Scout: An Impact Analysis Tool for Building Energy-Efficiency Technologies

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ABSTRACT

Evaluating the national impacts of candidate U.S. building energy-efficiency technologies has historically been difficult for organizations with large energy efficiency portfolios. In particular, normalizing results from technology-specific impact studies is time-consuming when those studies do not use comparable assumptions about the underlying building stock. To equitably evaluate its technology research, development, and deployment portfolio, the U.S. Department of Energy's Building Technologies Office has developed Scout, a software tool that quantitatively assesses the energy and CO_2 impacts of building energy-efficiency measures on the national building stock.

Scout efficiency measures improve upon the unit performance and/or lifetime operational costs of an equipment stock baseline that is determined from the U.S. Energy Information Administration Annual Energy Outlook (AEO). Scout measures are characterized by a market entry and exit year, unit performance level, cost, and lifetime. To evaluate measures on a consistent basis, Scout uses EnergyPlus simulation on prototype building models to translate measure performance specifications to whole-building energy savings; these savings impacts are then extended to a national scale using floor area weighting factors. Scout represents evolution in the building stock over time using AEO projections for new construction, retrofit, and equipment replacements, and competes technologies within market segments under multiple adoption scenarios.

Scout and its efficiency measures are open-source, as is the EnergyPlus whole building simulation framework that is used to evaluate measure performance. The program is currently under active development and will be formally released once an initial set of measures has been analyzed and reviewed.

Introduction

DOE's Building Technologies Office (BTO) is charged with meeting legislative and executive mandates for energy savings in the national building stock. To achieve these objectives, BTO is divided into sub-programs that act as a technology development, commercialization, deployment, and regulation pipeline. To help guide its investments along this pipeline, BTO uses conventional information channels such as technology reviews, market research, and stakeholder feedback. In 2010, BTO began developing a tool to enable additional in-house evaluation of the individual and combined impacts of the various technologies and deployment efforts on the national building stock in future years. Originally branded as the Strategic Prioritization Tool (or "P-Tool") (Farese 2012a, 2012b), this quantitative analysis framework has been used to identify promising technology areas by their energy and carbon impact potential, and to develop performance and cost targets for prospective instances of those technologies in future years. BTO has developed a second-generation program called Scout that builds upon and improves the analytical capabilities of the P-Tool while establishing a longer-term framework for building energy-efficiency impact analysis. This paper describes the Scout analysis framework and presents initial results. Key features of Scout include:

- Nationwide estimates of the total energy use reductions, avoided CO_2 emissions, and cost-effectiveness of a suite of energy-efficiency measures over a pre-defined time horizon, under various adoption assumptions.
- A granular view of the building stock that accounts for building type and vintage, climate zone, and technology type within a building and a similarly granular view of energy consumption by end use and fuel type.
- The use of energy simulation to translate measure performance to whole-building energy savings.
- Compact measure definitions that support probability distributions for measure inputs and grouping individual measures into packages.

Scout is implemented in the Python programming language with an emphasis on modularity and flexibility. This approach facilitates the use of different baseline building stock models (e.g., state or service territory) and technology and program portfolios, which enables Scout to be used by utilities, manufacturers, and other organizations with similar large-scale energy-efficient measure analysis needs. To encourage these broad use cases, BTO plans to make Scout public and freely accessible.[1] Scout is currently under active development and testing. Scout will be officially released once an initial set of residential and commercial measures have been developed and measure evaluation has been fully tested.

Methodology

Scout estimates the degree to which baseline building energy consumption markets and associated CO_2 emissions[2] are impacted by various energy efficiency measures that diffuse into these markets over time, under three technology adoption scenarios. Baseline markets are established from the EIA Annual Energy Outlook (AEO) reference case for the residential and commercial building sectors. Efficiency measures are characterized by the baseline markets to which they apply and by their per unit installed cost, energy performance, and lifetime. The magnitude of each measure’s energy impact is determined by its captured market share, which depends on year-to-year stocks-and-flows in applicable baseline markets and its competitiveness with other candidate measures that apply to the same markets. Impacts can be summarized at the individual measure level or aggregated across all measures, and the cost-effectiveness of measure energy savings can also be assessed.

[1] The Scout source code is available online at https://github.com/trynthink/scout.
[2] Scout accounts for the CO_2 emissions attributable to on-site fuel combustion (e.g., natural gas for heating) as well as from the on-site consumption of purchased electricity. It does not currently account for emissions of greenhouse gases aside from CO_2 (e.g., methane), or for CO_2 equivalent emissions from refrigerant leaks.

Baseline Markets and Market Dynamics

A Scout market represents a unique subset of total energy use and corresponding CO_2 emissions associated with residential and commercial buildings in the U.S. Markets are generally non-overlapping; the sum of energy use in all markets is equal to the total energy use in residential and commercial buildings. Each market is defined by a climate zone, building type, end use, fuel type, and, if applicable, technology type. For example, a market might correspond to cooling with electric air-source heat pumps in single family homes in a southern climate zone. The quantitative details of each market include the baseline equipment stock size (e.g., number of installed units) and the cost, energy performance, and lifetime (i.e., service life) of the baseline equipment. Scout currently uses AIA climate zones (EIA 2016), which are based on heating and cooling degree days (HDD and CDD), however, the market data will eventually be recast to Building America climate zones, which are defined using a broader range of climate-related data (Baechler et al. 2015).

The baseline energy data for each market are generally derived from the EIA AEO. EIA uses an array of models, including the National Energy Modeling System (NEMS), to develop projections of domestic energy use through the year 2040 (EIA 2014a, 2014b). Scout uses the AEO time-series baseline equipment stock data to create a stock-and-flow model of how the installed equipment mix in each market evolves over time. For the purposes of evaluating measures, the stock-and-flow model differentiates between new equipment in new construction (“new”), equipment up for replacement at the end of its useful life (“replacement”), and elective upgrades of existing equipment to reduce operating costs and/or improve operational performance (“retrofit”). In addition to stock changes, the AEO baseline case used in Scout includes conservative assumptions about improvements in the efficiency of the installed stock of equipment over time (EIA 2014a, 2014b). The AEO time-series energy and CO_2 data reflect these stock-and-flow dynamics and efficiency assumptions.

Measure Definitions

Scout energy efficiency measures are defined primarily by five attributes, namely: a) applicable baseline market, b) year of market entry/exit, c) performance level, d) installed cost, and e) lifetime. In general, the transparency of Scout measure definitions is ensured by requiring consistent cost, performance, and lifetime input specification across measures and direct reporting of input parameter units and data sources. Furthermore, the Scout measure database will be posted to a GitHub repository, where all changes to it can be tracked and annotated over time. This approach to measure input definition and curation is an important improvement over that of the P-Tool, where, for example, measure definitions vary in their use of absolute or incremental cost and performance values, and supporting input parameter units and data sources are occasionally missing. It is anticipated that measures will be reviewed regularly for program planning purposes, and individuals can also review measures and suggest updates via GitHub.

Scout measures may be assigned a **market entry and exit year**. The latter typically reflects a future efficiency standard that renders the measure obsolete. Where no legislation or efficiency standard precludes the future adoption of a measure, the measure may still be displaced through competition with other measures.

Measure performance is defined at the unit level, and may be specified in absolute terms (e.g., U-value and solar heat gain coefficient for a window, or COP for a heat-pump) or as a percentage relative savings value. In the latter case, Scout improves upon the accuracy and consistency of P-Tool savings definitions by determining savings values using EnergyPlus whole building energy simulations (DOE 2016). EnergyPlus can model many of the energy-efficient technologies and strategies that are current and potential targets for BTO investment. EnergyPlus is also open-source and extensively documented, supporting transparency in the measure energy savings calculation process (DOE 2016). Scout uses OpenStudio Measures[3] to automatically apply a particular measure to prototype building models of different types, vintages, and climate zones (Roth, Goldwasser, and Parker 2016; NREL 2016b). The resulting energy savings estimates are broken down by fuel type and end use. This granularity provides insight into measure performance variability across application contexts, and enables finer control in calculating the impacts of measure packages.

Measure installed cost is defined on a per unit equipment basis for residential measures that do not relate to the building envelope, and on a per square foot floor space basis for residential envelope and commercial measures. The installed cost is used to determine incremental installed cost relative to the baseline. In cases where a measure directly replaces the service of a comparable baseline technology (e.g., a more efficient air source heat pump), the measure's incremental installed cost is calculated relative to that of the comparable baseline unit. In "add-on" cases where a measure enhances the performance of a baseline technology (e.g., a window film), the baseline installed cost is zero and the measure's incremental installed cost is equal to its installed cost. Measure cost data is sourced from relevant product literature, or from publicly available building product databases, including the National Renewable Energy Lab (NREL) National Residential Efficiency Measures Database (NREL 2016a), RSMeans (The Gordian Group 2016), ENERGY STAR Most Efficient product database (ENERGY STAR 2016), and EIA Building Sector Appliance and Equipment Costs (EIA 2015b).

Measure **lifetime** is specified in years. Data sources for measure lifetime are often the same as for measure cost, including relevant product literature and building product databases.

Uncertainty Distributions

Scout measure definitions also improve upon P-Tool measures by accommodating probability distributions on cost, performance, and lifetime inputs. Users may specify one of six distributions[4] along with the values required to parameterize the distribution and the number of samples to draw from it. The resultant range of possible input values are propagated through the analysis to generate a range of savings and cost-effectiveness outcomes. This ability to represent the uncertainty in measure inputs is particularly useful when evaluating the impact potential of emerging technology measures with ill-defined or uncertain attributes.

Measure Adoption Scenarios

Scout measures diffuse into their baseline markets under three possible adoption scenarios. The Technical Potential (TP) scenario assumes that all measures that are more efficient than the baseline technologies they replace (i.e., "efficient measures") completely replace all applicable baseline market stock in the year of their market introduction and capture

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[3] OpenStudio is a software development kit for EnergyPlus and OpenStudio Measures are scripts that perform transformations on OpenStudio models.

[4] Scout currently supports the normal, lognormal, uniform, gamma, Weibull, and triangular distributions, using the Python numpy.random module (see Scipy.org (2015) for more details on each distribution).

all new stock added after that year, regardless of cost effectiveness. TP represents the maximum impact that a measure could realize, limited only by its baseline market size. The Maximum Adoption Potential (MAP) scenario assumes that efficient measures completely replace the portions of their baseline market stock that are newly added, at the end of their lifetime, or electively upgraded via a retrofit in a given year. MAP represents a measure's maximum impact given realistic stocks-and-flows (see "Baseline Markets and Market Dynamics"). The Adjusted Adoption Potential (AAP) scenario assumes that efficient measures partially replace the new, replacement, and retrofit portions of their baseline market stock in a given year, while the remaining stock slated to turn over moves to an updated version of the baseline technology. AAP represents measure impact given both realistic stocks-and-flows and realistic consideration of consumer choices between baseline (e.g., conventional) technologies and efficient alternatives.

The current version of Scout implements only the TP and MAP scenarios. The omission of AAP reflects the lack of a comprehensive framework for representing the likely adoption tendencies of residential and commercial consumers when given a choice between conventional and efficient alternative technologies. While this choice may depend strongly on measure factors that are modeled in the current Scout implementation (e.g., incremental installed and operating costs), non-economic factors such as impact on user comfort, ease of installation, and social benefits must also be considered. The Scout framework has been constructed to accommodate the outputs of a viable consumer choice model once developed.

Measure Outputs

Scout can model the impacts of energy efficiency measures using several metrics. Scout directly calculates the annual energy savings and avoided CO_2 emissions potential of each measure for all adoption scenarios. Metrics can be aggregated across measures to determine the savings potential associated with specific end uses, climate zones, or building types.

Scout also calculates several metrics that incorporate measure cost or cost effectiveness. Simple payback is calculated by dividing the per-unit cost of the measure by the per-unit annual energy savings compared to the baseline unit. The Cost of Conserved Energy (CCE) is similar to simple payback in that it is a ratio of cost and energy, but it includes a discount rate applied to the energy and cost savings potential of a measure (Meier 1983). In the analyses in the "Sample Results" section, a common discount rate of 7% is assumed, however, the discount rate in Scout can be easily adjusted. The CCE for each measure can be compared to the cost of energy; for the purposes of BTO analysis, measures below the national consumption (by fuel) weighted average energy price are considered cost effective (see Figure 2). Cost of Conserved Carbon (CCC) can be used to consider the cost effectiveness of avoided CO_2 emissions, though in the absence of a carbon price, CCC is most readily compared to literature estimates for the externalized costs of CO_2 emissions, such as the social cost of carbon (IWGSCC 2015).

Internal rate of return (IRR) is the discount rate that balances the net present value of the measure cost (negative cash flow) against the savings realized by the measure on a per-unit basis (positive effective cash flow). Equivalent annual cost (EAC) is the cost per year of implementing a measure over its lifespan relative to a baseline technology. The present value of a measure's equivalent annual costs is equal to its Net Present Value (NPV).

Measure Competition

In some cases, multiple Scout measures compete for the same baseline market. For example, comparable residential windows that offer R-5, R-7, or R-10 levels of insulation could each replace the same baseline window. In such cases, Scout apportions the baseline market among the competing measures based on each measure's incremental capital and operating costs, where a measure with lower incremental capital costs and higher operating cost savings will capture a greater share of the baseline market. In an AAP scenario, these market shares would be applied to only the portion of the stock that is modeled as choosing a more efficient (non-conventional) technology. The specific methods used to determine measure market shares differ somewhat between the residential and commercial sectors, but generally weigh the EAC of each measure's incremental capital investment and lifetime operating cost. These methods are based on approaches developed by EIA and used in AEO simulations (EIA 2014a, 2014b). Once calculated, a measure's market share is used to scale down its un-competed energy savings value, effectively removing any overlapping impacts.

The apportioning of market shares across competing measures departs from the "staging" approach that was used in the P-Tool. Under this earlier measure competition scheme, a measure's CCE was used to iteratively rank it against competing measures, and highly ranked measures (i.e., those with a low CCE) would remove any overlapping savings for competing measures with a lower rank (Farese 2012a). This represented a "winner-take-all" approach to measure competition, under which measures with only marginally higher CCE values than the highest ranked measure would commonly be estimated to have zero savings potential. In moving to a market share-based measure competition approach, Scout accounts more realistically for overlapping measure savings because competing measures with similar cost effectiveness will have similar savings after adjusting for competition, rather than allowing the slightly more cost-effective measure to entirely displace the other.

For example, if two competing windows can each save 25% (or 500 TBtus) of a 2000 TBtu baseline heating and cooling energy market, but the first has a CCE of $15/MBtu while the second has a CCE of $14/MBtu, the P-Tool would apply the lower cost to the entire baseline market before the higher cost and "stage out" all 500 TBtus of energy savings potential for the higher cost window. Under the Scout market share approach, the lower cost window would achieve a somewhat higher market share than the higher cost window - perhaps a 55% share for the low cost window versus a 45% share for the high cost window. Accordingly, 225 TBtus of savings (45% market share x 500 TBtus savings potential) would remain for the high cost window after Scout competition, contrasting the null energy impact simulated for this measure under the former P-Tool staging approach.

Sample Results

To demonstrate the use of Scout in defining and evaluating the impact potential of efficiency measures, a set of eleven sample residential measures were evaluated under the Technical Potential (TP) and Maximum Adoption Potential (MAP) adoption scenarios, across a 2009-2040 time horizon. These sample measures, which cover a variety of end uses, are summarized in Table 1. A twelfth measure groups the "CFL Reflectors", "ENERGY STAR Electric WH", and "SEER 21 CAC" measures into a packaged measure. To illustrate the effect of probability distributions on measure parameters, a normal distribution is placed on the performance input of the "SEER 21 CAC" measure.

Table 1. Summary of key parameters for eleven residential measures used in a sample Scout analysis. The measures cover a variety of end uses, and vary between the use of absolute and relative performance inputs. Measure cost and lifetime inputs are both shown in absolute terms. In this sample analysis, no legislation or standards changes were modeled, thus none of the measures have a market exit year specified.

Measure Name	Applicable Baseline Market	Market entry/ exit year	Performance	Cost	Lifetime
ENERGY STAR CFL Reflectors	All incandescent and halogen reflector lighting	2010 / NA	40 lm/W	$8.83/unit	6.6 years
ENERGY STAR Refrigerators and Freezers	All refrigerators and freezers	2015 / NA	10% savings	$1025/unit (refrg.) $625/unit (freezer)	16 years
ENERGY STAR Electric WH	All electric water heaters	2010 / NA	2.0 EF	$1850/unit	13 years
ENERGY STAR Gas WH	All gas water heaters	2010 / NA	0.67 EF	$1245/unit	13 years
SEER 21 CAC	All central air conditioners	2013 / NA	N(μ =42% savings, σ=5% savings)	$6480/unit	17 years
Cold Climate HP	All electric heating and cooling in AIA climate zones 1, 2, and 4	2014 / NA	47% savings	$4960/unit	18 years
ENERGY STAR Gas Heating	All gas furnace and boiler heating	2010 / NA	0.88 AFUE	$2500/unit (furnace) $5050/unit (boiler)	15 years
ENERGY STAR Window SHGC	All homes in AIA climate zones 3, 4, and 5	2012 / NA	17% savings	$12/sq.ft.	30 years
R-5 Windows	All homes	2013 / NA	67% savings	$13.33/sq.ft.	30 years
Reduce Infiltration	All homes	2010 / NA	25% savings	$0.52/sq.ft.	30 years
VIP in Walls (N)	All single-family homes	2015 / NA	68% savings	$16/sq.ft.	30 years

Figure 1 shows primary energy consumption results for the packaged measure and for the three individual measures that contribute to this package. Consumption is shown under both competed and uncompeted TP and MAP scenarios, where savings that overlap across measures accessing the same baseline market are removed in the competed scenarios. As a result, competed measure energy consumption within the TP or MAP scenario is always higher than uncompeted consumption within that scenario. Additionally, the higher energy consumption in the MAP scenario than the TP scenario for earlier years reflects the consideration of realistic stock turnover in the MAP scenario; these stock changes yield a more gradual diffusion of the efficient measure into its baseline market and slower accumulation of associated measure energy savings. These results do not include a complete portfolio of measures, and since there are not more favorable measures competing in the reflector lamp market, the “ENERGY STAR CFL Reflectors” measure shows some energy savings throughout the modeled time horizon. Finally, the normal uncertainty distribution in the “SEER 21 CAC” performance input has propagated through to the individual and packaged measure primary consumption outputs.

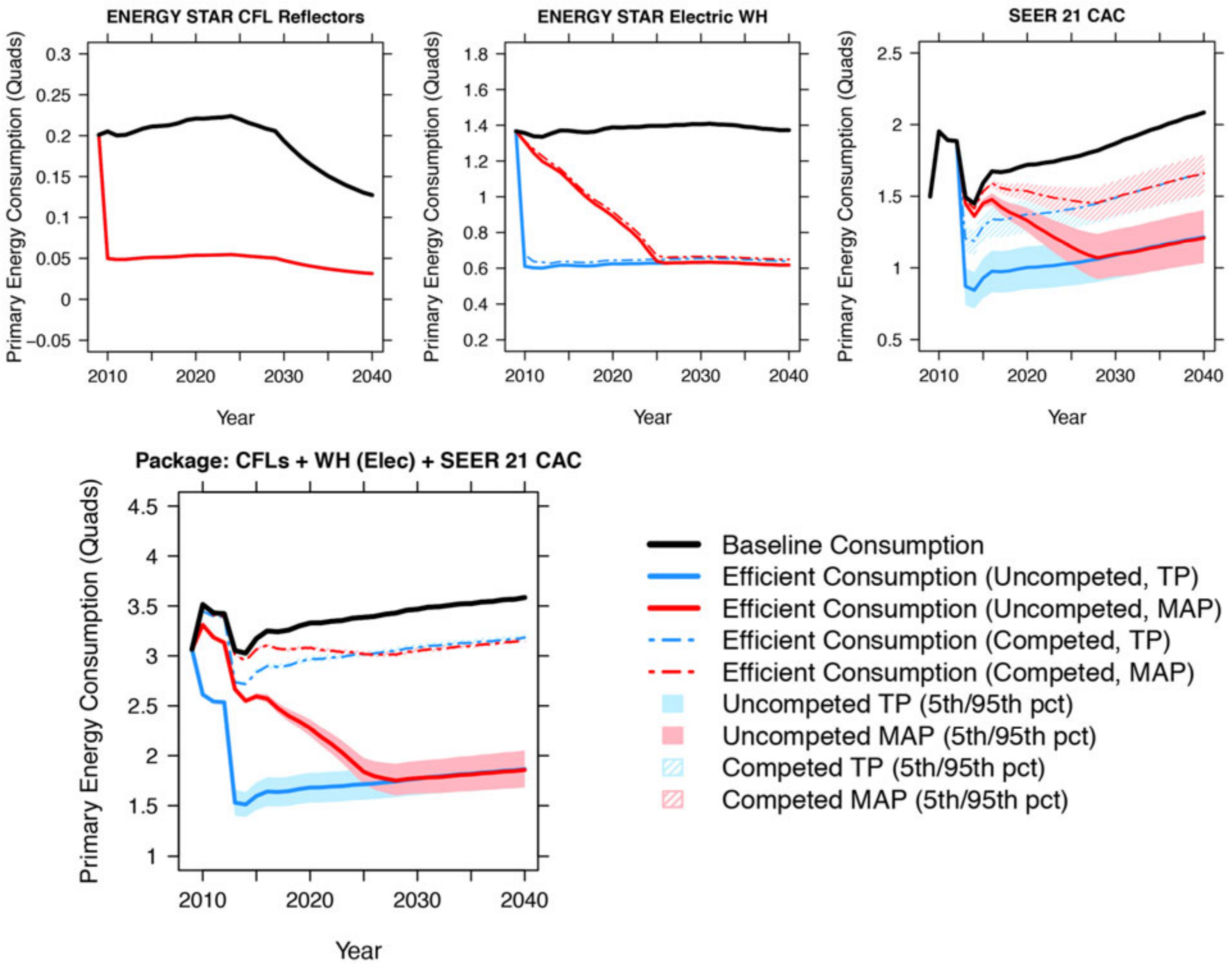

Figure 1. Primary energy consumption outcomes for a packaged Scout measure (bottom row) and its three constituent measures (top row), under a baseline, competed/uncompeted Technical Potential (TP), and competed/uncompeted Maximum Adoption Potential (MAP) measure adoption scenario. Competed scenarios account for overlapping savings between measures and therefore yield higher measure primary energy consumption than their uncompeted variants. Higher MAP vs. TP consumption outcomes in earlier years reflect the consideration of realistic stock-and-flow dynamics in the MAP scenario, which force more gradual diffusion of the efficient measure into its baseline market and the slower accumulation of associated energy savings. Note that a normal probability distribution has been placed on the performance input for the "SEER 21 CAC" measure, and this uncertainty has propagated through to the consumption outcomes for this measure and the packaged measure in which it is included. These results do not include a complete portfolio of measures, and since there are not more favorable measures competing in the reflector lamp market, the "ENERGY STAR CFL Reflectors" measure shows some energy savings throughout the modeled time horizon.

Figure 2 plots each of the sample measures' competed MAP energy savings for the year 2030 against its associated CCE in 2030, comparing its CCE to: a) the average cost of residential building energy in 2030 across fuel types (EIA 2015a), and b) the 2030 cost of energy plus an additional carbon price of $52 per metric ton (MTon) CO_2 (IWGSCC 2015). Note that different measures have different years of market entry; commercially available measures have a year of market entry corresponding to the current year, while R&D measures enter the market in future years. A measure is considered cost effective if its CCE is lower than the cost of energy or cost of energy and CO_2 threshold in the given year. Data points towards the bottom and right of the plot are most favorable (highest cost-effective energy savings impact).

In Figure 2, seven of the twelve sample measures have CCE values that are below the 2030 cost of energy threshold, together representing approximately 2 quads of cost-effective energy savings. Moving the cost effectiveness threshold upwards through the introduction of a carbon price does not change this result. Examining the figure by individual measures, ENERGY STAR electric water heaters yield the greatest cost-effective energy savings, while CFL reflectors have the lowest CCE due to their increased lifetime over baseline (incandescent and halogen) reflector lights (> 6 years versus < 1 year). All envelope measures are shown to be cost-effective, though the ENERGY STAR window solar heat gain coefficient (SHGC) and vacuum-insulated panels (VIPs) in walls measures have the lowest savings (<0.05 quads), likely due to their restricted baseline market applicability (see Table 1). Finally, the packaged measure looks far less favorable in Figure 2 than each of its three constituent measures, with lower savings than all but the SEER 21 CAC measure and a higher CCE than all three measures. This result is likely due to the packaged measure using the combined cost of all three measures, which overwhelms the competed energy savings benefits of the package. Scout can capture complementary cost and/or performance benefits from measures when packaged, and future analyses may explore these effects.

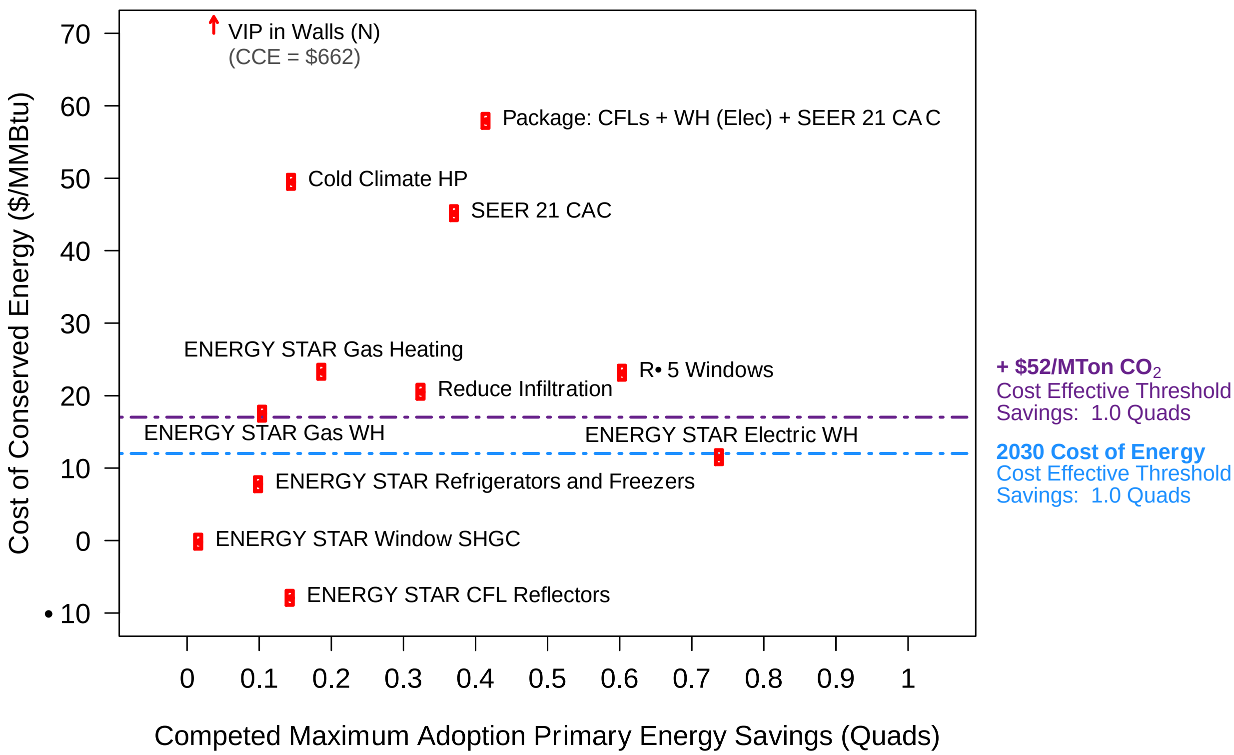

Figure 2. Maximum Adoption Potential (MAP) scenario primary energy savings versus cost of conserved energy (CCE) of eleven sample residential Scout measures and one measure package, shown for the year 2030. Each measure's CCE is compared to a cost effectiveness threshold determined by either the cost of energy in 2030 or the cost of energy in 2030 plus a carbon cost threshold (dotted horizontal lines). Seven of the twelve measures – together representing 2 quads of primary energy savings – are shown to be cost effective in 2030. ENERGY STAR electric water heaters offer the largest cost effective savings of the sample measures, while CFL reflectors have the lowest CCE. The four envelope-focused sample measures are all cost effective, though two with restricted markets yield low savings (VIP in walls and ENERGY STAR window SHGC). The packaged measure appears substantially less favorable than its constituent measures from both cost effectiveness and savings potential perspectives.

Future Directions

A principal motivation for developing Scout was to facilitate later extension of the model to other parameters and metrics. Beyond energy use and CO_2 emissions, the effects of various measures on peak electricity demand are of significant interest. EnergyPlus can compute time-dependent energy use metrics such as energy cost, and those metrics could be propagated to Scout and used in measure evaluation and competition. EnergyPlus also tracks both domestic and HVAC water use (e.g., cooling towers for commercial HVAC). Combining this metric with climate-zone specific indirect water use (i.e., water used for power plant cooling) would allow Scout to evaluate measures based on water use impacts.

DOE currently uses Scout to evaluate its technology R&D portfolio, but is interested in extending the Scout framework to evaluate commercial and residential market-engagement programs. Doing so would require the development of "adoption" measures that represent initiatives such as product campaigns, information services, and rating labels. Characterization of such measures requires a more sophisticated technology diffusion modeling framework than is currently available, as mentioned in the discussion of an "Adjusted Adoption Potential" model scenario. Addressing this gap in current building technology diffusion modeling capabilities is an area of potential future focus for DOE.

Although Scout is currently used for U.S.-wide technology investment portfolio analysis, the Scout framework is flexible and can support other applications. One promising application is analysis performed by many utilities to develop "deemed savings" values and corresponding incentives for ECMs. Re-purposing Repurposing Scout for this use case requires defining an energy baseline model corresponding to the appropriate service territory. The stock-and-flow model could also be customized if more specific regional projections are available, though re-scaled AEO stock-and-flow baseline data for the regionally-appropriate climate zone(s) might be an acceptable first approximation. OpenStudio Measures for the ECMs of interest would be needed, but might already be available or can be developed using existing OpenStudio Measures as templates. Adoption model parameters can also be readily replaced with region-specific market assumptions, if those data are available. An AAP analysis with measure competition would then be performed to develop a portfolio of ECMs to meet a regional energy savings target. ECM-specific incentives could be established by testing the effect of adjusted costs on adoption outcomes.

Scout is an open-source software project, but to promote its broader use, DOE is considering exposing it via a web interface. The interface would initially allow users to review measure definitions and to explore results and modeling assumptions from a pre-defined set of simulations. Potential extensions would allow users to define their own measures and explore the implications of changing the modeling assumptions.

References

Baechler, M. C., T. L. Gilbride, P. C. Cole, M. G. Hefty, and K. Ruiz. 2015. *Guide to Determining Climate Regions by County*. Washington, DC: U.S. Department of Energy. *Building America Best Practices Series* 73. http://energy.gov/sites/prod/files/2015/10/f27/ba_climate_region_guide_7.3.pdf.

Department of Energy (DOE). 2016. "EnergyPlus." Washington, DC: U.S. Department of Energy, Building Technologies Office. Accessed March 16, 2016. https://energyplus.net.

Energy Information Administration (EIA). 2014a. *Commercial Demand Module of the National Energy Modeling System: Model Documentation 2014*. Washington, DC: U.S. Energy Information Administration. http://www.eia.gov/forecasts/aeo/nems/documentation/commercial/pdf/m066(2014).pdf.

———. 2014b. *Residential Demand Module of the National Energy Modeling System: Model Documentation 2014.* Washington, DC: U.S. Energy Information Administration. http://www.eia.gov/forecasts/aeo/nems/documentation/residential/pdf/m067(2014).pdf.

———. 2015a. "Annual Energy Outlook." Washington, DC: U.S. Energy Information Administration. http://www.eia.gov/forecasts/aeo/.

———. 2015b. *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies*. Washington, DC: U.S. Energy Information Administration. https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf.

———. 2016. "Residential Energy Consumption Survey (RECS) Maps." Washington, DC: U.S. Energy Information Administration. Accessed March 18, 2016. https://www.eia.gov/consumption/residential/maps.cfm.

ENERGY STAR. "ENERGY STAR Most Efficient 2016." Accessed March 16, 2016. https://www.energystar.gov/products/energy_star_most_efficient.

Farese, P. 2012a. *A Tool for Prioritizing Energy Efficiency Investments*. Golden, CO: National Renewable Energy Laboratory. Accessed March 16, 2016. http://www.nrel.gov/docs/fy12osti/54799.pdf. Accessed 03/16/16.

———. 2012b. "Technology: How to build a low energy future." *Nature* 488: 275-277.

Interagency Working Group on Social Cost of Carbon (IWGSCC). 2015. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. July. Washington, DC: United States Government. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

Meier, A. 1983. *The Cost of Conserved Energy as an Investment Statistic*. Heating/Piping/Air Conditioning 55 (9): 73-77.

National Renewable Energy Laboratory (NREL). 2016a. "National Residential Efficiency Measures Database." Accessed March 16, 2016. http://www.nrel.gov/ap/retrofits/group_listing.cfm.

———. 2016b. "OpenStudio." https://www.openstudio.net.

Roth, A., Goldwasser, D., and Parker, A. 2016. *There's a measure for that!* Energy and Buildings 117 (1): 321-331.

Scipy.org. 2015. “Random sampling (numpy.random).” http://docs.scipy.org/doc/numpy/reference/routines.random.html.

The Gordian Group. 2016. “RSMeans: Construction Cost Estimating Data.” https://www.rsmeans.com.