fixed effects (α_i) absorb time-invariant heterogeneity while year fixed effects (τ_t) account for common shocks across all buildings in a given year.

The $Post_t$ indicator is coded as 1 beginning in 2021, consistent with the implementation of BEPS 1, but only for buildings meeting the statutory eligibility thresholds: public buildings with a reported floor area of at least 10,000 square feet and private buildings with a reported floor area of at least 50,000 square feet. For all other cases, including buildings below the size cutoffs or observations prior to 2021, the Post indicator equals 0.

$$Post_t = \begin{cases} 1, \ if \ t \geq 2021 \ and \begin{cases} public \ building \ with \ floor \ area_i \geq 10{,}000 \ ft^2, \\ private \ building \ with \ floor \ area_i \geq 50{,}000 \ ft^2, \end{cases} \\ 0, \ otherwise \end{cases}$$

The interaction term, $Post_t \ x \ Gap_{i,v}$, captures whether buildings with larger pre-policy shortfalls relative to the BEPS standard experienced greater changes in energy efficiency and emissions outcomes once the policy became binding.

The TWFE specification is motivated by the standard DiD framework in which outcomes are regressed on unit fixed effects, time fixed effects, and the interaction of a post-treatment indicator with a treatment intensity variable, an approach recommended by Cameron and Trivedi (2005); Angrist and Pischke, (2008); and Wooldridge (2010). Recent advances according to Wooldridge

(2021); Callaway et al. (2021) and de Chaisemartin et al. (2023) show that in multi-period settings, the β_0 can be interpreted as an Average Causal Response to Treatment (ACRT), which extends the dose–response framework of Angrist and Imbens (1995) to panel data with multiple time periods. It corresponds to the marginal effect of a one-unit increases in the pre-policy Gap on post-policy building outcomes.

Estimation is conducted using the gap derived from Method A**,** defined as the property-type average threshold. Results are presented for both the unweighted TWFE specification and an alternative specification that applies IPW derived from the attrition model. To further explore heterogeneity in policy effects, the analysis is also replicated on subsamples consisting of private buildings and public buildings**,** respectively. The IPW-adjusted estimation corrects for potential attrition bias by giving greater weight to buildings with lower predicted probabilities of staying in the sample, while the unweighted model provides a benchmark for comparison.

3.6 Event-Study Analysis

To complement the TWFE estimations, event-study models are implemented to assess the validity of the identifying assumptions and to examine the dynamic effects of BEPS over time. Event studies serve two primary purposes in this context. First, they provide a diagnostic check of the parallel trends in intensity assumption**,** by comparing pre-policy trajectories of buildings with different levels of compliance gaps. Second, they allow for the estimation of the temporal profile of treatment effects, capturing whether impacts emerge immediately following policy implementation or materialize gradually over subsequent years. The event-study specification extends the TWFE model by replacing the single interaction term with a series of leads and lags relative to the policy implementation date:

$$Y_{it} = \sum_{k \neq -1} \delta_k 1\{t - t_0 = k\} \times Gap_{i,v} + \alpha_i + \tau_t + \mathcal{E}_{it}$$

where t_0 denotes the final pre-policy year (2018), and k indexes the number of years relative to that baseline. Each coefficient δ_k traces the relationship between treatment intensity and outcomes k years before or after BEPS took effect. The omitted category is

$k = -1$, corresponding to the year immediately preceding policy implementation, so all coefficients are interpreted relative to 2018.

The estimated pre-policy coefficients ($\delta_k\ for\ k < 0$) serve as a direct test of the identifying assumption. Flat and statistically insignificant pre-trends provide evidence that, absent BEPS, outcomes would have evolved similarly across buildings with different Gaps. Conversely, significant pre-trends would undermine identification, suggesting that results could be driven by differential trajectories rather than the policy itself. Post-policy coefficients ($\delta_k\ for\ k \geq 0$) capture the dynamic causal response of outcomes to the compliance gap in each year following BEPS implementation. These effects can reveal whether improvements in energy efficiency and emissions occur immediately in the first compliance cycle or accumulate more gradually as building owners undertake investments and operational adjustments.

The analysis is conducted using Method A gaps (defined as property-type averages) and is applied to the full dataset as well as separately to private and public buildings. In the plots that present these estimates, the pre-policy period is expected to display coefficients that fluctuate narrowly around zero, confirming the absence of systematic differential trends prior to BEPS. In contrast, the post-policy period should show whether treatment effects strengthen over time: immediate effects would be reflected in sharp movements in the first years after 2018, while more gradual adjustments would appear as a progressive divergence across subsequent years. Confidence intervals around the estimates are expected to illustrate both the statistical significance of the effects and the degree of uncertainty in their temporal evolution.

3.7 Robustness and Subsample Analyses

A series of robustness checks and subsample analyses are conducted to assess the reliability and consistency of the estimated effects of BEPS. First, the baseline analysis relies on the gap measure from Method A (property-type averages), but alternative definitions of the gap are employed to test sensitivity. Method B, which uses type-specific percentiles (25th for lower-is-better outcomes and 75th for higher-is-better outcomes), provides a benchmark that emphasizes efficiency at the leading edge of performance within each property type. Method C, which uses citywide averages as the benchmark, offers a uniform reference across all buildings regardless of type. Comparing results across these three approaches allows assessment of whether findings are robust to alternative constructions of the compliance gap.

Second, the estimation is repeated using IPW weights derived from the attrition model. These weights correct for potential selection bias due to exiters and reweight the sample toward buildings with a lower probability of remaining. The comparison of unweighted and IPW-weighted models serves as a test of whether attrition meaningfully biases the estimated treatment effects. Third, the analysis is repeated on subsamples disaggregated by ownership type, focusing separately on private buildings and public buildings. Together, these robustness checks and subsample analyses ensure that the main findings are not artifacts of a particular gap definition, weighting strategy, or ownership composition of the sample. Instead, they demonstrate that the estimated effects of BEPS remain consistent across multiple specifications and building subsamples, reinforcing the credibility of the empirical results.

4.0 Empirical Findings

4.1 Causal Impacts of BEPS on Energy Efficiency and Emissions

Table 4.1 presents the causal impacts of BEPS estimated using property-type mean compliance Gaps as the continuous treatment variable. The unweighted TWFE estimates (Panel A) indicate that, after BEPS implementation, each additional unit of pre-policy shortfall relative to the property-type mean causally reduced Site EUI by 0.34 kWh/ft^2 and Source EUI by 0.47 kWh/ft^2, while raising the Energy Star score by 0.41 points. On the environmental side, total GHG emissions decreased by 0.38 million $KgCO_2e$ and emissions intensity by 0.70 $KgCO_2e$/ft^2 per unit increase in Gap. Substantively, this implies that a building that was 10 unit above its property-type threshold before the policy is expected to reduce its Site EUI by about 3.4 kWh/ft^2 and its Source EUI by about 4.7 kWh/ft^2, while simultaneously achieving an increase of 4.1 points in Energy Star Score, a reduction of 3.8 million $KgCO_2e$ in total emissions, and a decrease of 7.0 $KgCO_2e$/ft^2 in emissions intensity after BEPS took effect.

Panel B reports the IPW-weighted estimates, which adjust for potential attrition bias, and the results remain robust. The magnitudes of causal effects on energy intensity and Energy Star performance are nearly identical to the unweighted specification, while the impact on GHG emissions strengthens to a reduction of 0.57 million $KgCO_2e$ per unit increase in Gap. Similarly, emissions intensity continues to decline by approximately 0.73 $KgCO_2e/ft^2$ per additional unit of Gap. Substantively, this implies that a building 10 units above its pre-policy threshold causally reduced its total emissions by 5.7 million $KgCO_2e$ and its emissions intensity by 7.3 $KgCO_2e/ft^2$ following BEPS. These findings demonstrate that BEPS induced disproportionately larger efficiency gains and emissions reductions among buildings with greater initial performance shortfalls.

Table 4.1: BEPS Impacts Estimated with Property-Type Mean Compliance Gaps

	Site EUI (kWh/ft^2)	**Source EUI (kWh/ft^2)**	**Energy Star Score**	**GHG Emissions ($KgCO_2e$)**	**GHG Intensity ($KgCO_2e/ft^2$)**
			A: Unweighted Estimates		
Post × Compliance Gap	-0.343*** (0.036)	-0.472*** (0.059)	0.412*** (0.039)	-0.375*** (0.084)	-0.704*** (0.039)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	12,347	12,347	10,980	12,347	12,347
R^2 (within)	0.108	0.245	0.063	0.356	0.340
			B: IPW-Weighted Estimates		
Post × Compliance Gap	-0.323*** (0.038)	-0.459*** (0.063)	0.415*** (0.040)	-0.566*** (0.063)	-0.728*** (0.035)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,654	11,654	10,980	11,654	11,654
R^2 (within)	0.097	0.236	0.063	0.130	-2.427

Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Figure 4.1 presents the dynamic treatment effects of BEPS on building performance outcomes. Across all five outcomes, the pre-policy coefficients remain relatively flat and statistically insignificant at 5%, supporting the validity of the parallel trends in intensity assumption. Following the enactment of BEPS in 2019, modest adjustments are observed, but the most pronounced effects appear after 2021, coinciding with the beginning of the first compliance cycle. For Site EUI (kWh/ft^2), buildings with larger pre-policy Gaps show reductions of roughly 0.4–0.6 kWh/ft^2 relative to baseline levels by 2022–2023. Source EUI (kWh/ft^2) follows a similar trajectory, declining by approximately 0.5–0.7 kWh/ft^2 over the same period. The Energy Star Score exhibits a strong upward response, rising by about 0.5 to 0.6 points post-2021. Environmental outcomes show parallel improvements, total GHG emissions ($KgCO_2e$) fall by 0.4–0.5 million $KgCO_2e$ relative to pre-policy levels, while GHG intensity ($KgCO_2e/ft^2$) declines by approximately 0.4–0.5 $kgCO_2e/ft^2$. Together, these results suggest that BEPS generated gradual but increasingly strong effects after compliance obligations became binding in 2021.

Figure 4.1: Event-study plots of BEPS impacts

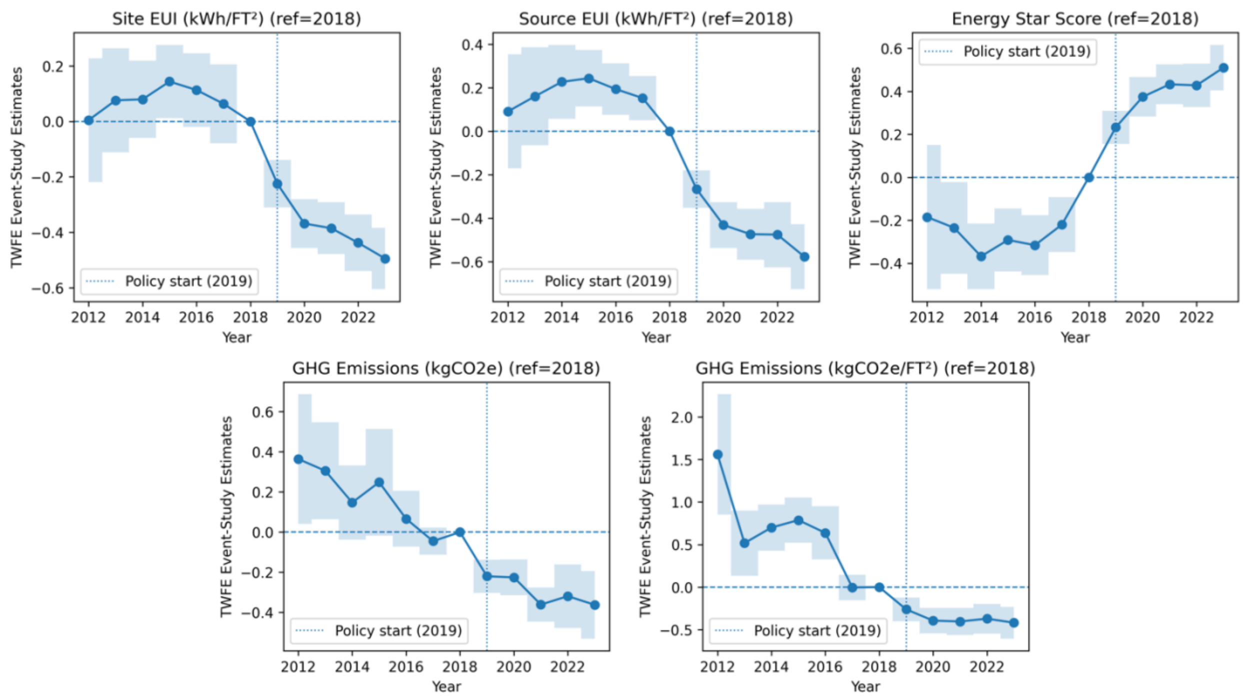


Table 4.2 reports the causal impacts of BEPS on public buildings. The unweighted estimates (Panel A) suggest that BEPS produced significant improvements in both energy performance and environmental outcomes for publicly owned properties. Specifically, each additional unit of pre-policy shortfall is associated with a reduction of 0.28 kWh/ft² in Site EUI and 0.46 kWh/ft² in Source EUI, alongside a 0.35-point increase in Energy Star score. On the environmental side, total GHG emissions decline by 0.43 million $KgCO_2e$, and GHG intensity falls by 0.42 $KgCO_2e/ft^2$ per unit increase in Gap. Substantively, this implies that a public building with a 10 unit larger pre-policy shortfall would, following BEPS, reduce its Site EUI by 2.8 kWh/ft², Source EUI by 4.6 kWh/ft², increase its Energy Star score by 3.5 points, and reduce its emissions by approximately 4.3 million $KgCO_2e$, or 4.2 $KgCO_2e/ft^2$ in emissions intensity.

Panel B presents the IPW-weighted estimates. The magnitudes of the causal effects are similar to the unweighted estimates for energy efficiency outcomes, with Site EUI reduced by 0.21 kWh/ft² and Source EUI by 0.27 kWh/ft² per unit Gap, while Energy Star scores rise by 0.34 points. On the environmental side, however, the impact strengthens, total GHG emissions decrease by 0.49 million $KgCO_2e$ and emissions intensity by 0.41 $KgCO_2e/ft^2$ per unit Gap. Substantively, this means a building with a 10-unit shortfall lowered its emissions by nearly 4.9 million $KgCO_2e$ after BEPS, underscoring particularly strong environmental improvements in the public sector.

Table 4.2: BEPS impacts on public buildings estimated with property-type mean compliance gaps

	Site EUI (kWh/ft^2)	**Source EUI (kWh/ft^2)**	**Energy Star Score**	**GHG Emissions ($KgCO_2e$)**	**GHG Intensity ($KgCO_2e/ft^2$)**
			A: Unweighted Estimates		
Post × Compliance Gap	-0.280** (0.135)	-0.457* (0.273)	0.346*** (0.092)	-0.427*** (0.088)	-0.416** (0.193)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,062	1,062	889	1,062	1,062
R^2 (within)	0.396	0.319	0.518	0.668	0.466
			B: IPW-Weighted Estimates		
Post × Compliance Gap	-0.205*** (0.053)	-0.270*** (0.090)	0.338*** (0.092)	-0.487*** (0.108)	-0.409** (0.190)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	935	935	889	935	935
R^2 (within)	0.413	0.289	0.518	0.559	0.438

Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Figure 4.2 presents the event-study estimates for public buildings across the five outcome variables. The pre-policy coefficients are generally close to zero and statistically insignificant, which supports the validity of the parallel trends assumption in the public building subsample. After the introduction of BEPS in 2019, clear shifts emerge, particularly from 2021 onward when compliance obligations became binding. Site EUI (kWh/ft^2) shows a gradual decline, with reductions approaching 0.8–1.0 kWh/ft^2 relative to baseline levels by 2022–2023. A similar pattern is observed for Source EUI (kWh/ft^2), which falls by about 1.0–1.5 kWh/ft^2 post-2021. The Energy Star Score rises steadily after 2020, with improvements of roughly 1–2 points, suggesting that public buildings with larger initial performance Gaps made meaningful efficiency gains. On the environmental side, both total GHG emissions and GHG emissions intensity decline markedly after 2021, with reductions of approximately 0.5 million $KgCO_2e$ and 0.6–0.8 $KgCO_2e/ft^2$, respectively, by 2023.

Figure 4.2: Event-study plots of BEPS impacts on public buildings

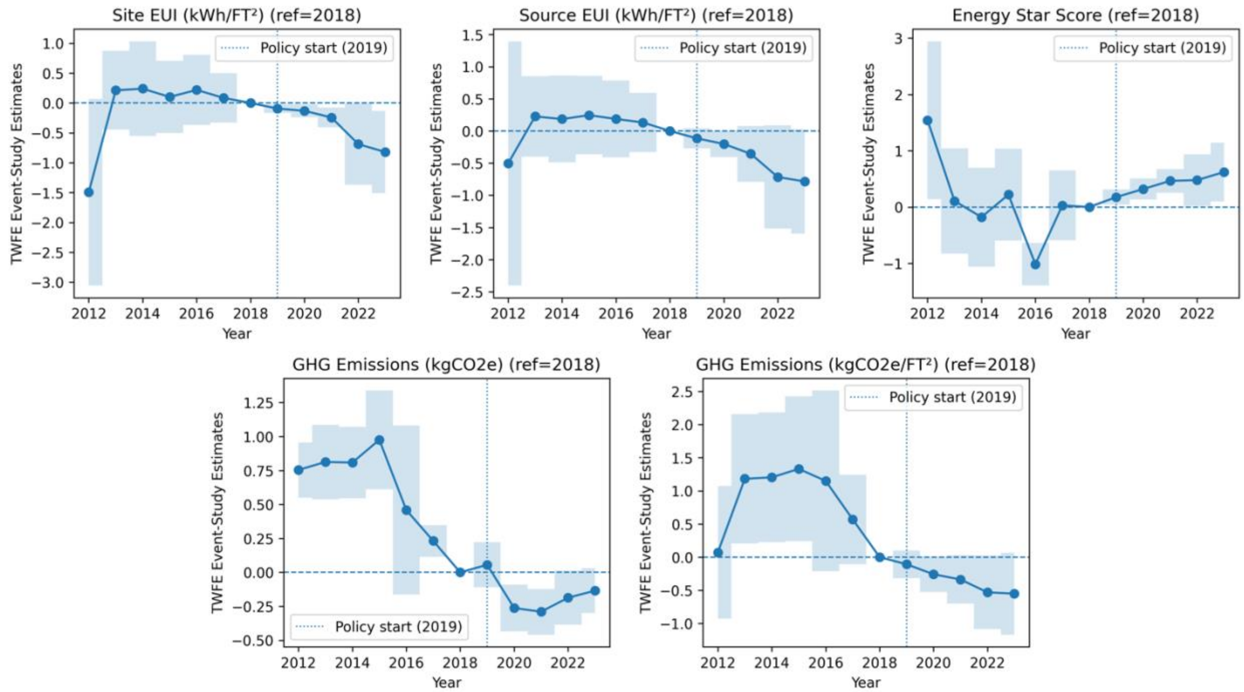


Table 4.3 presents the causal impacts of BEPS on private buildings. The unweighted estimates (Panel A) show that private buildings with greater pre-policy shortfalls experienced significant efficiency and emissions gains after BEPS implementation. Each additional unit of Gap reduced Site EUI by 0.35 kWh/ft² and Source EUI by 0.47 kWh/ft², while raising the Energy Star score by 0.42 points. On the environmental side, total GHG emissions declined by 0.36 million $KgCO_2e$, and GHG intensity fell by 0.71 $KgCO_2e/ft^2$ per unit Gap. Substantively, this implies that a private building with a 10 unit larger shortfall relative to its property-type threshold would, post-BEPS, reduce its Site EUI by 3.5 kWh/ft² and its Source EUI by 4.7 kWh/ft², while achieving a 4.2-point increase in Energy Star score, lowering total emissions by 3.6 million $KgCO_2e$, and reducing emissions intensity by 7.1 $KgCO_2e/ft^2$.

The IPW-weighted estimates (Panel B) confirm the robustness of these results. The magnitudes of the efficiency gains remain consistent, with Site and Source EUI reductions of 0.34 and 0.47 kWh/ft² per unit Gap, respectively, and Energy Star scores increasing by 0.43 points. The environmental outcomes, however, show stronger causal effects under weighting, with total GHG emissions declining by 0.57 million $KgCO_2e$ and emissions intensity by 0.73 $KgCO_2e/ft^2$ for each additional unit of Gap. Substantively, this means that a private building with 10-unit shortfall lowered emissions by 5.7 million $KgCO_2e$ and reduced emissions intensity by 7.3 $KgCO_2e/ft^2$ after BEPS.

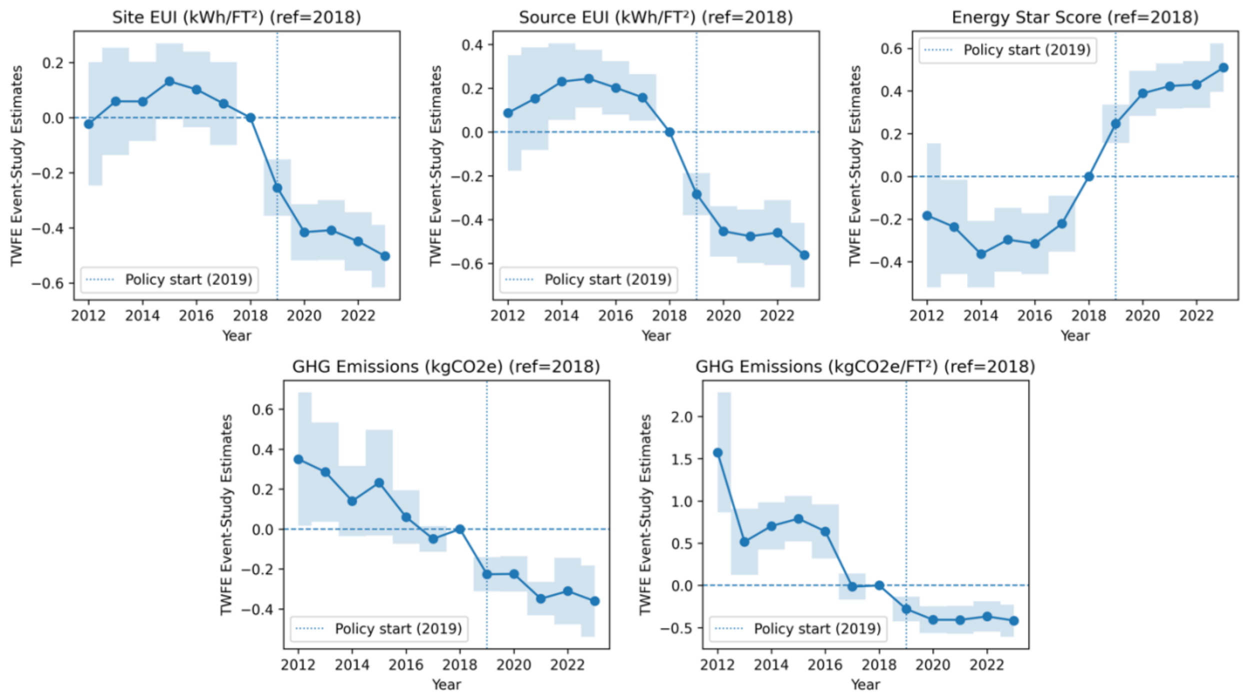
Table 4.3: BEPS impacts on private buildings estimated with property-type mean compliance gaps

	Site EUI (kWh/ft^2)	**Source EUI (kWh/ft^2)**	**Energy Star Score**	**GHG Emissions ($KgCO_2e$)**	**GHG Intensity ($KgCO_2e/ft^2$)**
A: Unweighted Estimates					
Post × Compliance Gap	-0.349*** (0.038)	-0.467*** (0.060)	0.418*** (0.042)	-0.363*** (0.089)	-0.705*** (0.041)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,285	11,285	10,091	11,285	11,285
R^2 (within)	0.110	0.247	0.058	0.339	0.337
B: IPW-Weighted Estimates					
Post × Compliance Gap	-0.340*** (0.043)	-0.466*** (0.067)	0.426*** (0.044)	-0.565*** (0.068)	-0.727*** (0.037)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	10,719	10,719	10,091	10,719	10,719
R^2 (within)	0.101	0.240	0.057	-0.193	-2.671

Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Figure 4.3 presents the event-study estimates for private buildings across the five outcome variables. As with the full sample, the pre-policy coefficients are generally flat and statistically insignificant, consistent with the parallel trends assumption. Following the enactment of BEPS in 2019, modest adjustments are observed, but the strongest effects appear from 2021 onward, coinciding with the start of the binding compliance cycle. Site EUI (kWh/ft^2) declines by approximately 0.3–0.5 kWh/ft^2 relative to pre-policy levels by 2022–2023, while Source EUI (kWh/ft^2) shows somewhat larger reductions of 0.4–0.6 kWh/ft^2. The Energy Star Score rises steadily beginning in 2020, improving by about 0.4–0.6 points relative to the 2018 baseline, indicating incremental gains in efficiency performance. On the environmental side, total GHG emissions fall by roughly 0.3–0.4 million $KgCO_2e$, and GHG emissions intensity decreases by about 0.3–0.4 $kgCO_2e/ft^2$, with the sharpest reductions concentrated in the 2021–2023 period.

Figure 4.3: Event-study plots of BEPS impacts on private buildings



A comparison of the overall, public, and private building estimates shows both common patterns and notable differences in the causal impacts of BEPS. Across all samples, buildings with larger pre-policy compliance Gaps experienced significant post-policy improvements in energy performance and environmental outcomes, with reductions in Site and Source EUI, higher Energy Star scores, and declines in both total and intensity-adjusted GHG emissions. The magnitudes, however, differ by ownership type. Public buildings show somewhat smaller energy efficiency effects—Site EUI reductions of 0.21–0.28 kWh/ft² and Source EUI reductions of 0.27–0.46 kWh/ft² per unit Gap compared to private buildings, which exhibit stronger reductions of 0.34–0.35 and 0.46–0.47 kWh/ft², respectively. By contrast, public buildings achieve relatively larger emissions reductions in substantive terms, lowering total GHG emissions by up to 4.9 million $KgCO_2e$ per 10-unit shortfall, compared with approximately 3.6–5.7 million $KgCO_2e$ for private buildings. These differences suggest that while private buildings respond more strongly on energy efficiency metrics, public buildings deliver particularly pronounced environmental benefits.

The event-study analysis across all BEPS buildings, public, and private buildings subsample demonstrates the consistent evidence of BEPS impacts. For the full sample, reductions in Site EUI and Source EUI of 0.4–0.7 kWh/ft², coupled with modest increases in Energy Star scores (0.5–0.6

points) and declines in emissions intensity of 0.4–0.5 $kgCO_2e/ft^2$, demonstrate broad improvements following the onset of compliance in 2021. Public buildings exhibit the strongest responses, with Site and Source EUI falling by 0.8–1.5 kWh/ft^2, Energy Star scores increasing by 1–2 points, and emissions intensity dropping by 0.6–0.8 $kgCO_2e/ft^2$. Private buildings show lesser improvement, with Site and Source EUI reductions of 0.3–0.6 kWh/ft^2, Energy Star score increases of 0.4–0.6 points, and emissions intensity declines of 0.3–0.4 $kgCO_2e/ft^2$. This evidence indicates that BEPS had broad impacts across ownership types, but with stronger effects in the public sector, a pattern consistent with the continuous-treatment identification strategy in which larger pre-policy gaps and more binding obligations translate into greater post-policy responses.

The TWFE and event-study analyses consistently show that BEPS produced substantial gains in both energy efficiency and environmental outcomes. The TWFE results indicate that private buildings achieved stronger improvements in Site and Source EUI per unit of compliance gap, while the event studies highlight earlier and more pronounced reductions in GHG emissions among public buildings. Together, these findings point to heterogeneous pathways of compliance, with private buildings improving efficiency more intensively and public buildings delivering larger and timelier environmental benefits. These patterns motivate the subsequent robustness checks, which assess whether the results hold under alternative gap constructions.

4.2 Robustness Estimates of Impacts of BEPS on Energy Efficiency and Emissions

Robustness checks (Table 4.4) using property-type percentile compliance gaps (Method B) confirm the main findings across the overall, public, and private buildings. For the full sample, a one-unit larger pre-policy gap reduced Site EUI by about 0.24 kWh/ft^2 and Source EUI by 0.38 kWh/ft^2, increased Energy Star scores by 0.32 points, and lowered GHG emissions by 0.30–0.44 million $KgCO_2e$, equivalent to reductions of 5.5–6.3 kWh/ft^2 in energy intensity for a 10-unit shortfall. Public buildings show slightly smaller efficiency effects (reductions of 0.18–0.22 kWh/ft^2 in Site EUI and 0.25–0.35 kWh/ft^2 in Source EUI per unit gap) but comparable gains in Energy Star scores and stronger environmental benefits, with emissions reductions of 2.8–3.5 million $KgCO_2e$ for a 10-unit shortfall. Private buildings mirror the full-sample results, with reductions of 0.24 and 0.37 kWh/ft^2 in Site and Source EUI, Energy Star increases of 0.33 points, and larger weighted emissions intensity declines of 5.6-6.30 $KgCO_2e/ft^2$ per unit gap for a 10-unit shortfall. These robustness checks demonstrate that BEPS impacts hold under percentile-based definitions of compliance gaps, with private buildings exhibiting stronger efficiency responses and environmental gains.

Table 4.4: Robustness estimates with property-type percentile compliance gaps

	Site EUI (kWh/ft^2)	**Source EUI (kWh/ft^2)**	**Energy Star Score**	**GHG Emissions ($KgCO_2e$)**	**GHG Intensity ($KgCO_2e/ft^2$)**
A: All Buildings (Unweighted Estimates)					
Post × Compliance Gap	-0.240*** (0.024)	-0.375*** (0.037)	0.322*** (0.024)	-0.302*** (0.060)	-0.557*** (0.033)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	12,347	12,347	10,980	12,347	12,347
R^2 (within)	0.105	0.252	0.077	0.367	0.346
B: All Buildings (IPW-Weighted Estimates)					
Post × Compliance Gap	-0.234*** (0.025)	-0.373*** (0.040)	0.327*** (0.025)	-0.443*** (0.056)	-0.630*** (0.042)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,654	11,654	10,980	11,654	11,654
R^2 (within)	0.096	0.243	0.077	0.122	2.426
C: Public Buildings (Unweighted Estimates)					
Post × Compliance Gap	-0.218** (0.088)	-0.349** (0.175)	0.274*** (0.059)	-0.283*** (0.064)	-0.366*** (0.121)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,062	1,062	889	1,062	1,062
R^2 (within)	0.399	0.323	0.526	0.662	0.481
D: Public Buildings (IPW-Weighted Estimates)					
Post × Compliance Gap	-0.179*** (0.039)	-0.249*** (0.064)	0.270*** (0.060)	-0.345*** (0.085)	-0.365*** (0.118)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	935	935	889	935	935
R^2 (within)	0.421	0.300	0.526	0.552	0.454
E: Private Buildings (Unweighted Estimates)					
Post × Compliance Gap	-0.242*** (0.025)	-0.372*** (0.038)	0.327*** (0.026)	-0.295*** (0.065)	-0.558*** (0.035)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,285	11,285	10,091	11,285	11,285
R^2 (within)	0.107	0.253	0.072	0.349	0.343
F: Private Buildings (IPW-Weighted Estimates)					
Post × Compliance Gap	-0.242*** (0.028)	-0.379*** (0.043)	0.335*** (0.027)	-0.448*** (0.061)	-0.633*** (0.041)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	10,719	10,719	10,091	10,719	10,719
R^2 (within)	0.099	0.247	0.071	0.187	2.672

Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Robustness estimates (Table 4.5) using citywide mean compliance Gaps (Method C) confirm the consistency of BEPS impacts across the full sample, public, and private buildings. For all buildings combined, a one-unit larger pre-policy gap reduced Site and Source EUI by 0.26 and 0.40 kWh/ft^2, increased Energy Star scores by 0.38 points, and lowered emissions by 2.8–4.5 million $KgCO_2e$ per 10-unit shortfall. Public buildings show slightly smaller efficiency effects (0.20–0.27 kWh/ft^2 reductions in Site and 0.23–0.38 kWh/ft^2 in Source EUI) but comparable Energy Star improvements and robust emissions reductions of 2.2–3.6 million $KgCO_2e/ft^2$. Private buildings exhibit efficiency effects nearly identical to the full sample, with 2.5–3.9 kWh/ft^2 reductions in Site and Source EUI for a 10-unit shortfall, a 4-point Energy Star gain, and 2.7–4.6 million $KgCO_2e$ fewer emissions. These results show that BEPS effects are robust to citywide definitions of compliance Gaps, with private buildings driving stronger efficiency improvements and public buildings sustaining environmental gains.

Table 4.5: Robustness estimates with citywide mean compliance gaps

	Site EUI (kWh/ft²)	**Source EUI (kWh/ft²)**	**Energy Star Score**	**GHG Emissions ($KgCO_2e$)**	**GHG Intensity ($KgCO_2e/ft^2$)**
A: Unweighted Estimates					
Post × Compliance Gap	-0.258*** (0.032)	-0.395*** (0.044)	0.380*** (0.034)	-0.276*** (0.075)	-0.621*** (0.036)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	12,347	12,347	10,980	12,347	12,347
R^2 (within)	0.099	0.253	0.066	0.351	0.348
B: IPW-Weighted Estimates					
Post × Compliance Gap	-0.250*** (0.034)	-0.389*** (0.046)	0.380*** (0.035)	-0.452*** (0.088)	-0.653*** (0.040)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,654	11,654	10,980	11,654	11,654
R^2 (within)	0.089	0.245	0.065	-0.149	-2.423
C: Public Buildings (Unweighted Estimates)					
Post × Compliance Gap	-0.267** (0.121)	-0.382* (0.199)	0.258*** (0.080)	-0.224*** (0.066)	-0.393** (0.162)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	1,062	1,062	889	1,062	1,062
R^2 (within)	0.397	0.326	0.511	0.650	0.476
D: Public Buildings (IPW-Weighted Estimates)					
Post × Compliance Gap	-0.204*** (0.060)	-0.232*** (0.075)	0.253*** (0.082)	-0.357*** (0.102)	-0.366** (0.146)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	935	935	889	935	935
R^2 (within)	0.414	0.293	0.511	0.536	0.444
E: Private Buildings (Unweighted Estimates)					
Post × Compliance Gap	-0.253*** (0.033)	-0.390*** (0.044)	0.396*** (0.037)	-0.274*** (0.084)	-0.621*** (0.038)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	11,285	11,285	10,091	11,285	11,285
R^2 (within)	0.100	0.254	0.062	0.334	0.345
F: Private Buildings (IPW-Weighted Estimates)					
Post × Compliance Gap	-0.252*** (0.037)	-0.395*** (0.049)	0.404*** (0.039)	-0.455*** (0.097)	-0.655*** (0.040)
Building FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	10,719	10,719	10,091	10,719	10,719
R^2 (within)	0.092	0.249	0.061	0.215	2.668

Standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

These findings contribute to the empirical literature on building energy policy by providing the first ex post, building-level causal evidence of the effectiveness of Washington, DC's BEPS. While prior studies have primarily relied on ex-ante simulations or descriptive assessments, this analysis demonstrates realized efficiency and emissions gains using a continuous-treatment TWFE framework. By uncovering heterogeneous responses across public and private ownership structures, the results show how performance-based mandates can generate both complementary and distribution-specific outcomes—efficiency gains in the private buildings and emissions reductions in the public buildings. This evidence advances understanding of how mandatory performance standards operate in practice, offering empirical validation of BEPS as a scalable regulatory approach for urban decarbonization and energy policy design.

5.0 Conclusion

This study evaluates the causal impacts of Washington, DC's Building Energy Performance Standards (BEPS). Motivated by the need to understand whether mandatory energy standards can drive measurable improvements in efficiency and emissions, the study leverages a panel dataset of buildings from 2012-2023, sourced from Open Data DC, and applies a continuous-treatment two-way fixed effects framework. Central to the empirical strategy is the construction of a gap variable, defined as the difference between a building's pre-policy baseline performance and the BEPS threshold, using three alternative approaches: the property-type mean, the property-type percentile, and the citywide mean. These continuous gaps are then interacted with the post-policy indicator to estimate whether properties with greater pre-policy shortfalls experience larger efficiency and emissions improvements once BEPS becomes binding. In addition, event-study models are employed to test the parallel trends assumption and to trace the dynamic impacts of BEPS over time, providing evidence on when effects emerge and how they evolve across the pre- and post-policy periods.

The empirical analysis demonstrates that BEPS produced measurable improvements in both energy efficiency and emissions outcomes, with stronger impacts observed among buildings with larger pre-policy shortfalls. Using property-type mean compliance gaps, the TWFE estimates show that each additional unit of pre-policy gap reduced Site and Source EUI by 0.34 and 0.47 kWh/ft^2, respectively, raised Energy Star scores by 0.41 points, and lowered GHG emissions by 0.38 million $KgCO_2e$ and 0.70 $KgCO_2e/ft^2$ in intensity. Weighted estimates confirm these results, increasing the emissions reductions to 0.57 million $KgCO_2e$ per unit gap. Event-study models show that effects emerged gradually after BEPS's passage in 2019, but became most pronounced from 2021 onward, aligning with the first compliance cycle.

Disaggregated analysis highlights differences between public and private buildings. Public properties achieved significant emissions gains, with reductions of 0.21–0.28 kWh/ft² in Site EUI and 0.27–0.46 kWh/ft² in Source EUI per unit gap, coupled with relatively larger emissions benefits—up to 4.9 million $KgCO_2e$ for a 10-unit shortfall compared with private buildings. By contrast, private properties delivered stronger energy efficiency improvements, reducing Site and Source EUI by 0.34–0.35 and 0.46–0.47 kWh/ft² per unit gap, while achieving Energy Star increases of 0.42–0.43 points and emissions reductions of 3.6–5.7 million $KgCO_2e$ for a 10-unit shortfall. Event-study results confirm these ownership differences, public buildings exhibited more pronounced reductions in emissions and faster post-2021 responses, while private buildings registered stronger gains in energy intensity.

Robustness checks using alternative compliance gap constructions (percentile- and citywide-based) reinforce the validity of these findings. Across specifications, the results consistently show that BEPS led to significant efficiency and environmental improvements, with private buildings driving stronger reductions in Site and Source EUI and public buildings achieving relatively larger emissions benefits. These results underscore both the credibility of the identification strategy and the durability of the estimated impacts. Overall, the evidence highlights BEPS as an effective regulatory instrument that induced heterogeneous but complementary improvements across building types, ensuring broad gains in energy efficiency and emissions mitigation.

The policy implications of this research extend beyond Washington, DC. By demonstrating that BEPS produced verifiable efficiency and emissions gains, the findings strengthen the case for adopting performance-based standards in other U.S. cities and internationally, especially where disclosure-only regimes have reached diminishing returns. The evidence suggests that carefully designed standards can balance efficiency and environmental outcomes, with ownership structures shaping pathways of compliance. Future research should build on this analysis by exploring long-term adjustments across compliance cycles, spillover effects on market valuations and tenant behavior, and interactions with complementary policies such as renewable energy incentives. More broadly, the results contribute to the global debate on building decarbonization by highlighting BEPS as a scalable and adaptable framework capable of driving deep emissions reductions in urban energy systems.

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