ORNL/TM-2022/2774

Framework for Incorporating Social Cost of Carbon in Weatherization

Bill Eckman
Mini Malhotra

February 2023

OAK RIDGE
National Laboratory

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2022/2774

Energy and Transportation Science Division

FRAMEWORK FOR INCORPORATING SOCIAL COST OF CARBON IN WEATHERIZATION

Bill Eckman
Mini Malhotra

February 2023

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

ABSTRACT

This document provides a framework for incorporating [avoided] social cost of carbon (SCC) when calculating cost effectiveness of energy measures under the U.S. Department of Energy Weatherization Assistance Program (WAP). The framework describes the relevant metrics, calculation methodology, and implementation approach that can be adopted by any energy audit software for use under the WAP.

1. BACKGROUND AND PURPOSE

The U.S. Department of Energy created the Weatherization Assistance Program in 1976 to increase the energy efficiency of dwellings owned or occupied by low-income persons or to provide such persons renewable energy systems or technologies, reduce their total residential expenditures, and improve their health and safety…" (10 CFR §440, 2022). In Fiscal Year 2020, Congress amended the authorizing statute for the Weatherization Assistance Program (WAP) and included directions that WAP should "take into consideration improvements in the health and safety of occupants of dwelling units, and other non-energy benefits, from weatherization." (42 U.S. Code § 6863(b)4). While there are many "non-energy" related impacts (NEI) of weatherization, the key NEI items that have been considered or reported to-date include water use reduction, improved indoor air quality, jobs supported, emissions reduction, improved occupant health, and estimations of reduced disability-adjusted life years (DALY).

Historically, emissions reduction and/or decarbonization have been incidental consequences of the energy-conservation and/or health and safety retrofits completed through WAP and generally not recognized as a goal of WAP by all implementers. In 2021, the Biden Administration set forth the goal of net-zero greenhouse gas emissions by 2050 through electrification and clean energy technologies (Whitehouse.gov, 2021; Fedcenter.gov, 2021). This emphasizes the need to not only account for the carbon-reduction benefits from weatherization measures, but also consider this as one of the key criteria for selection of weatherization measures.

Therefore, WAP seeks program structures and processes that provide opportunities for incorporating non-energy benefits (e.g., reduced carbon emissions, improved indoor air quality, and water use reduction) that align with the goals set forth by the Biden Administration, related to climate change and energy and environmental justice, and the top immediate actions ("weatherization" and "energy efficiency in buildings") for achieving meaningful decarbonization over the next three decades presented by scientists, policy experts, and energy professionals (Pacala et. al., 2021; Hawken, 2017).

The framework proposed in this report is demonstrated to account for carbon emissions savings only, and may be expanded to include other non-energy benefits.

2. EXISTING APPROACHES

The Seattle Office of Housing proposed a process that would maintain the standard savings-to-investment ratio (SIR) calculations used in WAP, and incorporate SCC, by increasing the standard fuel cost used in the cost-savings calculations by an amount equal to the monetized value of SCC (Rogers, 2021). The proposed process (herein called the "Seattle Method") maintains current metrics and program processes, could be implemented quickly, and retains the direct causal relationship between the energy-savings and client energy cost reductions.

The Seattle Method aligns with current WAP regulations and processes. Likewise, when tested using Weatherization Assistant Version 8.9 (approved WAP single-family energy audit tool) it appears to produce favorable results for space-heating electrification, reducing WAP client energy expenditures, and reducing atmospheric carbon dioxide (CO_2) production related to residential building space conditioning in the Seattle climate, select mixed climates, and some hot climates. However, when the Seattle Method is applied to other cold climates (to which WAP funding is heavily skewed) (WPN 21-2, 2021), unintended consequences may result in the selection of non-beneficial electrification retrofits, increased client energy expenditures, and non-optimal atmospheric CO_2 production.

Current federal guidance (WPN 22-10, 2022) provides a specific method for adoption of SCC (and water usage reduction) into the WAP energy audit procedures (for any Grantee that wishes to incorporate them) and generally follows the Seattle Method. Similar to the Seattle Method, the guidance directly includes the monetized SCC emissions in the fuel price used in the energy audit cost-effectiveness calculations by adding a modifier to the site-specific fuel costs. Likewise, the guidance also includes values for a national fuel price modifier in terms of cost per unit of fuel (e.g., cents per kilowatt hour (¢/kwh) of electricity) for the most common primary fuel types encountered by the WAP network. These fuel cost modifiers are to be included in the total fuel cost used in the energy audit for the evaluation of all energy conservation measures (ECMs).

Carbon emission rates for fossil fuels burned in the home for space or water heating do not vary regionally, so there is little reason to consider values other than the national value. However, emission rates for electricity production can vary drastically in some regions or states due to the primary source of energy used. To allow Grantees the option to account for the variation in electricity production emissions from the national average, the guidance provides two options for selecting the fuel cost modifiers used in program implementation:

1. Use the national average values for all fuel types.
2. Use the national average values for on-site combustion and an electric emissions modifier calculated specifically for the region or state that the Grantee serves.

While the SCC inclusion guidance is simple to implement it does have certain potential for unintended impacts when conducting fuel switching evaluations (WPN 22-10, 2022). The potential for undesirable unintended consequences exists, similar to those found when applying the Seattle Method nationwide, and are noted within the guidance and may arise during fuel-switching analysis "due to the increase in fuel costs not being related to out-of-pocket costs to the client" (WPN 22-10, 2022). To clarify, the fuel cost modifiers proposed within the guidance represent "the monetary value of the net harm to society associated with adding a carbon to the atmosphere" (WPN 22-10, 2022) and not directly related to costs borne by the WAP client as a residential cost through utility bills or other direct expenses. Thus, the proposed fuel costs to be used in the cost-effectiveness calculations may not retain a sufficient causal relationship with the client's residential costs to protect against an increase in energy burden when the energy source is changed as a consequence of weatherization activities. For this reason, implementation of any fuel-switching must be undertaken with caution to ensure that the client does not experience an increase in energy burden resulting from weatherization activities.

3. PROPOSED APPROACH

The proposed approach for incorporating SCC when selecting cost-effective measures and package of measures for weatherization projects is centered on three key objectives:

1. Achieve Carbon Emissions Reduction: Reduce carbon dioxide emissions associated with post-retrofit house operations
2. Protect Participants from Increased Energy Burden: Reduce total residential expenditures while improving occupant health and safety (10 CFR §440, 2022)
3. Maintain Statutory and Regulatory Compliance for retrofit measure selection and package assembly: Individual ECMs and retrofit packages must be cost-effective using relevant metrics, as described in Section 3.1

The proposed approach is analogous to the standard approach for determining the cost-effectiveness of measures and package (10 CFR §440.21, 2022). The standard approach considers only energy cost savings (thus, non-SCC) and generates a list of recommended measures using the minimum acceptable SIR as the criteria. The proposed approach involves developing a revised list of "SCC/utility cost optimized" measures using two criteria metrics: SIR (or external SIR) and annual utility cost savings, as described in Section 3.1. In addition, an informative metric 'carbon emissions reduction' is used to quantify the reduction in carbon emissions from the package.

3.1 RELEVANT METRICS

Following are the relevant metrics needed to implement the proposed approach. Dependent upon specific implementation goals, minimum or maximum thresholds may be necessary, determined, and adjusted to meet administrative guidance and updated administrative goals. Thresholds may achieve safeguards against undesirable unintended consequences of SCC inclusion and may be determined by the WAP for program-wide implementation or defined within individual State Plans (10 CFR §440.14, 2022).

3.1.1 External SIR

The SIR is a commonly used measure of economic performance for a project alternative expressed by the ratio of savings resulting from the project and investment cost. It is considered most useful as a means of ranking that project along with other independent projects as a guide for allocating limited investment funding (NIST 2022a). For weatherization projects, it is typically computed as the ratio of present value of lifetime 'energy' cost savings resulting from a retrofit measure to the cost of retrofit and is used for ranking individual measures to be included in a package.

The external SIR (denoted as SIR' elsewhere) introduced in the proposed approach will be computed as the ratio of present value of lifetime 'energy and emissions' cost savings to the cost of retrofit. The term ‘external’ indicates that the lifetime emissions savings (or the avoided cost of emissions) used in the calculation is attributable to society and will not be available to the client, directly.

3.1.2 Annual Utility Cost Savings

In the standard approach for evaluating weatherization projects based on SIR, all selected measures would essentially result in utility cost savings, directly available to the client (or household). However, when evaluating measures using external SIR, fuel-switching measures (e.g., replacement of a natural gas furnace with a heat pump) may rank higher due to higher reduction in carbon emissions but result in increased utility cost for the client due to higher cost of the replacement energy source (fuel) when compared to the existing energy source (fuel).

Therefore, the proposed approach utilizes annual utility cost savings as a criterion. Adhering to the scope of this framework, it will be computed as the difference between the annual energy cost borne by the client before and after retrofit. When expanding the scope of the framework to include other non-energy benefits, the utility cost savings from reduced water consumption and wastewater discharge would be included in the annual utility cost savings metric as well. Through the Annual Utility Cost Savings metric, WAP implementers can ensure that client energy burden is not increased as a result of weatherization (as a minimum criteria) or stipulate a minimum required reduction in order to qualify for funding.

3.1.3 Carbon Emissions Reduction

Quantifying the carbon emissions reduction from retrofits will be useful when evaluating the program effectiveness. It will be computed as the difference between the fuel-use related carbon emissions before and after retrofit.

Currently used energy audit software within the WAP only report annual fuel savings. Therefore, the calculation methodology provided under the proposed approach does not account for carbon emission reductions variations due to seasonal, daily, nor hourly variations in electricity production emissions intensity. As the underlying calculation engine for software used within the WAP, additional emissions savings/penalties resulting from temporal variations in electricity demand may be calculated.

3.2 IMPLEMENTATION APPROACH

Following are the key components of implementation of this proposed approach in an energy audit software. The calculation methodology is described in Section 3.2.3.

3.2.1 User Input

To allow the user to indicate if the software should generate a revised list of “SCC/utility cost optimized” recommended measures for an audit, a user input field is needed. This user input field can be a checkbox with a default status of unchecked. It can be placed with the overall audit data input fields or presented before an audit run is conducted.

3.2.2 Library Inputs

To accomplish the calculations for developing the SCC/utility cost optimized package, additional library inputs, analogous to those used in the standard SIR calculations, would be needed. Table 1 lists the library inputs needed for the standard (non-SCC) approach and the proposed approach, side by side. These include:

1. Economic parameters (Note these may be specific to region or states and need to be revised annually)
    - Uniform present value for future energy and emissions cost savings

2. Criteria: For adding measures in the "SCC/utility cost optimized" package, two criteria must be fulfilled by a measure, for which WAP/states should set thresholds:
    - Minimum SIR (typically, 1.0)
    - Minimum ratio of annual utility cost savings after weatherization to annual utility cost before weatherization (typically, 0.0); this sets a minimum percentage annual utility cost savings that must be achieved in the home with a range of up to 1.0 (100%). The typical value of 0.0 reflects no minimum savings threshold, and a value of 0.99 (99%) would require that 99% of the before weatherization utility costs must be saved for the measure. Negative values (e.g., -0.1) are not recommended.

The software will use these criteria to generate the set of recommended measures.

3.2.3 Calculations

To describe the calculation for developing "SCC/utility cost optimized" package of measures, it is imperative to first outline the same for the standard non-SCC package that is generated by the software. Table 2 lists the calculation steps of the standard approach and the proposed approach, side by side.

3.2.3.1 Non-SCC Package

The procedure for adding measures in the non-SCC package involves following steps:

1. For each *measure* that is evaluated or applied individually to the house, individual SIR is calculated (equations C1a, C2a, C2b in Table 2), which is used for initial ranking of the measures' effectiveness.

2. Next, measures are incrementally added to the house in order of their ranking, starting with the highest individual measure SIR, and the "interacted" SIR for each measure is calculated (equations C1a, C2a, C2b).

   a. To select between two mutually exclusive measures, use the SIR or net present value[1] (NPV) criteria programmed in the software. For example, select the measure with higher NPV (equation C2c).

3. [Criteria] If the interacted SIR for a measure is equal to or exceeds the minimum SIR (criteria L4a), the measure is left implemented, else it is removed so that the next measure's effectiveness is not dependent on it.
   a. Measures that are required and but have interacted SIR lower than minimum SIR are left implemented.

4. Additional useful metrics that may be computed and reported for each measure include interacted annual energy savings, interacted lifetime energy cost savings, installation cost, and interacted SIR.

3.2.3.2 SCC/utility cost optimized package

The procedure for adding measures to develop an "SCC/utility cost optimized" package involves following steps:

1. For each *measure* that is evaluated or applied individually to the house, calculate individual measure SIR' accounting for fuel and carbon emissions (equations C1a, C2a, C2b) for initial ranking of the measures' effectiveness.

2. Next, add measures incrementally to the house in order of their ranking starting with the highest individual measure SIR', and calculate the interacted SIR' for each measure (equations C1a, C2a, C2b).
   a. To select between two mutually exclusive measures, use the SIR or NPV criteria programmed in the software. For example, select the measure with higher NPV' or external NPV (equation C2c).

3. **[Criteria 1]** If the interacted SIR' for a measure equals or exceeds the minimum SIR' (criteria L4a), keep the measure implemented, else remove it so that the next measure's effectiveness is not dependent on it.
   a. Measures that are required and but have interacted SIR' lower than minimum SIR' are left implemented.

4. For each implemented measure, calculate interacted annual utility cost savings (equation C2d). Flag measures with a negative interacted annual utility cost savings (in other words, penalty).

5. Calculate the annual utility cost savings from the final package (equation C3b), which will be the difference between annual utility costs before weatherization and after implementing the last measures.

---

[1] Net present value is the difference between the present value of all cash inflows and the present value of all cash outflows over the period of the investment (NIST, 2017); in other words, the difference of life-time savings and installation cost of a measure (Gettings, 2003).

6. **[Criteria 2]** If the ratio of annual utility cost savings from the package to annual utility cost before weatherization is lower than the threshold determined by WAP/states (criteria L4b), then remove a measure in the package with the highest annual energy penalty (calculated in step 5) and add the subsequent measures incrementally (starting with step 2). This will ensure that measures with energy cost "penalty" that have the highest impact to raise the annual utility cost of the entire package above the threshold are excluded.

3.2.4 Audit Output

The output for SCC package will be analogous to the standard approach, depending on the software output. A revised set of tables representing the "SCC/utility cost optimized" package of measures will be generated.

Table 1. Library Inputs

	Non-SCC Package, Items of interest: *fuel* (Electricity and fossil-fuels)	**SCC/Utility Cost Optimized Package,** Items of interest: *fuel*, CO_2
L1	**Measure Costs Library** a. $I_{measure}$: Installation cost of *measure* b. $L_{measure}$: Life of *measure*	**Measure Costs Library** a. $I_{measure}$: Installation cost of *measure* b. $L_{measure}$: Life of *measure*
L2	**Fuel Cost Library** $\$_{fuel}$: Price of *fuel* (for each *fuel* = electricity, natural gas, propane, fuel oil, kerosene, wood, coal, and other)	**Fuel Cost Library** $\$_{fuel}$: Price of *fuel* (for each *fuel* = electricity, natural gas, propane, fuel oil, kerosene, wood, coal, and other)
L3	**Economics Parameters Library** a. $FPI_{fuel,i}$: Fuel price index for $fuel$ for year i, from NIST (2022b) b. $UPV_{fuel,year,r}$: Uniform present value of future energy cost savings for *fuel* during each *year* = 1 through 30 at discount rate *r* = 3%, calculated as $UPV_{fuel,year,r} = \sum_{i=1}^{year} \frac{FPI_{fuel,i}}{(1+r)^i}$	**Economics Parameters Library** a. $FPI'_{fuel,i}$: Modified fuel price index for $fuel$ for year i, calculated as $FPI'_{fuel,i} = \frac{\$_{fuel,i} + \$Modifier_{fuel,i}}{\$_{fuel,i=0} + \$Modifier_{fuel,i=0}}$ where $\$_{fuel,i} = \$_{fuel} * FPI_{fuel,i}$ $\$_{fuel}$ = Price of $fuel$, from fuel cost library $FPI_{fuel,i}$ = fuel price index for $fuel$ for year i, from NIST (2022b) $\$Modifier_{fuel,i}$ = fuel cost modifier for $fuel$ for year i, from WPN 22-10[2],[3] b. $UPV'_{fuel,year,r}$: Uniform present value of future energy and emissions cost savings from *fuel* during each *year* = 1 through 30 at discount rate *r* = 3%, calculated as $UPV'_{fuel,year,r} = \sum_{i=1}^{year} \frac{FPI'_{fuel,i}}{(1+r)^i}$
L4	**Key Parameters Library** (Criteria) a. Minimum SIR: Minimum savings-to-investment ratio = 1.0	**Key Parameters Library** (Criteria) a. Minimum SIR′: Minimum external savings-to-investment ratio = 1.0 b. Minimum Ratio of $AnnualSavings_{utility\ cost,package}$ to Annual Utility $Cost_{pre\text{-}wx}$, to be determined by WAP/states

[2] In WPN 22-10, fuel cost modifiers are provided for year 2022 through 2043. For year 2044 and beyond, the value corresponding to year 2043 is used.
[3] In WPN 22-10, fuel cost modifiers are not provided for wood, coal and other fuel.

Table 2. Equations

	Non-SCC Package, Items of interest: fuel (Electricity and fossil-fuels)	**SCC/Utility Cost Optimized Package,** Items of interest: fuel, CO^2
C1	Annual fuel savings from each *measure* a. Annual $Savings_{fuel, measure}$ for each *fuel* (in fuel unit)	Annual fuel and CO_2 emissions savings from each *measure*: a. $AnnualSavings_{fuel, measure}$ for each *fuel* (in fuel unit) b. $AnnualSavings_{CO_2,measure}$ (in $lbCO_2$), calculated as $AnnualSavings_{CO_2,measure} = \sum_{\text{all fuel}} [Emissions_{CO_{2fuel}} * Annual\ Savings_{fuel, measure}]$ where, $Emissions_{CO_{2fuel}} = CO_2$ emissions from $fuel$ (in $lbCO_2$/fuel unit), from WPN 22-10[4]
C2	Cost-effectiveness calculations for each *measure* a. Present value of lifetime energy cost savings of *measure* $PV_{measure} = \sum_{\text{all fuel}} [AnnualSavings_{fuel,measure} * \$_{fuel} * UPV_{fuel,year=L_{m}}$ a. Savings-to-investment ratio of *measure*, $SIR_{measure} = \frac{PV_{measure}}{I_{measure}}$ b. Net present value of *measure*, $NPV_{measure} = PV_{measure} - I_{measure}$	Cost-effectiveness calculations for each *measure* a. Present value of lifetime energy and emissions cost savings of *measure* $PV'_{measure} = \sum_{\text{all fuel}} [AnnualSavings_{fuel,measure} * (\$_{fuel} + \$Modifier_{fuel,i=0}) * UPV$ b. External savings-to-investment ratio of *measure* $SIR'_{measure} = \frac{PV'_{measure}}{I_{measure}}$ c. External net present value of *measure*, $NPV'_{measure} = PV'_{measure} - I_{measure}$ d. Annual utility cost savings from *measure* $AnnualSavings_{utility\ cost,\ measure} = \sum_{\text{all fuel}} [AnnualSavings_{fuel,measure} * \$_{fuel}]$
C3	Cost-effectiveness calculations for the *package* a. Savings-to-investment ratio for *package*, $SIR_{package} = \frac{\Sigma_{all\ measures}(PV_{measure})}{\Sigma_{measure}(I_{measure})}$	Cost-effectiveness calculations for the *package* a. External savings-to-investment ratio for *package*, $SIR'_{package} = \frac{\Sigma_{all\ measures}(PV'_{measure})}{\Sigma_{all\ measure}(I_{measure})}$ b. Annual utility cost savings from *package*, $AnnualSavings_{utility\ cost,\ package} = \sum_{\text{all measures}} AnnualSavings_{utility\ cost,\ measure}$

[4] In WPN 22-10, fuel cost modifiers are not provided for wood, coal and other fuel.

REFERENCE

10 CFR §440. 2022. Title 10 CFR Part 440 – Weatherization Assistance for Low-Income Persons, amended 12/23/2022. Electronic Code of Federal Regulations. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-440

DOE. 2022. Weatherization Program Notice 22-10 Revised, Issue Date: October 21, 2022. https://www.energy.gov/eere/wap/articles/weatherization-program-notice-22-10-revised-including-non-energy-impacts-within

Fedcenter.gov. 2021. Executive Order (EO) 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability. https://www.fedcenter.gov/programs/eo14057/

Gettings, M.B. 2003. The National Energy Audit Tool (NEAT) Engineering Manual (Version 7). ORNL/CON-469/R1. September 2003. Oak Ridge, TN: Oak Ridge National Laboratory. https://weatherization.ornl.gov/wp-content/uploads/2018/05/NEATEngineering.pdf. Accessed July 2018.

IWG. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates under Executive Order 13990. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. February 2021. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

NIST. 2017. Investment Analysis Methods. NIST Advanced Manufacturing Series 200-5. https://nvlpubs.nist.gov/nistpubs/ams/NIST.AMS.200-5.pdf

NIST. 2022a. LIFE CYCLE COSTING MANUAL for the Federal Energy Management Program. NIST Handbook 135, 2022 edition. https://doi.org/10.6028/NIST.HB.135e2022

NIST. 2022b. Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2022, Annual Supplement to NIST Handbook 135. NISTIR 85-3273-37 update 1. https://doi.org/10.6028/NIST.IR.85-3273-37-upd1

Rogers, C. 2021. Incorporating the Cost of Carbon Emissions into the Weatherization Assistance Program's Cost-Effectiveness Test. Seattle Office of Housing.

Whitehouse.gov. 2021. FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies. April 22, 2021.

APPENDIX A. DETRMINATION OF ECONOMICS PARAMETERS FOR INCORPORATING SCC

APPENDIX A. DETERMINATION OF ECONOMICS PARAMETERS FOR INCORPORATING SCC

Step 1. Determining fuel price modifier for year 1 through 30

In WPN 22-10, fuel price modifiers are provided for year 2022 through 2043. To account for SCC when evaluating the cost-effectiveness of measures with more than 21-year life, fuel cost modifiers for year 2044 and beyond are needed. We considered two extreme and a middle approach for setting fuel cost modifiers for year 2044 and beyond. The resulting modified uniform present value (UPV’) are compared to estimate of the scale of impact on the savings-to-investment ratio.

Approach 1. No estimation made for fuel cost modifier for year 2044 and beyond,

Approach 2. Use the fuel cost modifier for year 2043 for all future years,

Approach 3. Linearly-extrapolate based on the trend from previous years.

Figure A-1 shows the three approaches for fuel cost modifiers for natural gas (left) and electricity (right). For approach 3, the trend line for natural gas is based on the values for year 2022 through 2043, whereas the trend line for electricity is based on values for year 2036 through 2043 where the trend is linear.

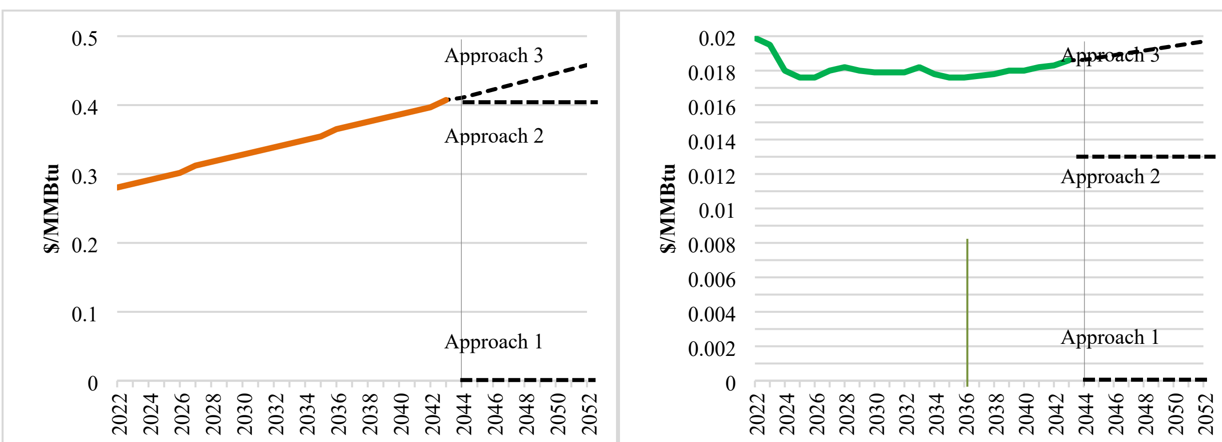

Figure A-1. Fuel cost modifiers for natural gas (left) and electricity (right).

The resulting UPV’ for year 30 are shown in Figure A-2. Approaches 1 and 3, which represent the two extremes, result in UPV’ that are different by 5.74% (natural gas) and 3.34% (electricity). The UPV’ from approach 2 is very close to that from approach 3. Considering that there is not enough increased value by going with the trend extrapolation method to support the additional uncertainty and potential concerns, we recommend approach 2 to be followed for determining fuel cost modifiers for year 2044 and beyond for all fuel types.

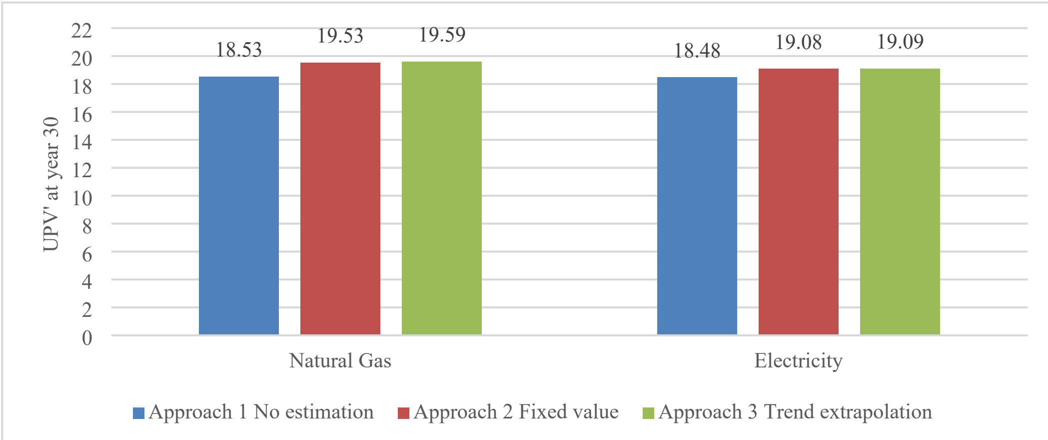

Figure A-2. Comparison of modified uniform present value from three approaches.

Step 2. Determining economic parameters

Economics parameters for natural gas

Price of natural gas, $\$_{fuel}$ = 14.23 \$/MMBtu, from Fuel Cost Library

Discount rate, r = 3%

From NIST 2022b				Calculated	From WPN 22-10[5]	Calculated		
	i	$FPI_{fuel,i}$	$UPV_{fuel,year,r}$	$\$_{fuel,i}$	$\$Modifier_{fuel,i}$	$\$'_{fuel,i}$	$FPI'_{fuel,i}$	$UPV'_{fuel,year,r}$
Year	Year #	Fuel price index	Uniform present value	Fuel price	Fuel price modifier	Modified fuel price	Modified fuel price index	Modified uniform present value
				$/MMBtu	$2020/therm	$/MMBtu		
2022	0	1.000	1.000	14.230	0.2804	17.034	1.000	1.000
2023	1	0.972	0.943	13.828	0.2857	16.685	0.979	0.951
2024	2	0.930	1.820	13.238	0.2910	16.148	0.948	1.845
2025	3	0.903	2.646	12.843	0.2963	15.806	0.928	2.694
2026	4	0.887	3.434	12.620	0.3016	15.636	0.918	3.509
2027	5	0.879	4.192	12.504	0.3122	15.626	0.917	4.301
2028	6	0.884	4.933	12.578	0.3175	15.753	0.925	5.075
2029	7	0.897	5.662	12.768	0.3228	15.996	0.939	5.839
2030	8	0.906	6.377	12.892	0.3280	16.172	0.949	6.588
2031	9	0.932	7.091	13.259	0.3333	16.592	0.974	7.335
2032	10	0.943	7.793	13.418	0.3386	16.804	0.986	8.069
2033	11	0.954	8.482	13.577	0.3439	17.016	0.999	8.790
2034	12	0.960	9.156	13.662	0.3492	17.154	1.007	9.497
2035	13	0.958	9.808	13.638	0.3545	17.183	1.009	10.184
2036	14	0.958	10.442	13.638	0.3651	17.289	1.015	10.855
2037	15	0.962	11.059	13.687	0.3704	17.391	1.021	11.510
2038	16	0.964	11.660	13.722	0.3757	17.479	1.026	12.149
2039	17	0.967	12.245	13.760	0.3810	17.570	1.031	12.773
2040	18	0.969	12.814	13.787	0.3862	17.649	1.036	13.382
2041	19	0.971	13.368	13.814	0.3915	17.729	1.041	13.976
2042	20	0.971	13.906	13.821	0.3968	17.789	1.044	14.554
2043	21	0.972	14.428	13.828	0.4074	17.902	1.051	15.119
2044	22	0.971	14.935	13.815	0.4074	17.889	1.050	15.667
2045	23	0.972	15.427	13.826	0.4074	17.900	1.051	16.199
2046	24	0.973	15.906	13.842	0.4074	17.916	1.052	16.717
2047	25	0.974	16.371	13.863	0.4074	17.937	1.053	17.220
2048	26	0.975	16.823	13.870	0.4074	17.944	1.053	17.708
2049	27	0.977	17.263	13.900	0.4074	17.974	1.055	18.183
2050	28	0.978	17.690	13.919	0.4074	17.993	1.056	18.645
2051	29	0.979	18.106	13.936	0.4074	18.010	1.057	19.093
2052	30	0.981	18.510	13.954	0.4074	18.028	1.058	19.530

[5] In WPN 22-10, fuel cost modifiers are provided for year 2022 through 2043. For year 2044 and beyond, the value corresponding to year 2043 is used.

Economics parameters for electricity

Price of electricity, $\$_{fuel}$ = 0.11 \$/kWh, from Fuel Cost Library

Discount rate, r = 3%

From NIST 2022b				Calculated	From WPN 22-10[6]	Calculated		
	i	$FPI_{fuel,i}$	$UPV_{fuel,year,r}$	$\$_{fuel,i}$	$\$Modifier_{fuel,i}$	$\$'_{fuel,i}$	$FPI'_{fuel,i}$	$UPV'_{fuel,year,r}$
Year	Year #	Fuel price index	Uniform present value	Fuel price	Fuel price modifier	Modified fuel price	Modified fuel price index	Modified uniform present value
				\$/kWh	\$2020/kWh	\$/kWh		
2022	0	1.000	1.000	0.110	0.0199	0.130	1.000	1.000
2023	1	0.995	0.966	0.109	0.0195	0.129	0.993	0.964
2024	2	0.978	1.888	0.108	0.018	0.126	0.967	1.875
2025	3	0.970	2.776	0.107	0.0176	0.124	0.957	2.751
2026	4	0.969	3.637	0.107	0.0176	0.124	0.956	3.601
2027	5	0.971	4.475	0.107	0.018	0.125	0.961	4.430
2028	6	0.975	5.292	0.107	0.0182	0.126	0.966	5.239
2029	7	0.980	6.089	0.108	0.018	0.126	0.968	6.026
2030	8	0.983	6.864	0.108	0.0179	0.126	0.970	6.792
2031	9	0.987	7.621	0.109	0.0179	0.126	0.973	7.538
2032	10	0.991	8.358	0.109	0.0179	0.127	0.977	8.265
2033	11	0.996	9.078	0.110	0.0182	0.128	0.984	8.975
2034	12	1.001	9.780	0.110	0.0178	0.128	0.985	9.666
2035	13	0.999	10.460	0.110	0.0176	0.128	0.982	10.335
2036	14	0.998	11.120	0.110	0.0176	0.127	0.980	10.983
2037	15	0.994	11.758	0.109	0.0177	0.127	0.978	11.611
2038	16	0.990	12.375	0.109	0.0178	0.127	0.976	12.219
2039	17	0.990	12.974	0.109	0.018	0.127	0.977	12.810
2040	18	0.990	13.556	0.109	0.018	0.127	0.977	13.384
2041	19	0.989	14.120	0.109	0.0182	0.127	0.977	13.941
2042	20	0.989	14.667	0.109	0.0183	0.127	0.978	14.483
2043	21	0.987	15.198	0.109	0.0186	0.127	0.979	15.009
2044	22	0.983	15.711	0.108	0.0186	0.127	0.975	15.518
2045	23	0.982	16.209	0.108	0.0186	0.127	0.975	16.012
2046	24	0.981	16.691	0.108	0.0186	0.127	0.974	16.491
2047	25	0.980	17.159	0.108	0.0186	0.126	0.973	16.956
2048	26	0.980	17.614	0.108	0.0186	0.126	0.973	17.407
2049	27	0.979	18.055	0.108	0.0186	0.126	0.973	17.845
2050	28	0.974	18.481	0.107	0.0186	0.126	0.968	18.268
2051	29	0.971	18.893	0.107	0.0186	0.125	0.966	18.678
2052	30	0.969	19.292	0.107	0.0186	0.125	0.964	19.075

[6] In WPN 22-10, fuel cost modifiers are provided for year 2022 through 2043. For year 2044 and beyond, the value corresponding to year 2043 is used.

APPENDIX B. COMPARISON OF MEASURE AND PACKAGE COST-EFFECTIVENESS WITHOUT AND WITH SCC

APPENDIX B. COMPARISON OF MEASURE AND PACKAGE COST-EFFECTIVENESS WITHOUT AND WITH SCC

Example 1: Heating system replacement measures without and with fuel switching

Assumptions:

- Annual space heating load = 60 MMBtu
- Standard efficiency, natural gas furnace: 80% efficiency
- High- efficiency, natural gas furnace: 96% efficiency
- Electric furnace: 98% efficiency
- Heat pump: 2.8 COP

Table B1. Fuel price and economic parameters (from libraries)

Fuel	Fuel Price	Economic parameters for 15-year measure lifetime		Economic parameters for 18-year measure lifetime	
		UPV	UPV'	UPV	UPV'
Natural gas	14.23 $/MMBtu	11.059	11.510	12.814	13.382
Electricity	0.11 $/kWh	11.758	11.611	13.556	13.384

Table B2. Measure cost-effectiveness without SCC

	Measure	Measure cost ($)	Measure Life (yr)	Annual Fuel Savings		Present Value of lifetime energy cost savings ($)[1]			SIR
				Natural Gas (MMBtu)	Electricity (kWh)	Natural Gas	Electricity	Total	
1	Standard to high-efficiency gas furnace replacement	3000	18	12.5		2279	0	2279	0.76
2	Standard gas furnace to heat pump replacement	5000	15	75.0	-6278.6	11803	-8121	3682	0.74
3	Electric furnace to heat pump replacement	5000	15		6906.4	0	8933	8933	1.79

[1]Present value of lifetime energy cost savings = Σ(annual fuel savings * fuel price * UPV)

Table B3. Measure cost-effectiveness with SCC

	Measure	Measure cost ($)	Measure Life (yr)	Annual Fuel Savings		Present Value of lifetime energy and emission cost savings ($)[2]			SIR'
				Natural Gas (MMBtu)	Electricity (kWh)	Natural Gas	Electricity	Total	
1	Standard to high-efficiency gas furnace replacement	3000	18	12.5		2849	0	2849	0.95
2	Standard gas furnace to heat pump replacement	5000	15	75.0	-6278.6	14705	-9470	5235	1.05
3	Electric furnace to heat pump replacement	5000	15		6906.4	0	10417	10417	2.08

[2]Present value of lifetime energy and emissions cost savings = Σ(annual fuel savings * (fuel price + fuel price modifier) * UPV')

Table B4. Utility cost and carbon emissions savings

	Measure	Utility Cost Savings ($)			Annual CO2 savings (lb)		
		Natural Gas	Electricity	Total	Natural Gas	Electricity	Total
1	Standard to high-efficiency gas furnace replacement	177.9	0.0	**177.9**	1458	0	**1458**
2	Standard gas furnace to heat pump replacement	1067.3	-690.6	**376.6**	8748	-5337	**3412**
3	Electric furnace to heat pump replacement	0.0	759.7	**759.7**	0	5870	**5870**

Example 2: Package of measures

Fuel Price:

- Natural Gas: 14.23 $/MMBtu
- Electricity: 0.11 $/kWh

Annual energy use and cost for existing building (from audit output):

- Annual energy use = 82.86 MMBtu (heating), 6.49 MMBtu (cooling)
- Annual energy cost = $1338

Table B5. Package cost-effectiveness without SCC

	Recommended Measures	Measure cost ($)	Measure Life (yr)	Annual Fuel Savings		Present Value of lifetime energy cost savings ($)			SIR
				Natural Gas (MMBtu)	Electricity (kWh)	Natural Gas	Electricity	Total	
1	Infiltration Redctn	95.0	10	10.1	85.6	1120	79	1199	12.62
2	Fill Ceiling Cavity	1260.0	20	14.4	287.4	2849	464	3312	2.63
3	DWH Pipe Insulation	15.0	13	0.0	151.5	0	174	174	11.62
4	Duct Insulation	294.6	20	14.6	0.0	2898	0	2898	9.84
5	Smart Thermostat	75.0	15	3.4	0.0	536	0	536	7.15
6	DWH Tank Insulation	40.0	13	0.0	266.9	0	307	307	7.68
7	Wall Insulation	1147.4	20	18.2	397.6	3603	641	4244	3.70
8	Floor Ins. R-30	1540.0	20	24.9	-82.9	4922	-134	4788	3.11
9	Window Replacement	1384.0	20	7.5	-16.4	1488	-26	1461	1.06
	Package	**5851.0**		**93.2**	**1089.7**			**18921**	**3.23**

Table B6. Package cost-effectiveness with SCC

	Recommended Measures	Measure cost ($)	Measure Life (yr)	Annual Fuel Savings		Present Value of lifetime energy and emissions cost savings ($)			SIR’
				Natural Gas (MMBtu)	Electricity (kWh)	Natural Gas	Electricity	Total	
1	Infiltration Redctn	95.0	10	10.1	85.6	1389	92	1480	15.58
2	Fill Ceiling Cavity	1260.0	20	14.4	287.4	3569	541	4110	3.26
3	DWH Pipe Insulation	15.0	13	0.0	151.5	0	203	203	13.56
4	Duct Insulation	294.6	20	14.6	0.0	3630	0	3630	12.32
5	Smart Thermostat	75.0	15	3.4	0.0	668	0	668	8.91
6	DWH Tank Insulation	40.0	13	0.0	266.9	0	358	358	8.96
7	Wall Insulation	1147.4	20	18.2	397.6	4514	748	5262	4.59
8	Floor Ins. R-30	1540.0	20	24.9	-82.9	6167	-156	6011	3.90
9	Window Replacement	1384.0	20	7.5	-16.4	1864	-31	1833	1.32
	Package	**5851.0**		**93.2**	**1089.7**			**23556**	**4.03**

Table B7. Utility cost and carbon emissions savings with SCC

	Recommended Measures	Utility Cost Savings ($)			Annual CO2 savings (lb)		
		Natural Gas	Electricity	Total	Natural Gas	Electricity	Total
1	Infiltration Redctn	143.8	9.4	153.2	1178	73	1251
2	Fill Ceiling Cavity	204.9	31.6	236.5	1679	244	1924
3	DWH Pipe Insulation	0.0	16.7	16.7	0	129	129
4	Duct Insulation	208.4	0.0	208.4	1708	0	1708
5	Smart Thermostat	48.5	0.0	48.5	398	0	398
6	DWH Tank Insulation	0.0	29.4	29.4	0	227	227
7	Wall Insulation	259.1	43.7	302.8	2124	338	2462
8	Floor Ins. R-30	354.0	-9.1	344.9	2902	-70	2831
9	Window Replacement	107.0	-1.8	105.2	877	-14	863
	Package			**1445.4**			**11792**