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Attaching public health benefits to building efficiency measures at the national and regional scales

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ABSTRACT

Building efficiency offers large potential reductions in U.S. primary energy use and operating costs; however, efficient buildings also benefit the economy and society in ways that are challenging to quantify in dollar terms at the national scale. Improved public health is an important non-energy benefit that is largely absent from assessments of building efficiency program impacts at scale. Accordingly, such assessments underestimate the value of building efficiency as a means to improve health and well-being.

We incorporate recently published EPA estimates of energy efficiency's public health benefits (dollars per avoided kilowatt-hour of electricity generation) in an analysis using the Scout impact assessment software (scout.energy.gov), examining how this addition affects the estimated cost savings of U.S. building efficiency measure portfolios compared to a base-case where only measure operating cost savings are considered. Effects are explored both at the national and regional levels. Overall, we find that the inclusion of public health benefits substantially increases the cost savings of building efficiency portfolios, with stronger effects in regions with higher air pollution emissions rates for electricity generation and higher population densities. We conclude by discussing the importance of factoring public health benefits into future analyses of the building efficiency resource.

Introduction

In 2019, residential and commercial buildings accounted for nearly 40% of U.S. annual primary energy use and 75% of annual electricity consumption (EIA 2020). Given buildings' substantial share of both current and projected energy consumption through 2050, the buildings sector offers large potential savings in primary energy use and in building operating costs. The savings potential of energy efficiency programs has been thoroughly assessed and quantified at regional and national scales in the U.S., and there is clear consensus that energy efficiency is a cost-effective resource with considerable untapped potential (Langevin et al. 2019; EPRI 2017; Gowrishankar and Levin 2017; EPRI 2014; Azevedo et al. 2013; Granade et al. 2009).

In addition to providing economic benefits related to reduced energy use, energy efficiency delivers important non-energy benefits. For example, the International Energy Agency (IEA) has found that energy efficiency can alleviate poverty, increase energy access, and improve public health and well-being (IEA 2019). Public health benefits include both improvements to physical health, such as those resulting from reduced air pollution, and improvements to mental health, which come from alleviating thermal discomfort and anxiety related to fuel poverty (Liddell and Morris 2010). In addition, many studies have found efficiency measures can improve health through better indoor environments (Wilson et al. 2016). In this paper, we limit our focus to public health benefits that result from avoiding fossil fuel-based electricity generation through building efficiency, thereby improving outdoor air quality.

Although the electric power sector in the U.S. has changed rapidly in the past decade, with non-hydro renewables growing from less than 5% of total generation in 2010 to nearly 20% in 2019 (EIA 2020), generating electricity still produces significant air pollution. In 2018, the electricity sector emitted 1.26 million tons of sulfur dioxide (SO_2) and 1.02 million tons of nitrogen oxides (NO_x) (EIA 2018). The electricity sector produced more fine particulate matter ($PM_{2.5}$) in 2014 than highway vehicles (EPA 2018). The physical health impacts of these emissions include respiratory issues, rheumatism, arthritis, and allergies (IEA 2019).

The public health impacts of electricity generation have been studied extensively (e.g., (Thind et al. 2019; Perera 2017) and in some cases quantified in dollar terms in regional analyses (Buonocore et al. 2016), but most economic assessments of U.S. energy efficiency potential do not incorporate the value of non-energy benefits related to public health improvements. This gap is especially evident at the national scale, as quantifying the value of health benefits from existing or planned energy efficiency programs is challenging. Until recently, there were no comprehensive datasets on the monetized health benefits of energy savings across the entire U.S. Moreover, relevant datasets that do exist do not appropriately differentiate emissions across regions, which is needed to account for geographical differences in the electricity generation mix, and methodological inconsistencies across studies that attempt to estimate these benefits make comparing results difficult (EPA 2019).

To address these data gaps and assist state and local decision-makers in accurately estimating the full value of energy efficiency programs, the U.S. Environmental Protection Agency (EPA) recently released a comprehensive assessment of the health benefits of avoided electricity generation—in dollars per avoided kilowatt hour (kWh) of generation—from energy efficiency deployment in electric grid regions that span the contiguous U.S. (EPA 2019). The analysis is informed by best practices for estimating the public health benefits of avoided generation that account for differences in both the timing of avoided generation and regional differences in electricity generation and air pollution control strategies.

Drawing from these new estimates of the public health benefits of efficiency, this paper assesses the national and regional cost savings potential of building energy efficiency measure portfolios when implemented across the U.S. residential and commercial building stock. Specifically, we integrate the new public health benefits data into Scout (scout.energy.gov), an open-source software program developed by the U.S. Department of Energy (DOE) for national building efficiency impact assessment (BTO 2020). By incorporating the EPA's estimates of the public health benefits of efficiency into Scout, we aim to explore how including public health benefits affects the cost savings of building energy efficiency measures when deployed at scale in the U.S. We examine how consideration of public health costs influences the cost effectiveness of these measures, and assess the degree to which the relationship between measure cost savings and energy savings changes when these benefits are included.

The paper is organized as follows. In the next section, we briefly explain Scout's analysis approach and how the EPA's valuation of the public health benefits from energy efficiency is incorporated into Scout's analysis workflow. Next, we present results of total cost savings and measure cost effectiveness at both the national level and at regional levels in order to identify the regions in which additional cost savings related to public health benefits are most pronounced. Finally, we conclude by discussing the importance of incorporating public health benefits into future studies of building energy efficiency technology research, development, and deployment in order to more holistically evaluate the U.S. building efficiency resource.

Methods

The EPA estimates the value of public health benefits resulting from changed electricity generation using two peer-reviewed tools, AVERT (AVoided Emissions and geneRation Tool) and COBRA (Co-Benefits Risk Assessment) (EPA, 2019). AVERT estimates how changes in fossil-fired electricity generation affect NO_x, SO_2, $PM_{2.5}$, and CO_2 emissions. The input to AVERT could be an energy efficiency measure that impacts energy use during peak periods of generation, or that impacts energy use uniformly across all periods of generation. COBRA draws on epidemiological studies to estimate how avoided NO_x, SO_2, $PM_{2.5}$, and CO_2 emissions affects a number of health outcomes, including the number of avoided premature deaths, hospital admissions, and illness-related work loss days, among others. COBRA estimates high and low monetary values for these health benefits based on published literature and consistent with standard EPA methodology (e.g., $31,446–$263,795 for a non-fatal heart attack). In addition, COBRA can compute estimates with either a 3% or 7% discount rate for the value of future benefits. The total value of health benefits for each case is divided by total avoided electricity generation to arrive at a $/kWh generation value. With this approach, a range of public health benefit estimates is constructed, reflecting either a uniform efficiency impact or peak period efficiency impact, and either a 3% discount rate or a 7% discount rate.

Figure 1a summarizes EPA's public health benefit estimates by AVERT region (with the region map shown in Figure 1b) for four cases from the EPA analysis described above that are considered in this paper: 1) uniform efficiency, 3% discount rate ('Uniform EE – high'), 2) uniform efficiency, 7% discount rate ('Uniform EE – low'), 3) efficiency during peak hours, 3% discount rate ('EE at Peak (12-6PM) – high'), and 4) efficiency during peak hours, 7% discount rate ('EE at Peak (12-6PM) – low'). Together, these cases establish upper and lower bounds on the value of public health benefits as they are incorporated into assessments of energy efficiency measure impacts. In Figure 1a, a high degree of regional variability is observed, owing to regional differences in generation mix: the highest regional benefit (in the Mid-Atlantic, which has both a large population and high air pollution emissions rates) is estimated to be nearly eight times larger than the smallest regional benefit (in California, which has a high penetration of lower-emitting natural gas generation). Within-region estimates also suggest a high degree of uncertainty: the upper bounds on benefit estimates are consistently more than two times larger than the lower bounds on these estimates, across all regions. On the other hand, little difference is observed between benefit estimates for kWh reductions that occur uniformly across the day vs. those that occur during the peak hours of 12-6 PM, with the Northeast region showing the largest difference between uniform and on-peak public health benefits (~1 cent/kWh). We direct readers to the EPA's report for more detail on the methodology used to estimate peak vs. uniform benefits (EPA 2019).

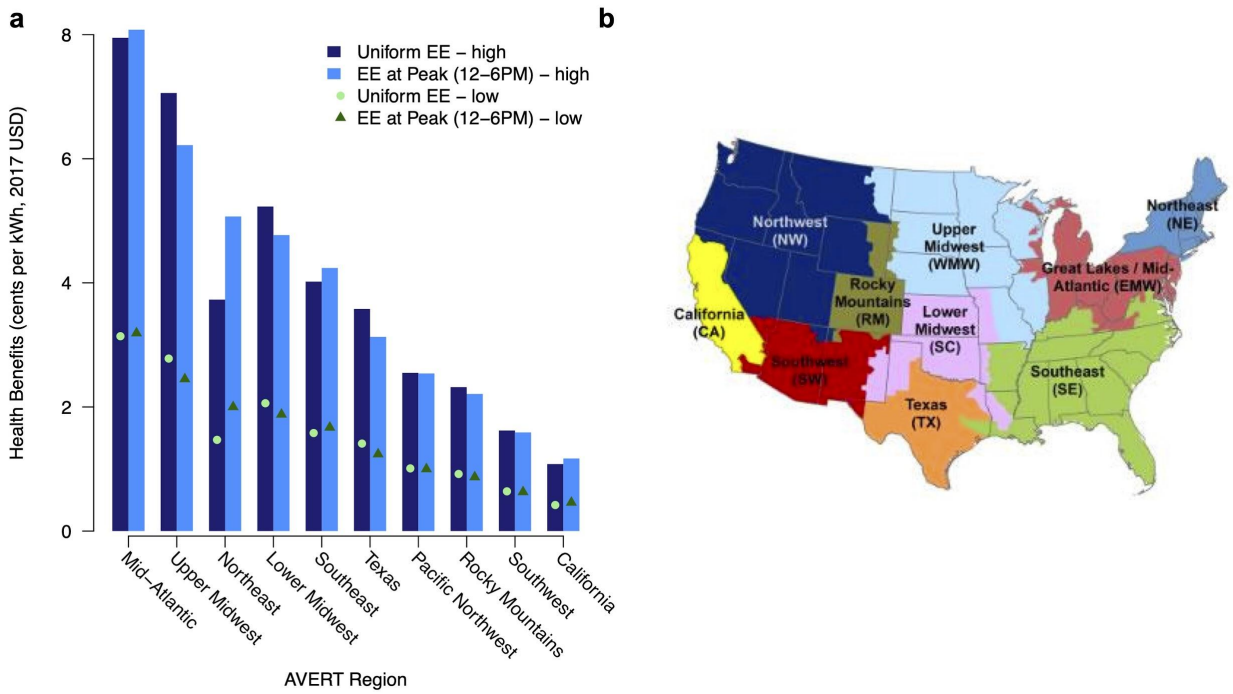

Figure 1. **a.** EPA AVERT region map. **b.** EPA estimates of the health benefits of energy efficiency, in cents per kWh generation avoided, for each of the 10 AVERT regions. Benefit estimates are shown for the four most extreme scenarios in the EPA analysis: 1) uniform energy efficiency, 3% discount rate ('Uniform EE - high'), 2) uniform energy efficiency, 7% discount rate ('Uniform EE - low'), 3) energy efficiency during peak hours, 3% discount rate ('EE at Peak (12-6 PM) - high'), and 4) energy efficiency during peak hours, 7% discount rate ('EE at Peak (12-6 PM) - low').

To determine the influence of EPA's public health benefits estimates on building efficiency impact assessments at scale, we add these benefits to the Scout impact assessment software.[1] Scout estimates the national energy use, CO_2 emissions, and operating cost savings potential of emerging building energy conservation measures (ECMs) in all residential and commercial building types across a long time horizon (2015-2050). Savings can be explored under multiple technology adoption cases nationally or for a subset of climate zones.

Scout's analysis approach has been described in detail elsewhere (Langevin et al. 2019). Here, we focus on the elements of the Scout assessment framework that are affected by the introduction of public health benefit estimates, as well as the changes to Scout's baseline data that were required to integrate these estimates.

First, since the public health benefit estimates developed by the EPA concern electricity generation only, we focus our analysis on the subset of efficient building technologies in Scout's publicly available 'core' measures set that applies to the electric fuel type.[2] This focus excludes all measures pertaining to natural gas or fuel oil—including fuel switching measures—as well as measures such as sensors and controls and envelope component changes, which apply to multiple fuel types. In total, 52 measures from the full set of core measures are used (20 commercial, 32 residential - spanning single and multi-family homes). In addition to restricting the measure set considered, we restrict the projection year of focus to 2020, given the EPA data's applicability to

[1] Scout version 0.5.1 was adapted for this analysis.
[2] See https://doi.org/10.5281/zenodo.3706923.

current electricity generation conditions and associated public health impacts. Finally, we restrict Scout's technology adoption assumptions to a technical potential scenario,[3] assuming that efficiency measures achieve full stock penetration in the 2020 year of focus. This assumption removes the need to consider baseline technology stock turnover dynamics, greatly simplifying the understanding of changes in efficiency measure cost savings before and after accounting for public health benefits.

Within Scout's analysis engine, the introduction of public health benefits data primarily affects the calculation of an ECM's total electricity cost savings, $\Delta\psi$:

$$\Delta\psi = \sum_{z}^{Z}\sum_{b}^{B}\sum_{u}^{U_b}\sum_{t}^{T_{b,u}}\sum_{v}^{V}\Delta\psi_{z,b,u,t,v}\, a_{(z,b,u,t,v)} \quad (1)$$

$$\Delta\psi_{z,b,u,t,v} = (E^{base}_{z,b,u,t,v} - E^{ecm}_{z,b,u,t,v})\phi^{eia}_{b} \quad (2)$$

Where:

- Z is the set of all regions affected by the ECM,
- B is the set of building types affected by the ECM, and V is the set of building vintages (new or existing) affected by the ECM,[4]
- U_b is the set of end uses for building type b that are affected by the ECM,
- $T_{b,u}$ is the set of technologies for building type b, and end use u that are affected by the ECM,
- $\Delta\psi_{z,b,u,t,v}$ is the portion of an ECM's total electricity cost savings attributable to the baseline market described by region z, building type b, end use u, technology t, and building vintage v,
- $a_{z,b,u,t,v}$ is a competition adjustment factor that removes overlaps between the cost savings impact of an ECM and competing ECMs that apply to the same baseline market,
- $E^{base}_{z,b,u,t,v}$ is the baseline source energy use attributable to the baseline market described by region z, building type b, end use u, technology t, and building vintage v,
- $E^{ecm}_{z,b,u,t,v}$ is the same quantity after ECM adoption, and
- ϕ^{eia}_{b} is the 2020 national average electricity price from the U.S. Energy Information Administration's (EIA) 2019 Annual Energy Outlook ($/source MMBtu) for building type b (EIA 2019).

For this analysis, we replace the electricity cost term in Equation 2, ϕ^{eia}_{b},with an alternative term that reflects both the base EIA cost of electricity and the EPA health cost estimates for region z, building type b, and health cost estimation scenario p, $\phi^{alt}_{z,b,p}$:

$$\phi^{alt}_{z,b,p} = \gamma\phi^{eia}_{b} + \phi^{epa}_{z,p} \quad (3)$$

Where:

- $\phi^{epa}_{z,p}$ is the EPA public health cost benefit estimate ($/kWh electricity generation avoided) for region z and health cost estimation scenario p, and

[3] The technical potential scenario assumes that as soon as an ECM is introduced, the entire baseline market instantaneously and completely switches to the new ECM, and the ECM retains a complete sales monopoly in subsequent years. Results from this scenario represent the maximum impact an ECM could have, limited only by baseline market size.

[4] Constructed after the start of the Scout modeling time horizon (2015).

- $\gamma = 293.07107$ (a conversion between \$/MMBtu and \$/kWh).

By adding the public health costs of electricity generation to the cost of electricity in Equation 3, we assume that utilities directly pass these costs on to the consumer.[5] Accordingly, the public health costs factor into Scout's calculations of technology cost effectiveness from a consumer perspective (e.g., internal rate of return, simple payback) and into calculations of technology adoption, in which technology capital costs are weighed against annual energy cost savings. We refer the reader to the Supplementary Information of Langevin et al. (2019) for details on Scout's ECM cost effectiveness and technology adoption calculation methods.

Beyond these modifications to Scout's cost calculation inputs, we modify the default American Institute of Architects (AIA) climate zone resolution of Scout's baseline energy and cost data such that these data map directly into the AVERT regions that are used to report public health cost data.[6] Drawing from EIA electricity sales data,[7] we recast Scout's baseline data into the 22 Annual Energy Outlook 2019 Electricity Market Module (EMM) regions (EIA 2018), which can be aggregated directly into the 10 AVERT region boundaries.[8]

Finally, to accommodate EPA's public health cost estimates for the two peak hour generation scenarios considered ('EE at Peak' low and high), we translate Scout's baseline energy use data from an annual time resolution to an hourly time resolution. To do this, we determine the fractions of annual electricity use in a given EMM region that are attributable to each hour of the year and apply these fractions to annual electricity use estimates for that region to achieve hourly electricity use estimates by region (z), building type (b), and end use (u), $E_{z,b,u,h}$:

$$E_{z,b,u,h} = E_{z,b,u}\theta_{z,b,u,h} \qquad (4)$$

Where:

- $E_{z,b,u}$ is the annual electricity use in 2020 for a given combination of EMM region (z), building type (b), and end use (u), and
- $\theta_{z,b,u,h}$ is the fraction of this annual electricity use that is attributable to hour of the year (h). Hourly load fractions are derived from baseline end-use load shape data generated for residential buildings using the ResStock tool (NREL 2020) and for commercial buildings using the DOE EnergyPlus Prototype Models (DOE 2020); baseline load shapes are further distinguished by 90.1–2016 climate zone and end use. This approach yields a data point for the electricity use of a given region, building type, and end use combination

[5] We do not account for other potential costs to a utility under a scenario in which public health benefits are directly valued in energy policymaking, such as the costs of complying with regulations implemented to mitigate the public health impacts of emissions from electricity generation.

[6] See https://www.eia.gov/consumption/residential/maps.php.

[7] The electricity sales data are the same as those used by EIA to map buildings sector projections broken out by Census Division (the resolution of the raw EIA baseline data that are used to construct Scout's baseline scenario) to an Electricity Market Module (EMM) breakout in AEO 2019; the data were provided upon request by Laura Martin of EIA (laura.martin@eia.gov).

[8] The mapping is (AVERT (EMM)): Northwest (NWPP); California (CAMX); Rocky Mountains (RMPA), Southwest (AZNM); Upper Midwest (MROW, SRGW, MROE); Lower Midwest (SPNO, SPSO), Mid-Atlantic (RFCM, RFCW, RFCE), Southeast (SRDA, SRSE, FRCC, SRVC, SRCE), Texas (ERCT), Northeast (NYUP, NYCW, NYLI, NEWE).

across all 8,760 hours of the year. Within those 8,760 data points, electricity use for hours that correspond to 12-6 PM ST is multiplied by EPA's 'EE at Peak' health costs for the given region, while electricity use for all other hours is multiplied by EPA's 'Uniform EE' health costs for the given region.

Results

In this section, we present results concerning the cost savings potential of the full ECM portfolio (52 measures applicable to electricity use) at the national and regional scale as well as the cost and energy savings of individual ECMs in different regions. In our results, we focus on how the addition of the EPA's public health benefit estimates impact cost savings potential relative to the Scout baseline scenario in which public health benefits are excluded.

Figure 2 shows the cost savings potential of the full portfolio of ECMs under the various scenarios of public health benefits considered. The results in Figure 2 reflect technical potential estimates after accounting for competition across ECMs in the portfolio (e.g., 'competed' technical potential estimates). Figure 2a shows that at the national scale, including the value of public health benefits substantially increases portfolio cost savings potential – more than doubling the savings in the 'EE at Peak (12-6PM) - high' case compared to the base-case, for example. In Figure 2b, the regional impacts of introducing public health benefits vary considerably, with the most pronounced changes from base-case potential concentrated in the Southeast and Mid-Atlantic regions, where introducing the health benefits yields up to over three times the total portfolio cost savings under both the 'Uniform EE - high' and 'EE at Peak (12-6PM) – high' scenarios, compared to the base-case. These regions are among the largest in terms of annual electricity demand, and the Mid-Atlantic also has the highest public health benefit estimates (in cents/kWh) in Figure 1a. Nationally and in every region, we find that cost savings in the scenarios with public health benefits included are similar between the 'Uniform EE' and 'EE at Peak' cases, which is expected given the EPA's estimates shown in Figure 1a.

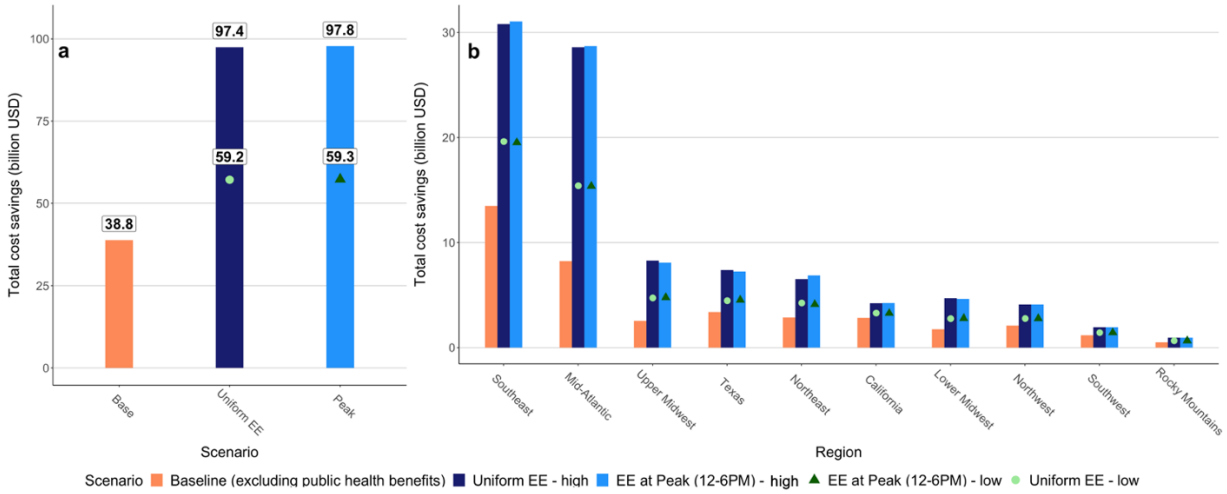

Figure 2. Cost savings potential for ECM portfolio evaluated in 2020 for baseline Scout scenario (excluding public health benefits) and scenarios incorporating public health benefits; competed technical potential. **a.** National-scale cost savings potential in 2020. **b.** Cost savings potential by EPA AVERT region in 2020.

Figure 3 presents maps of the absolute and percentage cost savings potential from adding upper bound ('EE at Peak (12-6PM) - high') public health benefits to baseline cost savings by EMM region (again, EMM regions aggregate into AVERT regions). As in Figure 2, these results show 'competed' technical potential estimates. In absolute terms (Figure 3a), EMM regions within the larger Mid-Atlantic AVERT region show the largest additional cost savings potential, again consistent with the high electricity demand and large public health benefit estimates observed for this region. However, there is substantial variation across the EMM regions within the Mid-Atlantic, with some showing over 10 billion dollars in additional cost savings potential and some showing less than 2.5 billion dollars in additional potential. By contrast, the percentage changes in savings from the base-case (Figure 3b) are more consistent across the EMM regions, generally demonstrating the same pattern as the public health benefit estimates in Figure 1a, with California and the Southwest showing the least potential, and the Mid-Atlantic and Upper Midwest showing the most.

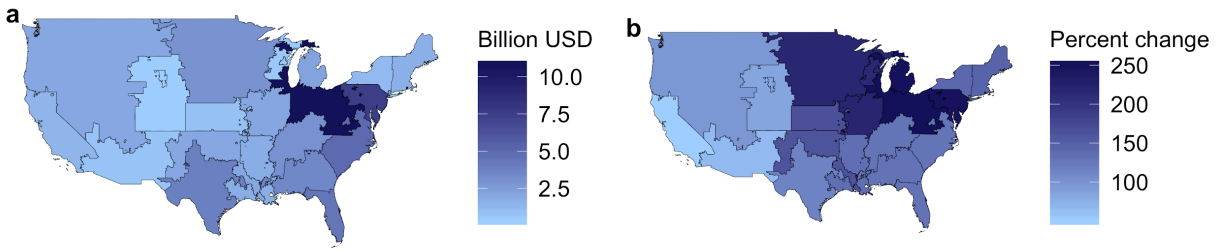

Figure 3. Regional cost savings in 'EE at Peak (12-6PM) - High' EPA scenario in 2020 relative to baseline scenario (in which public health benefits are excluded) shown for EIA's EMM regions; competed technical potential. **a.** Real increases in cost savings over baseline scenario. **b.** Percent change in cost savings over baseline scenario.

Next, we assess the relationship between energy and cost savings for individual ECMs in the Scout base-case compared to the 'EE at Peak (12-6PM)' low and high scenarios; here, we exclude the 'Uniform EE' scenario results for simplicity, as their results are similar to those of the 'EE at Peak' scenarios. Figure 4 shows the relationship between national percent energy savings and percent cost savings (relative to baseline energy and costs) for individual ECMs before considering any competition across the ECM set (e.g., 'uncompeted' technical potential estimates). Individual ECMs are represented as dots in the figure, and we apply linear fit lines to show the relationship between an ECM's percent energy savings and percent cost savings. Under the base-case, ECM energy and cost savings percentages have a 1:1 relationship. In the 'EE at Peak' low and high scenarios, however, the ECM cost savings percentages are substantially higher than ECM energy savings percentages, ranging from roughly 1.5 times higher under the 'EE at Peak (12-6PM) – low' scenario to more than 2 times higher under the 'EE at Peak (12-6PM) - high' scenario.

The additional cost savings accrued when considering the public health benefits of ECMs in Figure 4 also serve to improve ECM cost effectiveness. Figure 5 shows how the estimated payback time for individual ECMs changes as various levels of public health benefits ('EE at Peak' low/high) are introduced. In the plot, we include only measures where the payback time is between 5 to 20 years in the base-case, restricting the focus to measures where improvements to cost effectiveness would likely improve adoption potential from a consumer perspective.[9]

[9] In the base scenario, there are 10 individual measures with payback times greater than 20 years, and these have payback times ranging from 22 to 48 years.

Incorporating public health benefits can considerably reduce the payback time on investment for individual measures, generally halving the payback time in the 'EE at Peak (12-6 PM) – high' scenario and reducing payback by a third in the 'EE at Peak (12-6PM) – low' scenario compared to the base-case. Of the 13 ECMs summarized in Figure 5, six yield a payback of less than five years under the 'EE at Peak (12-6 PM) – high' scenario, while the remaining seven yield a payback of less than 10 years under this scenario.

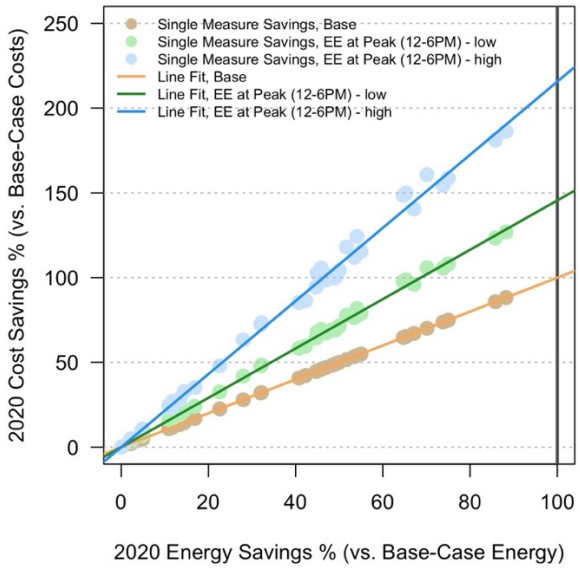

Figure 4. Relationship between individual building efficiency measure energy and cost savings percentages in 2020, under the baseline, 'EE at Peak (12-6PM) - low', and 'EE at Peak (12-6PM) - high' scenarios; uncompeted technical potential.

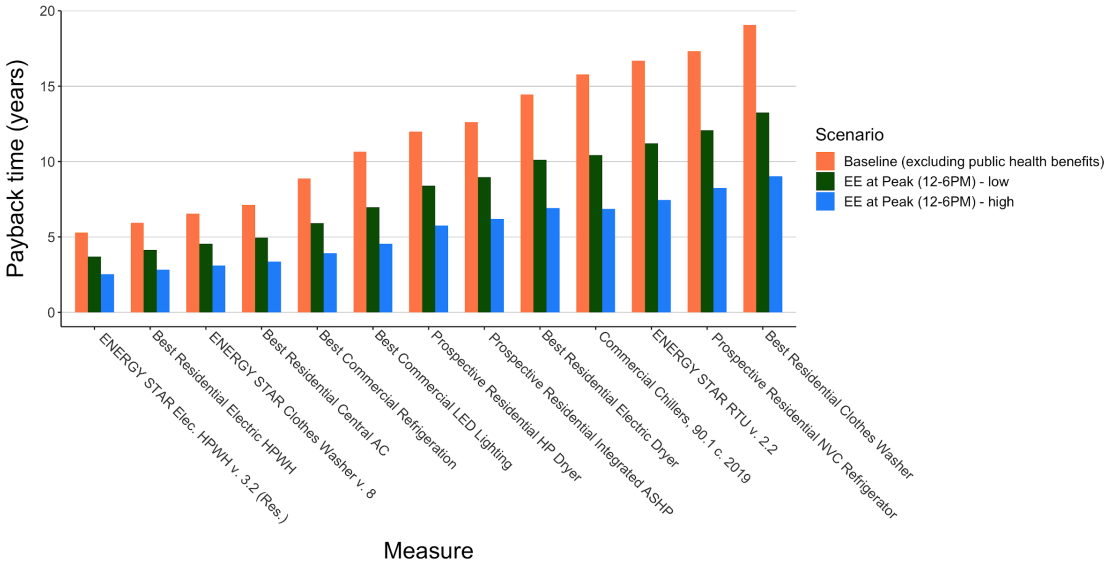

Figure 5. Cost effectiveness for individual building efficiency measures deployed in 2020, in terms of investment payback time in years; uncompeted technical potential. Payback times are shown for baseline, 'EE at Peak (12-6PM) – low', and 'EE at Peak (12-6PM) – high' scenarios. Measures shown are those that have a payback time between 5 to 20 years in the baseline scenario.

Finally, Figure 6 highlights the individual ECMs in each AVERT region that stand to benefit the most from the inclusion of public health benefits, plotting the additional ECM cost savings that result in the 'EE at Peak (12-6PM) - high' case relative to the baseline case (a) and the added energy savings for the same ECMs in the 'EE at Peak (12-6PM) - high' case (b). The results in Figure 6 account for measure competition and thus represent 'competed' technical potential estimates. We restrict the ECMs shown in both panels to the top five with the highest added cost savings. Figure 6a shows that overall, added ECM savings are again concentrated in the Mid-Atlantic and Southeast regions. Individual measures with the highest cost savings include prospective commercial solid-state lighting (SSL),[10] prospective residential carbon dioxide (CO_2) heat pump water heaters (HPWH), and prospective residential non-vapor compression (NVC) refrigerators.

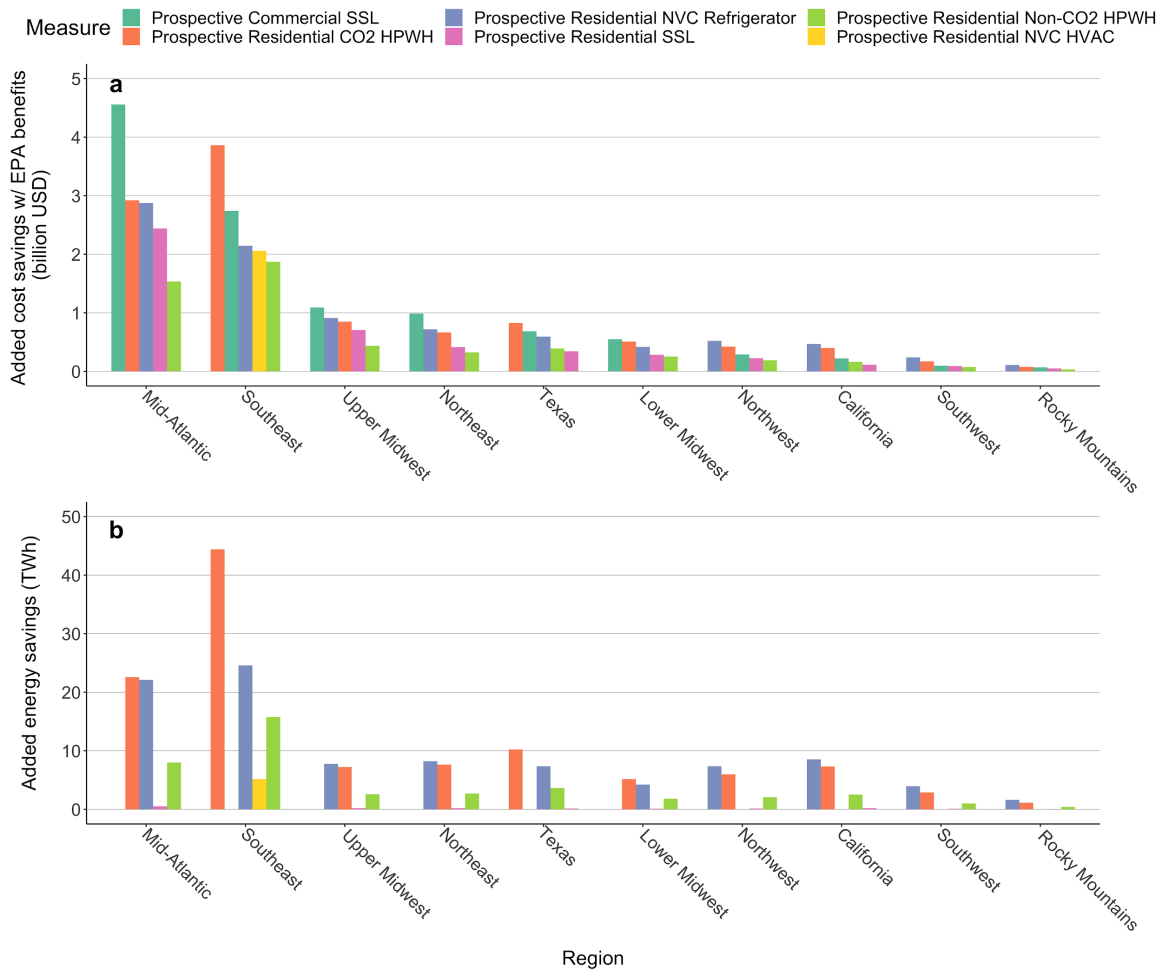

Figure 6. Individual building efficiency measures with the greatest change in total potential cost savings in 2020 after introduction of public health benefits; competed technical potential. **a.** Additional cost savings for top five individual ECMs in 'EE at Peak (12-6PM) - high' scenario relative to baseline scenario in 2020 by EPA AVERT region. **b.** Added energy savings for each of these ECMs in the 'EE at Peak (12-6PM) - high' scenario relative to baseline scenario in 2020 by EPA AVERT region.

[10] Prospective measures are defined in Scout as those that describe technologies currently under development to meet future unit performance and cost targets, which may not be commercially available.

Comparing the added cost savings for these ECMs to their added energy savings in Figure 6b reveals important differences in the drivers of the added cost savings. In the Mid-Atlantic region, for example, the prospective commercial SSL ECM shows strong added cost savings without adding any energy savings, while prospective HPWHs and NVC refrigerators show added savings for both cost and energy. The former case suggests that the SSL ECM has already captured most or all of the target market in the baseline case; thus, the added cost savings for this ECM are driven entirely by the higher electricity costs resultant of incorporating public health benefits (Equation 3). In the latter case, the ECM is able to capture more of its target market (and thus yield more energy savings) after public health benefits are accounted for; thus, cost savings for these ECMs are driven both by higher electricity costs *and* the improved ECM cost effectiveness and market share that results from the inclusion of public health benefits.

Discussion and Conclusions

This paper assesses the degree to which accounting for the public health benefits energy efficiency affects the estimated cost savings potential of energy efficient building technology deployment in the U.S. at both the national and regional scales. We incorporate the EPA's recently-published estimates of the public health benefits of efficiency (in cents per avoided kWh electricity generation) into Scout, a building efficiency impact assessment software, to quantify the degree to which the introduction of these benefits changes the national and regional cost savings potential of building efficiency measures and measure portfolios, relative to a base-case in which no public health benefits are considered.

We find that accounting for the public health benefits of energy efficiency significantly increases the cost savings potential of building efficiency measures, nearly doubling the national cost savings potential of the full measure portfolio considered over the base-case. Added cost savings from public health benefits are concentrated in regions with high population and annual electricity demand and a stronger reliance on generation sources with high rates of air pollution emissions (e.g., the Southeast and Mid-Atlantic AVERT regions). Importantly, accounting for public health benefits also markedly improves the cost effectiveness of individual building efficiency measures, in many cases reducing the payback time for these measures from a third to half, depending on the scenario of public health benefit estimates used.

Our results have significant implications for U.S. building energy efficiency policy decision-making. Most economic assessments of U.S. building efficiency potential – especially at the national scale – do not address the value of non-energy benefits, such as those related to improved public health. This omission of non-energy benefits precludes decision-makers from fully characterizing the value of building efficiency when making technology research and development investment decisions. Indeed, our analysis shows that accounting for the public health benefits of efficiency can substantially improve the economic case for building energy efficiency deployment, especially in regions where public health costs of electricity generation are high. The regional results presented here can help inform state and local efforts to accelerate energy efficiency adoption while also supporting existing tools and analyses of the local public health benefits of energy efficiency (e.g., Hayes, Kubes, and Gerbode 2020).

Further, from the consumer perspective, pricing public health benefits into the operational costs of individual building efficiency measures and associated cost effectiveness assessments can substantially improve measure adoption potential by reducing expected payback times on initial investments. Since at present the public health costs of building energy use are

hidden to the consumer, none of the five established cost-effectiveness tests for energy efficiency measures explicitly recognizes changes to this metric (Energy and Environmental Economics, Inc. and Regulatory Assistance Project 2008). The results presented herein strengthen the case for explicitly recognizing the value of such benefits in energy market designs, consumer technology adoption models, and cost-effectiveness tests, which will in turn encourage further investment in and more rapid penetration of energy efficient building technologies.

While the analysis presented in this paper focuses on EPA point estimates of the public health benefits of energy efficiency, the analytical framework can accommodate other types of non-energy benefits in assessments of the cost savings potential of building efficiency technology deployment. The Scout program and related data we use are open source and available to the public, ensuring that the current analysis is repeatable and can be shared with policymakers at various levels of government. Furthermore, Scout is updated regularly; as the EPA refines its methodology for estimating the public health benefits of energy savings, our input data and results will be updated in kind, ensuring that our insights remain relevant to important policy questions about the impacts of building energy efficiency on the U.S. electricity system and the consumers that it serves.

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