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Environmental Emissions Nonenergy Benefits: Working Paper

David Carroll
Ferit Ucar

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Environmental Sciences Division

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ACRONYMS

APEEP	Air Pollution Emission Experiments and Policy Model
kWh	Kilowatt hours
MMBtu	Million British Thermal Units
NERC	North American Electric Reliability Corporation
NOx	Nitrogen Oxide
NRC	National Research Council
PM	Particulate Matter
SO2	Sulfur Dioxide
VOC	Volatile Organic Compound
WAP	Weatherization Assistance Program

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1. INTRODUCTION

Weatherization reduces energy usage by low-income households, and thereby reduces the environmental impacts of the production and consumption of energy and reduces the social costs associated with those environmental impacts. The nonenergy benefits study conducted as part of the Weatherization Assistance Program (WAP) evaluation focused on measuring the emissions reductions resulting from WAP program energy usage reductions and estimating the societal value of those emission reductions. While there are other environmental impacts associated with the WAP program, this study focused on emissions impacts because the 2010 National Research Council (NRC) report *Hidden Costs of Energy: The Unpriced Consequences of Energy Production and Use* (National Academy Press, 2010) recommended that Congress focus on emissions costs because they have the highest documented social impact costs.

2. METHODOLOGY

The starting point for estimating emissions nonenergy benefits is to measure the program energy impacts. The WAP evaluation measured electric and natural gas energy savings using billing data furnished by energy suppliers for a sample of WAP clients and measured fuel oil savings by directly metering homes heated with fuel oil for a sample of clients that were treated by the program. The evaluation then projected energy savings by fuel and housing unit type for each state (i.e., grantee) using state-specific data on WAP production and installed measures.

The analysis used projected energy savings by building type and state to estimate reductions in state-level emissions. There are two reasons for estimating emissions at the state level. First, emissions associated with electric production are best estimated for North American Electric Reliability Corporation (NERC) regions; each state is assigned to a NERC region and emissions per kWh are estimated for all electric power plants in the region. Second, Air Pollution Emissions Experiments and Policy model (APEEP) damage function estimates are based on existing emission levels, population, and other local factors; the social cost of a ton of emissions varies substantially from state to state.

The analysis used the APEEP model (recommended by the NRC and updated for purposes of the evaluation) to estimate value of state-level emissions benefits for each of the major criteria air pollutants – sulfur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter (PM) 2.5, and volatile organic compounds (VOC). It used OMB guidance on greenhouse gases (carbon dioxide (CO_2) equivalents) to estimate the value of greenhouse gas emission reductions. National estimates were developed by cumulating state-level values.

This approach to the estimation of emissions benefits is different from what is found in most of the literature on low-income weatherization in two ways. First, most of the literature sources reviewed for this study had lower estimates of the cost per ton for emissions. The estimates in previous studies were generally based on the market price of emissions as established in interstate and/or international emissions trading markets. This study used OMB guidance for valuation of greenhouse gas emissions and the APEEP model for valuation of criteria air pollutant emissions. Second, most of the literature sources reviewed for this study have substantially higher emissions rates per kWh for electricity generations than are reported here. In recent years, there have been substantial reductions in emissions at electric generation plants. By using updated emissions data and by adopting the NRC recommendation of projecting continued reductions in emissions over the analysis time period, the study projected much lower levels of avoided emissions associated with electricity usage reductions. The net effect of these two changes is that this study has higher estimated emissions benefits per weatherized unit than many previously published reports despite showing having lower levels of avoided emissions.

3. BENEFITS FROM GREENHOUSE GAS EMISSIONS REDUCTIONS

The estimates of avoided greenhouse gas emissions are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided greenhouse gases per unit of energy savings. In addition, for electricity, the amount of avoided greenhouse gases varies by geography because of differences in the fuels used to generate electricity in each geographic area.

The unit used for quantification of greenhouse gases is CO_2 equivalents. Greenhouse gases include CO_2, CH_4, and N_2O. Any emissions of CH_4 or N_2O are transformed into their CO_2 equivalent using the global warming potential furnished by EPA.[1]

3.1 NATURAL GAS AND PROPANE

The 2010 NRC report[2] furnished recommendations for computing the greenhouse gases associated with the extraction and combustion of natural gas. The report recommended using a value of 140 lbs per MCF of natural gas used (.062 metric tons per MMBtu). That includes 20 lbs per MCF for extraction and 120 pounds per MCF for combustion. The sources cited by the NRC report include Jaramillo (2007)[3] for upstream (i.e., extraction) and EPA AP-42[4] for downstream (i.e., combustion).

Table 3.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 0.34 metric tons. The projected lifetime savings per unit would be 1,152.74 therms and the lifetime avoided emissions would be 7.14 metric tons. (Note that installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

Table 3.1Avoided Emissions for CO_2 Equivalents Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[5]	Savings per Housing Unit (MMBtu)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	54.82	5.48	0.0620	0.34
Lifetime	1,152.74	115.27	0.0620	7.14

[1] U.S. Environmental Protection Agency *Overview of Greenhouse Gases Methane Emission*/ Environmental Protection Agency, September 9, 2013, Web. Accessed January 7, 2014. The CO2 equivalents (methane = 21, nitrous oxide = 310) are on the web pages: http://www.epa.gov/climatechange/ghgemissions/gases/ch4.html and http://www.epa.gov/climatechange/ghgemissions/gases/n2o.html.

[2] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 12.

[3] Jaramillo, P., W.M. Griffin, and H.S. Matthews. 2007. *Comparative life cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation*. Environ. Sci. Technol. 41(17):6290-6296.

[4] January 1995 U.S. Environmental Protection Agency *Compilation of Air Pollutant Emission Factors. Vol. 1. Stationary Point and Area Sources, 5th Ed. AP-42*. Environmental Protection Agency. Pp 1.1-5 Web. Accessed April 23, 2009.

[5] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (2.1% of savings in the example state), the potential bias is small.

3.2 FUEL OIL

The fuel oil CO_2 equivalent emissions rate was computed using several sources.

1. EIA provides CO_2 emissions factors for a range of fuels in the Technical Guidelines for Voluntary Reporting of Greenhouse Gases[6]. The emission factor for fuel oil used in homes and multifamily buildings was listed as 72.32 kg of CO_2 per MMBtu.
2. EPA furnishes estimates of the CH_4 and N_2O emissions factors in AP-42, Compilation of Air Pollutant Emissions[7]. For residential furnaces, emissions were estimated to be 1.78 lbs of CH_4 and 0.05 lbs of N_2O per 10^3 gallons of fuel oil.

The total CO_2 equivalent for fuel oil is estimated to be 0.0727 metric tons per MMBtu.

Table 3.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 0.06 metric tons. The projected lifetime savings per unit would be 127.46 gallons and the lifetime avoided emissions would be 1.29 metric tons. (Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

Table 3.2Avoided Emissions for CO_2 Equivalents Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[8]	Savings per Housing Unit (MMBtu)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	6.04	0.84	0.0727	0.06
Lifetime	127.46	17.68	0.0727	1.29

3.3 ELECTRICITY

The estimate of the emission rates for electricity is based on reported data for the NERC region in which the state is located. EPA's NERC emission summary tables were released in 2012.[9] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used

[6] U.S. Department of Energy, Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program, Chapter 1, Part C, Stationary Source Combustion, January 2007. Page 43.
[7] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. CH4 factor is on page 14 and N2O factor is on page 20. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf.
[8] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units that use fuel oil divided by the total number of housing units served by the program in that state.
[9] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.

the non-baseload emission rates for the NERC region in which the majority of each state's population resides, as recommended by the EPA.[10]

These tables furnish emission rates for CO_2 equivalents per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA NERC summary tables.[11]

Table 3.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 1,346 kWh and the avoided emissions per unit would be 0.83 metric tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 14.41 metric tons. (Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting to 25 years for insulation. So, the average savings per unit are lower in some of the later years.)

[10] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.
[11] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

Table 3.3 Avoided Emissions for CO_2 Equivalents Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source	Savings per Housing Unit (MMBtu Source)	Rate (Metric Tons/MMBtu)	Metric Tons per Housing Unit
First Year	1,346	1,466	5.00	0.1665	0.83
Lifetime	23,281	25,363	86.54	0.1665	14.41

For some emissions, the NRC observed that emission rates are expected to decline over time. The report recommended explicitly accounting for those expected reductions in emissions. They made no such recommendation for the emissions of greenhouse gases.

3.4 ESTIMATING THE VALUE OF AVOIDED GREENHOUSE GAS EMISSIONS (STATE-LEVEL)

The Office of Management and Budget issued a technical document in May 2013 that furnishes guidance for estimating the social cost of carbon.[12] That document furnishes the current social cost of carbon and annual values for the future cost through 2050. Table 3.4 shows cost statistics for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[13]

Table 3.4 Social Cost of CO_2 Equivalents ($ per metric ton) By Year (Nominal and 2013 Dollars) – Representative State

Year	$ Per Metric Ton (Nominal Value)	$ Per Metric Ton (2013 Dollars)
2013	$40.32	$40.32
2014	$41.44	$40.23
2015	$42.56	$40.12
2016	$43.68	$39.97
2017	$44.80	$39.80
Average for first five years	$42.56	$40.09
Average for analysis period	$50.48	$38.03

For each state, the avoided emissions per housing unit are listed in Tables 3.1-3.3. The total avoided emissions per housing unit for all energy types is multiplied by the dollars per metric ton in 2013 dollars

[12] OMB *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 Interagency Working Group on Social Cost of Carbon,* United States Government. May 2013. Page 18.

[13] Jeffrey D. Zients *M-13-04 MEMORANDUM FOR THE HEADS OF DEPARTMENTS AND AGENCIES.* Executive Office of Management and Budget. January 24, 2013.

to estimate the avoided emission benefit per unit at the state level. Table 3.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 3.6 shows the calculation for a representative state.

Table 3.5 Quantity and Value of Avoided Emissions for CO_2 Equivalents Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
Year	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit	Metric Tons per Unit	$ per Unit
2013	0.34	$13.69	0.06	$2.46	0.83	$33.59	1.23	$49.74
2014	0.34	$13.66	0.06	$2.45	0.83	$33.52	1.23	$49.64
2015	0.34	$13.63	0.06	$2.44	0.83	$33.42	1.23	$49.49
2016	0.34	$13.58	0.06	$2.44	0.83	$33.30	1.23	$49.32
2017	0.34	$13.52	0.06	$2.43	0.83	$33.16	1.23	$49.11
First five years	1.70	$68.08	0.30	$12.22	4.17	$167.01	6.17	$247.30
Lifetime	7.14	$269	1.29	$48	14.41	$551	22.84	$869

Table 3.6 Quantity and Value of Avoided Emissions for CO_2 Equivalents Aggregate Value – Representative State

Year	Units	Metric Tons Per Unit (All Fuels)	Aggregate Metric Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	1,186	1.23	1,463	$49.74	$58,997
2014	1,186	1.23	1,463	$49.64	$58,870
2015	1,186	1.23	1,463	$49.49	$58,700
2016	1,186	1.23	1,463	$49.32	$58,490
2017	1,186	1.23	1,463	$49.11	$58,242
First five years	1,186	6.17	7,316	$247.30	$293,298
Lifetime	1,186	22.84	27,086	$869	$1,030,084

3.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop the aggregate national value of avoided emissions. Table 3.7 shows the aggregate quantity of avoided emissions by fuel type. Table 3.8 shows the aggregate value of avoided emissions by fuel type. In total, the analysis shows that if the 2008 WAP program were implemented in 2013, it would be expected to result in a total reduction of 2,246,174 metric tons of CO_2 emissions (Table 3.7) at a lifetime value of $85,380,036 (Table 3.8). About 49 percent of the avoided emissions are from the reduction in the use of natural gas and propane, 17 percent from reduction in the use of fuel oil, and 34 percent from reduction in the use of electricity.

Table 3.7 Quantity of Avoided Emissions for CO_2 Equivalents National Aggregate Total by Fuel Type and Year

	Avoided Emissions (Metric Tons of CO_2)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
First Year	53,416	17,304	55,718	126,438
Lifetime	1,110,350	379,518	756,306	2,246,174

Table 3.8 Value of Avoided Emissions for CO_2 Equivalents National Aggregate Total by Fuel Type and Year

	Avoided Emissions (2013 Dollars)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	$2,153,735	$697,698	$2,246,532	$5,097,965
2014	$2,149,088	$696,193	$2,241,685	$5,086,966
2015	$2,142,885	$694,183	$2,235,215	$5,072,283
2016	$2,135,220	$691,700	$2,227,220	$5,054,141
2017	$2,126,184	$688,773	$2,217,794	$5,032,751
First five years	$10,707,112	$3,468,547	$11,168,447	$25,344,107
Lifetime	$41,883,785	$14,238,989	$29,257,261	$85,380,036

Table 3.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level are 26.14 metric tons with lifetime value of $994.

Table 3.9 Quantity and Value of Avoided Emissions for CO_2 Equivalents Per Housing Unit – National

Year	Units	Aggregate Metric Tons	Metric Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	85,931	126,438	1.47	$5,097,965	$59.33
2014	85,931	126,438	1.47	$5,086,966	$59.20
2015	85,931	126,438	1.47	$5,072,283	$59.03
2016	85,931	126,438	1.47	$5,054,141	$58.82
2017	85,931	126,438	1.47	$5,032,751	$58.57
First five years	85,931	632,188	7.36	$25,344,107	$294.94
Lifetime	85,931	2,246,174	26.14	$85,380,036	$994

4. BENEFITS FROM SULFUR DIOXIDE EMISSIONS REDUCTIONS

The estimates of avoided SO_2 are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided SO_2 per unit of energy savings. In addition, for electricity, the amount of avoided SO_2 varies by geographic region because of differences in the SO_2 emissions rates for generation plants.

4.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the SO_2 emissions factor from natural gas combustion in boilers and furnaces in AP-42[14]. Emissions are estimated to be 0.6 pounds of SO_2 per 10^6 standard cubic feet of natural gas (2.93×10^{-7} short tons per MMBtu).

Table 4.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 1.60×10^{-6} short tons. The projected lifetime savings would be 1,152.74 therms and the lifetime avoided emissions would be 3.37×10^{-5} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 4.1 Avoided Emissions for SO_2 Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[15]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	54.82	5.48	2.93E-07	1.60E-06
Lifetime	1,152.74	115.27	2.93E-07	3.37E-05

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (2.1% of savings in the example state), the potential bias is small.

4.2 FUEL OIL

The fuel oil SO_2 emissions rate was computed using the EPA estimated SO_2 emissions factor from AP-42[16], Compilation of Air Pollutant Emissions[17]. The EPA factor is 142 pounds per 10^3 gallons multiplied

[14]AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion
Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.
[15] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.
[16] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final

by the weight percentage of sulfur in the oil. Our model assumes 50% sulfur content for residential fuel oil[18] so the total SO_2 emissions for fuel oil are estimated at 71 pounds per 10^3 gallons (2.56×10^{-4} short tons per MMBtu).

Table 4.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 2.15×10^{-4} short tons. The projected lifetime savings would be 127.46 gallons and the lifetime avoided emissions would be 4.52×10^{-3} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 4.2 Avoided Emissions for SO_2 Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[19]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.04	0.84	2.56E-04	2.15E-04
Lifetime	127.46	17.68	2.56E-04	4.52E-03

4.3 ELECTRICITY

The estimate of the emissions rates for sulfur dioxide for electricity is based on reported data for the eGRID region in which the state is located. EPA's eGRID emission summary tables were released in 2012.[20] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used the non-baseload emission rates as recommended by EPA.[21]

These tables furnish emission rates for SO2 per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.22

Table 4.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first

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Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

[17] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

[18] Nishioka et al. "Integrating Risk Assessment and Life Cycle Assessment: A Case Study of Insulation." *Risk Analysis.* Vol. 22, no. 5, 2002, p. 1006.

[19] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.

[20] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.

[21] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.

[22] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

program year would be 1,346 kWh and the avoided emissions per unit would be 4.67 x 10-4 short tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 6.35 x 10-3 short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

The NRC observed that emission rates of SO2 from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel. 23 We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of SO2 emissions from electricity generation in our models.

Table 4.3 Avoided Emissions for SO_2 Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	1,346	1,466	5.00	9.33E-05	4.67E-04
2014	1,346	1,466	5.00	9.06E-05	4.53E-04
2015	1,346	1,466	5.00	8.80E-05	4.40E-04
2016	1,346	1,466	5.00	8.55E-05	4.28E-04
2017	1,346	1,466	5.00	8.31E-05	4.16E-04
First five years	6,730	7,331	25.01	8.81E-05	2.20E-03
Lifetime	23,281	25,363	86.54	7.34E-05	6.35E-03

4.4 ESTIMATING THE VALUE OF AVOIDED SULFUR DIOXIDE EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[24] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level SO_2 were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

[23] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.

[24] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].

Damage estimates of each additional short ton of point-source SO_2 emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document[25]. The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[26] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2 emissions.

Table 4.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[27]

[25] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.
[26] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[27] Jeffrey D. Zients *M-13-04 MEMORANDUM FOR THE HEADS OF DEPARTMENTS AND AGENCIES.* Executive Office of Management and Budget. January 24, 2013.

Table 4.4 Social Cost of SO_2 ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

Year	Point-Source Emissions		Ground-Level Emissions	
	$ Per Short Ton (Nominal Value)	$ Per Short Ton (2013 Dollars)	$ Per Short Ton (Nominal Value)	$ Per Short Ton (2013 Dollars)
2013	$9,547	$9,547	$34,274	$34,274
2014	$9,710	$9,427	$34,860	$33,845
2015	$9,876	$9,309	$35,456	$33,421
2016	$10,045	$9,193	$36,062	$33,002
2017	$10,217	$9,078	$36,679	$32,589
Average for first five years	$9,869	$9,318	$35,466	$33,426
Average for analysis period	$10,949	$8,672	$41,194	$30,147

For each state, the avoided emissions per housing unit are listed in Tables 4.1-4.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 4.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 4.6 shows the calculation for a representative state.

Table 4.5 Quantity and Value of Avoided Emissions for SO_2 Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	1.60E-06	$0.05	2.15E-04	$7.35	4.67E-04	$4.45	6.83E-04	$11.86
2014	1.60E-06	$0.05	2.15E-04	$7.26	4.53E-04	$4.27	6.69E-04	$11.59
2015	1.60E-06	$0.05	2.15E-04	$7.17	4.40E-04	$4.10	6.57E-04	$11.32
2016	1.60E-06	$0.05	2.15E-04	$7.08	4.28E-04	$3.93	6.44E-04	$11.07
2017	1.60E-06	$0.05	2.15E-04	$6.99	4.16E-04	$3.77	6.32E-04	$10.82
First five years	8.02E-06	$0.27	1.07E-03	$35.86	2.20E-03	$20.53	3.28E-03	$56.66
Lifetime	3.37E-05	$1.02	4.52E-03	$136.41	6.35E-03	$55.10	1.09E-02	$192.53

Table 4.6 Quantity and Value of Avoided Emissions for SO_2 Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	1,186	6.83E-04	0.81	$11.86	$14,070
2014	1,186	6.69E-04	0.79	$11.59	$13,745
2015	1,186	6.57E-04	0.78	$11.32	$13,430
2016	1,186	6.44E-04	0.76	$11.07	$13,125
2017	1,186	6.32E-04	0.75	$10.82	$12,829
First five years	1,186	3.28E-03	3.90	$56.66	$67,198
Lifetime	1,186	1.09E-02	12.94	$192.53	$228,344

4.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 4.7 shows the quantity of avoided emissions by fuel type. Table 4.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2008 WAP program were implemented in 2013, it would be expected to reduce SO_2 emissions by 3,275 short tons (Table 4.7) at a lifetime value of $139,164,170 (Table 4.8). Most of the avoided emissions accrue from the reductions in the use of fuel oil and electricity.

Table 4.7 Quantity of Avoided Emissions for SO_2 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (Short Tons of SO_2)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	0.25	60.92	172.75	233.93
2014	0.25	60.92	167.83	229.00
2015	0.25	60.92	163.04	224.22
2016	0.25	60.92	158.40	219.57
2017	0.25	60.92	153.88	215.06
First five years	1.26	304.62	815.90	1,121.79
Lifetime	5.25	1,336	1,934	3,275

Table 4.8 Value of Avoided Emissions for SO_2 National Aggregate Total by Fuel Type and Year

	Avoided Emissions (2013 Dollars)			
Year	**Natural Gas/Propane**	**Fuel Oil**	**Electricity**	**All Fuels**
2013	$11,647	$4,921,827	$3,757,633	$8,691,107
2014	$11,501	$4,860,185	$3,604,820	$8,476,507
2015	$11,357	$4,799,315	$3,458,222	$8,268,893
2016	$11,215	$4,739,207	$3,317,585	$8,068,007
2017	$11,074	$4,679,852	$3,182,668	$7,873,594
First five years	$56,795	$24,000,386	$17,320,928	$41,378,110
Lifetime	$214,453	$100,077,299	$38,872,419	$139,164,170

Table 4.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.0381 short tons with a lifetime value of $1,619.

Table 4.9 Quantity and Value of Avoided Emissions for SO_2 Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	85,931	234	0.0027	$8,691,107	$101.14
2014	85,931	229	0.0027	$8,476,507	$98.64
2015	85,931	224	0.0026	$8,268,893	$96.23
2016	85,931	220	0.0026	$8,068,007	$93.89
2017	85,931	215	0.0025	$7,873,594	$91.63
First five years	85,931	1,122	0.0131	$41,378,110	$481.53
Lifetime	85,931	3,275	0.0381	$139,164,170	$1,619

5. BENEFITS FROM NITROGEN OXIDE GAS EMISSIONS REDUCTIONS

The estimates of avoided NO_x are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided NO_x per unit of energy savings. In addition, for electricity, the amount of avoided NO_x varies by geographic region because of differences in the NO_x emissions rates for generation plants.

5.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the NO_x emissions factor from natural gas combustion in boilers and furnaces in AP-42[28]. Emissions are estimated to be 94 pounds of NO_x per 10^6 standard cubic feet of natural gas (4.59×10^{-5} short tons per MMBtu).

Table 5.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 2.51×10^{-4} short tons. The projected lifetime savings would be 1,152.74 therms and the lifetime avoided emissions would be 5.29×10^{-3} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 5.1 Avoided Emissions for NO_x Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[29]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	54.82	5.48	4.59E-05	2.51E-04
Lifetime	1,152.74	115.27	4.59E-05	5.29E-03

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (2.1% of savings in the example state), the potential bias is small.

5.2 FUEL OIL

The fuel oil NO_x emissions rate was computed using the EPA estimated NO_x emissions factor from AP-42[30], Compilation of Air Pollutant Emissions[31]. The EPA factor is 18 pounds per 10^3 gallons of residential fuel oil (6.49×10^{-5} short tons per MMBtu).

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[28] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion
Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-5.

[29] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

Table 5.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 5.44×10^{-5} short tons. The projected lifetime savings would be 127.46 gallons and the lifetime avoided emissions would be 1.15×10^{-3} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

[30] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

[31] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

Table 5.2 Avoided Emissions for NO_x Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[32]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.04	0.84	6.49E-05	5.44E-05
Lifetime	127.46	17.68	6.49E-05	1.15E-03

5.3 ELECTRICITY

The estimate of the emissions rates for Nitrogen Oxides for electricity is based on reported data for the eGRID region in which the state is located. EPA's eGRID emission summary tables were released in 2012.[33] These tables furnish estimates of baseload and non-baseload emission rates for each NERC region. For this analysis, we used the non-baseload emission rates as recommended by EPA.[34]

These tables furnish emission rates for NO_x per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[35]

Table 5.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 1,346 kWh and the avoided emissions per unit would be 7.68×10^{-4} short tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 1.05×10^{-2} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

The NRC observed that emission rates of NO_x from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel.[36] We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of NO_x emissions from electricity generation in our models.

[32] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.
[33] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012.
[34] Art Diem and Cristina Quiroz, *How to use eGRID for Carbon Footprinting Electricity Purchases in Greenhouse Gas Emission Inventories.* Environmental Protection Agency. Washington D.C. Page 10-11. July 2012.
[35] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.
[36] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.

Table 5.3 Avoided Emissions for NO_x Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	1,346	1,466	5.00	1.53E-04	7.68E-04
2014	1,346	1,466	5.00	1.49E-04	7.46E-04
2015	1,346	1,466	5.00	1.45E-04	7.25E-04
2016	1,346	1,466	5.00	1.41E-04	7.04E-04
2017	1,346	1,466	5.00	1.37E-04	6.84E-04
First five years	6,730	7,331	25.01	1.45E-04	3.63E-03
Lifetime	23,281	25,363	86.54	1.21E-04	1.05E-02

5.4 ESTIMATING THE VALUE OF AVOIDED NITROGEN OXIDE EMISSIONS (STATE-LEVEL)

The NRC report uses the Air Pollution Emission and Policy Analysis Model (APEEP) provided by Muller et al. (2009)[37] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level NO_x were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source NO_x emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document[38]. The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact

[37] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[38] *The Emissions & Generation Resource Integrated Database for 2012 (eGrid2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.

values.[39] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

Table 5.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[40]

Table 5.4 Social Cost of NO_x ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$4,835	$4,835	$9,075	$9,075
2014	$4,917	$4,774	$9,230	$8,961
2015	$5,002	$4,714	$9,388	$8,849
2016	$5,087	$4,655	$9,548	$8,738
2017	$5,174	$4,597	$9,712	$8,629
Average for first five years	$4,998	$4,719	$9,391	$8,850
Average for analysis period	$5,545	$4,392	$10,900	$7,985

For each state, the avoided emissions per housing unit are listed in Tables 5.1-5.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 5.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 5.6 shows the calculation for a representative state.

[39] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[40] Jeffrey D. Zients *M-13-04 MEMORANDUM FOR THE HEADS OF DEPARTMENTS AND AGENCIES.* Executive Office of Management and Budget. January 24, 2013.

Table 5.5 Quantity and Value of Avoided Emissions for NO_x Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	2.51E-04	$2.28	5.44E-05	$0.49	7.68E-04	$3.71	1.07E-03	$6.49
2014	2.51E-04	$2.25	5.44E-05	$0.49	7.46E-04	$3.56	1.05E-03	$6.30
2015	2.51E-04	$2.22	5.44E-05	$0.48	7.25E-04	$3.42	1.03E-03	$6.12
2016	2.51E-04	$2.20	5.44E-05	$0.48	7.04E-04	$3.28	1.01E-03	$5.95
2017	2.51E-04	$2.17	5.44E-05	$0.47	6.84E-04	$3.14	9.90E-04	$5.78
First five years	1.26E-03	$11.12	2.72E-04	$2.41	3.63E-03	$17.11	5.16E-03	$30.64
Lifetime	5.29E-03	$42.21	1.15E-03	$9.16	1.05E-02	$45.93	1.69E-02	$97.29

Table 5.6 Quantity and Value of Avoided Emissions for NO_x Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	1,186	1.07E-03	1.27	$6.49	$7,694
2014	1,186	1.05E-03	1.25	$6.30	$7,473
2015	1,186	1.03E-03	1.22	$6.12	$7,261
2016	1,186	1.01E-03	1.20	$5.95	$7,056
2017	1,186	9.90E-04	1.17	$5.78	$6,858
First five years	1,186	5.16E-03	6.11	$30.64	$36,342
Lifetime	1,186	1.69E-02	20.03	$97.29	$115,391

5.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 5.7 shows the quantity of avoided emissions by fuel type. Table 5.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2008 WAP program were implemented in 2013, it would be expected to reduce NO_x emissions by 1,825 short tons (Table 5.7) at a lifetime value of $19,133,849 (Table 5.8).

Table 5.7 Quantity of Avoided Emissions for NO_x National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Short Tons of NO_x)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	39.53	15.45	59.85	114.83
2014	39.53	15.45	58.15	113.13
2015	39.53	15.45	56.49	111.47
2016	39.53	15.45	54.88	109.86
2017	39.53	15.45	53.31	108.29
First five years	197.67	77.23	282.68	557.58
Lifetime	822	339	664	1,825

Table 5.8 Value of Avoided Emissions for NO_x National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$568,053	$260,581	$308,280	$1,136,914
2014	$560,938	$257,318	$295,743	$1,113,999
2015	$553,913	$254,095	$283,716	$1,091,724
2016	$546,976	$250,912	$272,178	$1,070,066
2017	$540,125	$247,770	$261,109	$1,049,004
First five years	$2,770,004	$1,270,676	$1,421,027	$5,461,708
Lifetime	$10,595,490	$5,392,188	$3,146,173	$19,133,849

Table 5.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.0212 short tons with a lifetime value of $223.

Table 5.9 Quantity and Value of Avoided Emissions for NO_x Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	85,931	114.83	0.0013	$1,136,914	$13.23
2014	85,931	113.13	0.0013	$1,113,999	$12.96
2015	85,931	111.47	0.0013	$1,091,724	$12.70
2016	85,931	109.86	0.0013	$1,070,066	$12.45
2017	85,931	108.29	0.0013	$1,049,004	$12.21
First five years	85,931	557.58	0.0065	$5,461,708	$63.56
Lifetime	85,931	1,825	0.0212	$19,133,849	$223

6. BENEFITS FROM PM 2.5 EMISSIONS REDUCTIONS

The estimates of avoided PM 2.5 are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided PM 2.5 per unit of energy savings. In addition, for electricity, the amount of avoided PM 2.5 varies by geographic region because of differences in the PM 2.5 emissions rates for generation plants.

6.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the PM 2.5 emissions factor from natural gas combustion in boilers and furnaces in AP-42[41]. Emissions are estimated to be 1.9 pounds of PM 2.5 per 10^6 standard cubic feet of natural gas (9.27×10^{-7} short tons per MMBtu).

Table 6.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 5.08×10^{-6} short tons. The projected lifetime savings would be 1,152.74 therms and the lifetime avoided emissions would be 1.07×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 6.1 Avoided Emissions for PM 2.5 Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[42]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	54.82	5.48	9.27E-07	5.08E-06
Lifetime	1,152.74	115.27	9.27E-07	1.07E-04

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (2.1% of savings in the example state), the potential bias is small.

6.2 FUEL OIL

The fuel oil PM 2.5 emissions rate was computed using the EPA estimated PM 2.5 emissions factor from AP-42[43], Compilation of Air Pollutant Emissions[44]. The EPA factor is 0.4 pounds of PM 2.5 per 10^3 gallons of residential fuel oil (1.44×10^{-6} short tons per MMBtu).

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[41] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion
Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.

[42] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

Table 6.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 1.21×10^{-6} short tons. The projected lifetime savings would be 127.46 gallons and the lifetime avoided emissions would be 2.55×10^{-5} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

[43] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-12.

[44] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

Table 6.2 Avoided Emissions for PM 2.5 Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[45]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.04	0.84	1.44E-06	1.21E-06
Lifetime	127.46	17.68	1.44E-06	2.55E-05

6.3 ELECTRICITY

The estimate of the emissions rates for particulate matter for electricity is based on reported data in the 2008 National Emissions Inventory.[46] The inventory furnishes quantities of PM 2.5 emitted by electric generation for each state and fuel sector. We used the EPA eGRID data[47] to calculate plant-level non-baseload generation as described in the eGRID technical support document.[48] These data were combined with the National Emissions Inventory data to calculate average PM 2.5 emission rates from non-baseload generation for each NERC region.

This method yielded emission rates for PM 2.5 per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[49]

Table 6.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 1,346 kWh and the avoided emissions per unit would be 2.53×10^{-5} short tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 3.44×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

The NRC observed that emission rates of PM 2.5 from power plants are expected to decline over time due to increased regulation and costs. The report recommended explicitly accounting for those expected reductions in emissions and provided estimates of 2030 emissions reductions varying by pollutant and power plant fuel.[50] We chose to apply a rough estimate of a 50% emissions reduction over the analysis period of 2013 to 2037. This translates to an annual reduction of 2.85% to the rate of PM 2.5 emissions from electricity generation in our models.

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[45] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.

[46] 2008 National Emissions Inventory Version 3, updated March 2013. Environmental Protection Agency. http://www.epa.gov/ttnchie1/net/2008inventory.html

[47] EPA *eGRID2012 Version 1.0 Year 2009*, updated May 2012. Environmental Protection Agency. Data files downloaded from http://www.epa.gov/cleanenergy/energy-resources/eGRID/index.html

[48] EPA *eGRID2012 Version 1.0 Year 2009 Technical Support Document*. Environmental Protection Agency. Washington, D.C. Page 18-19. April 2012.

[49] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

[50] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, pages 108 and 124.

Table 6.3 Avoided Emissions for PM 2.5 Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	1,346	1,466	5.00	5.06E-06	2.53E-05
2014	1,346	1,466	5.00	4.91E-06	2.46E-05
2015	1,346	1,466	5.00	4.77E-06	2.39E-05
2016	1,346	1,466	5.00	4.64E-06	2.32E-05
2017	1,346	1,466	5.00	4.50E-06	2.25E-05
First five years	6,730	7,331	25.01	4.78E-06	1.19E-04
Lifetime	23,281	25,363	86.54	3.98E-06	3.44E-04

6.4 ESTIMATING THE VALUE OF AVOIDED PARTICULATE MATTER EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[51] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level PM 2.5 were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source PM 2.5 emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document[52]. The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact

[51] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[52] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.

values.[53] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

Table 6.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[54]

Table 6.4 Social Cost of PM 2.5 ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$13,925	$13,925	$81,315	$81,315
2014	$14,163	$13,751	$82,706	$80,297
2015	$14,405	$13,578	$84,120	$79,291
2016	$14,652	$13,408	$85,559	$78,298
2017	$14,902	$13,240	$87,022	$77,318
Average for first five years	$14,395	$13,590	$84,144	$79,304
Average for analysis period	$15,970	$12,649	$97,674	$71,553

For each state, the avoided emissions per housing unit are listed in Tables 6.1-6.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 6.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 6.6 shows the calculation for a representative state.

[53] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.
[54] Jeffrey D. Zients *M-13-04 MEMORANDUM FOR THE HEADS OF DEPARTMENTS AND AGENCIES.* Executive Office of Management and Budget. January 24, 2013.

Table 6.5 Quantity and Value of Avoided Emissions for PM 2.5 Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	5.08E-06	$0.41	1.21E-06	$0.10	2.53E-05	$0.35	3.16E-05	$0.86
2014	5.08E-06	$0.41	1.21E-06	$0.10	2.46E-05	$0.34	3.09E-05	$0.84
2015	5.08E-06	$0.40	1.21E-06	$0.10	2.39E-05	$0.32	3.02E-05	$0.82
2016	5.08E-06	$0.40	1.21E-06	$0.09	2.32E-05	$0.31	2.95E-05	$0.80
2017	5.08E-06	$0.39	1.21E-06	$0.09	2.25E-05	$0.30	2.88E-05	$0.78
First five years	2.54E-05	$2.01	6.04E-06	$0.48	1.19E-04	$1.62	1.51E-04	$4.12
Lifetime	1.07E-04	$7.65	2.55E-05	$1.82	3.44E-04	$4.36	4.77E-04	$13.83

Table 6.6 Quantity and Value of Avoided Emissions for PM 2.5 Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	1,186	3.16E-05	0.0375	$0.86	$1,024
2014	1,186	3.09E-05	0.0366	$0.84	$1,000
2015	1,186	3.02E-05	0.0358	$0.82	$976
2016	1,186	2.95E-05	0.0350	$0.80	$953
2017	1,186	2.88E-05	0.0342	$0.78	$931
First five years	1,186	1.51E-04	0.1790	$4.12	$4,883
Lifetime	1,186	4.77E-04	0.5654	$13.83	$16,397

6.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 6.7 shows the quantity of avoided emissions by fuel type. Table 6.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2008 WAP program were implemented in 2013, it would be expected to reduce PM 2.5 emissions by 105.74short tons (Table 6.7) at a lifetime value of $7,605,273 (Table 6.8). Most of the avoided emissions accrue from the reductions in the use of fuel oil and electricity.

Table 6.7 Quantity of Avoided Emissions for PM 2.5 National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Short Tons of PM 2.5)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	0.80	0.34	7.30	8.45
2014	0.80	0.34	7.10	8.24
2015	0.80	0.34	6.89	8.04
2016	0.80	0.34	6.70	7.84
2017	0.80	0.34	6.51	7.65
First five years	4.00	1.72	34.50	40.21
Lifetime	16.61	7.53	81.60	105.74

Table 6.8 Value of Avoided Emissions for PM 2.5 National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$112,739	$121,413	$291,934	$526,086
2014	$111,328	$119,892	$280,061	$511,281
2015	$109,933	$118,391	$268,672	$496,996
2016	$108,556	$116,908	$257,746	$483,210
2017	$107,197	$115,444	$247,264	$469,905
First five years	$549,753	$592,048	$1,345,677	$2,487,478
Lifetime	$2,105,017	$2,504,465	$2,995,791	$7,605,273

Table 6.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.001230 short tons with a lifetime value of $88.50.

Table 6.9 Quantity and Value of Avoided Emissions for PM 2.5 Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	85,931	8.45	0.000098	$526,086	$6.12
2014	85,931	8.24	0.000096	$511,281	$5.95
2015	85,931	8.04	0.000094	$496,996	$5.78
2016	85,931	7.84	0.000091	$483,210	$5.62
2017	85,931	7.65	0.000089	$469,905	$5.47
First five years	85,931	40.21	0.000468	$2,487,478	$28.95
Lifetime	85,931	105.74	0.001230	$7,605,273	$88.50

7. BENEFITS FROM VOC EMISSIONS REDUCTIONS

The estimates of avoided VOC are made separately for natural gas and propane, fuel oil, and electricity. Each type of fuel has a different amount of avoided VOC per unit of energy savings. In addition, for electricity, the amount of avoided VOC varies by geographic region because of differences in the VOC emissions rates for generation plants.

7.1 NATURAL GAS AND PROPANE

The EPA furnished an estimate of the VOC emissions factor from natural gas combustion in boilers and furnaces in AP-42[55]. Emissions are estimated to be 5.5 pounds of VOC per 10^6 standard cubic feet of natural gas (2.68×10^{-6} short tons per MMBtu).

Table 7.1 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 54.82 therms and the avoided emissions per unit would be 1.47×10^{-5} short tons. The projected lifetime savings would be 1,152.74 therms and the lifetime avoided emissions would be 3.09×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect natural gas and propane usage, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average therms of savings per unit are lower in some of the later years.

Table 7.1 Avoided Emissions for VOC Natural Gas and Propane Usage Reductions – Representative State

Year	Savings per Housing Unit (therms)[56]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	54.82	5.48	2.68E-06	1.47E-05
Lifetime	1,152.74	115.27	2.68E-06	3.09E-04

For this calculation, it was assumed that the greenhouse gas emission rates for propane were the same as the rates for natural gas. While that is likely to be a reliable assumption for combustion, it is possible that the process for producing propane has different upstream emissions. However, since propane is a small part of the total energy savings associated with the program (2.1% of savings in the example state), the potential bias is small.

[55] AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ 1.4 Natural Gas Combustion
Final Section - Supplement D, July 1998. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf page 1.4-6.

[56] The savings per housing unit for any state is the projected aggregate natural gas and propane savings from housing units that use one of those fuels divided by the total number of housing units served by the program in that state.

7.2 FUEL OIL

The fuel oil VOC emissions rate was computed using the EPA estimated VOC emissions factors from AP-42[57], Compilation of Air Pollutant Emissions[58]. The EPA provided individual emissions factors from fuel oil combustion for 21 speciated organic compounds. These were aggregated to get total VOC emissions for fuel oil estimated at 1.48 x 10^{-7} short tons per MMBtu.

Table 7.2 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 6.04 gallons and the avoided emissions per unit would be 1.24 x 10-7 short tons. The projected lifetime savings would be 127.46 gallons and the lifetime avoided emissions would be 2.61 x 10-6 short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect fuel oil, the lifetime varies between 13 years for a setback thermostat to 25 years for insulation. So, the average savings per unit are lower in some of the later years.

Table 7.2 Avoided Emissions for VOC Fuel Oil Usage Reductions – Representative State

Year	Savings per Housing Unit (Gallons)[59]	Savings per Housing Unit (MMBtu)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
First Year	6.04	0.84	1.48E-07	1.24E-07
Lifetime	127.46	17.68	1.48E-07	2.61E-06

7.3 ELECTRICITY

The estimate of the emissions rates for volatile organic compounds for electricity is based on reported data in the 2008 National Emissions Inventory.[60] The inventory furnishes quantities of VOC emitted by electric generation for each state and fuel sector. We used the EPA eGRID data[61] to calculate plant-level non-baseload generation as described in the eGRID technical support document.[62] These data were combined with the National Emissions Inventory data to calculate average PM 2.5 emission rates from non-baseload generation for each NERC region.

[57] AP42, Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/ Section 1.3 Fuel Oil Combustion Final Section – Supplement E September 1999, corrected May 2010. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf, page 1.3-21.

[58] 29. N. F. Suprenant, *et al*., *Emissions Assessment Of Conventional Stationary Combustion Systems, Volume I: Gas And Oil Fired Residential Heating Sources*, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

[59] The savings per housing unit for any state is the projected aggregate fuel oil savings from housing units with fuel oil main heat divided by the total number of housing units served by the program in that state.

[60] 2008 National Emissions Inventory Version 3, updated March 2013. Environmental Protection Agency. http://www.epa.gov/ttnchie1/net/2008inventory.html

[61] EPA *eGRID2012 Version 1.0 Year 2009*, updated May 2012. Environmental Protection Agency. Data files downloaded from http://www.epa.gov/cleanenergy/energy-resources/eGRID/index.html

[62] EPA *eGRID2012 Version 1.0 Year 2009 Technical Support Document*. Environmental Protection Agency. Washington, D.C. Page 18-19. April 2012.

This method yielded emission rates for VOC per kWh generated at the source. We adjusted the kWh savings from the WAP evaluation to account for transmission losses. These estimates are provided in the EPA eGRID summary tables.[63]

Table 7.3 shows how avoided emissions were computed for one state studied in the WAP evaluation. The calculation for the representative state shows that the average projected savings per unit in the first program year would be 1,346 kWh and the avoided emissions per unit would be 1.53×10^{-5} short tons. The projected lifetime savings would be 23,281 kWh and the lifetime avoided emissions would be 2.65×10^{-4} short tons.

Note that the installed measures vary in terms of their estimated lifetime. For measures that affect electricity, the lifetime varies between 7 years for lighting and 25 years for insulation. So, the average savings per unit are lower in some of the later years.

[63] EPA *eGRID2012 Version 1.0 Year 2009 Summary Tables.* Environmental Protection Agency. Washington D.C. April, 2012. Pages 7 & 9.

Table 7.3 Avoided Emissions for VOC Electricity Usage Reductions – Representative State

Year	Savings per Housing Unit (kWh Site)	Savings per Housing Unit (kWh Source)	Savings per Housing Unit (MMBtu Source)	Rate (Short Tons/MMBtu)	Short Tons per Housing Unit
2013	1,346	1,466	5.00	3.06E-06	1.53E-05
2014	1,346	1,466	5.00	3.06E-06	1.53E-05
2015	1,346	1,466	5.00	3.06E-06	1.53E-05
2016	1,346	1,466	5.00	3.06E-06	1.53E-05
2017	1,346	1,466	5.00	3.06E-06	1.53E-05
First five years	6,730	7,331	25.01	3.06E-06	7.66E-05
Lifetime	23,281	25,363	86.54	3.06E-06	2.65E-04

7.4 ESTIMATING THE VALUE OF AVOIDED VOLATILE ORGANIC COMPOUNDS EMISSIONS (STATE-LEVEL)

The NRC report uses the APEEP provided by Muller et al. (2009)[64] to estimate the damages of one additional short ton of criteria air pollutants at the county level. The APEEP model differentiates between damages from ground-level emissions, such as emissions from fuel oil and natural gas heaters, and damages from point-source emissions, such as emissions from electric plants.

APPRISE contracted with the model developer to update the model with 2008 data. The 2008 county-level damage estimates of each additional short ton of ground-level VOC were weighted by the county population counts from the 2010 census to estimate the average damage values for each state. The state damage estimates for ground-level emissions were used to calculate the benefit of avoided emissions from natural gas, propane, and fuel oil.

Damage estimates of each additional short ton of point-source VOC emissions were calculated for each NERC region. The EPA eGRID data were used to estimate the annual non-baseload electricity generation for each county using procedures described in the eGRID technical support document[65]. The county-level damage estimates for point-source emissions were weighted by the county-level quantity of annual non-baseload electricity generation to generate averages for each NERC region. For each state, the benefit of avoided emissions from electricity was calculated using the damage estimate for point-source emissions for the NERC region in which the majority of each state's population resides.

The NRC estimated an increase in damages per ton of pollution of approximately 50% by 2030 due to growth in population combined with increases in the value of a statistical life and other health impact values.[66] We have applied a similar assumption to our models by incorporating an increase of 1.71% per year to damage values for SO_2, NO_X, PM 2.5, and VOC emissions.

[64] Muller, N.Z., and R.O. Mendelsohn. 2006. The Air Pollution Emission and Policy Analysis Model (APEEP). Yale University, New Haven, CT. December 2006 [online].
[65] *The Emissions & Generation Resource Integrated Database for 2012 (eGRID2012) Technical Support Document*. Environmental Protection Agency. Washington D.C. April, 2012, page 18.
[66] National Research Council *2010 Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academy Press, page 108.

Table 7.4 shows cost statistics in a representative state for the target analysis period – 2013 through 2037 – in nominal dollars and 2013 dollars (i.e., discounted by the recommended real discount rate furnished by OMB).[67]

Table 7.4 Social Cost of VOC ($ per short ton) By Year (Nominal and 2013 Dollars) – Representative State

	Point-Source Emissions		Ground-Level Emissions	
Year	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**	**$ Per Short Ton (Nominal Value)**	**$ Per Short Ton (2013 Dollars)**
2013	$1,324	$1,324	$7,648	$7,648
2014	$1,346	$1,307	$7,779	$7,552
2015	$1,369	$1,291	$7,912	$7,458
2016	$1,393	$1,275	$8,047	$7,364
2017	$1,417	$1,259	$8,185	$7,272
Average for first five years	$1,370	$1,291	$7,914	$7,459
Average for analysis period	$1,542	$1,189	$9,185	$6,731

For each state, the avoided emissions per housing unit are listed in Tables 7.1-7.3. The total avoided emissions per housing unit for electricity is multiplied by the dollars per short ton in 2013 dollars for point-source emissions. The total avoided emissions per housing unit for natural gas, propane, and fuel oil is multiplied by the dollars per short ton in 2013 dollars for ground-level emissions. The point-source and ground-level emissions benefits are combined to estimate the total avoided emission benefit per unit at the state level. Table 7.5 shows that calculation for a representative state. The aggregate emissions benefit for the state is estimated using the average per unit times the number of units served. Table 7.6 shows the calculation for a representative state.

[67] Jeffrey D. Zients *M-13-04 MEMORANDUM FOR THE HEADS OF DEPARTMENTS AND AGENCIES.* Executive Office of Management and Budget. January 24, 2013.

Table 7.5 Quantity and Value of Avoided Emissions for VOC Value per Unit by Fuel Type and Year (2013 Dollars) – Representative State

Year	Natural Gas/Propane		Fuel Oil		Electricity		All Fuels	
	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit	Short Tons per Unit	$ per Unit
2013	1.47E-05	$0.112	1.24E-07	$0.001	1.53E-05	$0.020	3.01E-05	$0.13
2014	1.47E-05	$0.111	1.24E-07	$0.001	1.53E-05	$0.020	3.01E-05	$0.13
2015	1.47E-05	$0.110	1.24E-07	$0.001	1.53E-05	$0.020	3.01E-05	$0.13
2016	1.47E-05	$0.108	1.24E-07	$0.001	1.53E-05	$0.020	3.01E-05	$0.13
2017	1.47E-05	$0.107	1.24E-07	$0.001	1.53E-05	$0.019	3.01E-05	$0.13
First five years	7.35E-05	$0.549	6.20E-07	$0.005	7.66E-05	$0.099	1.51E-04	$0.65
Lifetime	3.09E-04	$2.082	2.61E-06	$0.018	2.65E-04	$0.315	5.77E-04	$2.41

Table 7.6 Quantity and Value of Avoided Emissions for VOC Aggregate Value – Representative State

Year	Housing Units	Short Tons Per Unit (All Fuels)	Aggregate Short Tons	Value per Unit (2013 Dollars – All Fuels)	Aggregate Value (2013 Dollars – All Fuels)
2013	1,186	3.01E-05	0.04	$0.13	$159
2014	1,186	3.01E-05	0.04	$0.13	$157
2015	1,186	3.01E-05	0.04	$0.13	$155
2016	1,186	3.01E-05	0.04	$0.13	$153
2017	1,186	3.01E-05	0.04	$0.13	$151
First five years	1,186	1.51E-04	0.18	$0.65	$773
Lifetime	1,186	5.77E-04	0.68	$2.41	$2,863

7.5 NATIONAL TOTALS

The state-level analysis furnishes information on the aggregate avoided emissions, the aggregate emissions benefit, and the number of units served for each state. Those are cumulated to develop a national aggregate value of avoided emissions. Table 7.7 shows the quantity of avoided emissions by fuel type. Table 7.8 shows the value of avoided emissions by fuel type. The analysis shows that if the 2008 WAP program were implemented in 2013, it would be expected to reduce VOC emissions by 65.34 short tons (Table 7.7) at a lifetime value of $647,474 (Table 7.8). Most of the avoided emissions accrue from the reductions in the use of fuel oil and electricity.

Table 7.7 Quantity of Avoided Emissions for VOC National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (Short Tons of VOC)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	2.31	0.04	1.23	3.58
2014	2.31	0.04	1.23	3.58
2015	2.31	0.04	1.23	3.58
2016	2.31	0.04	1.23	3.58
2017	2.31	0.04	1.23	3.58
First five years	11.57	0.18	6.15	17.90
Lifetime	48.08	0.77	16.48	65.34

Table 7.8 Value of Avoided Emissions for VOC National Aggregate Total by Fuel Type and Year

Year	Avoided Emissions (2013 Dollars)			
	Natural Gas/Propane	Fuel Oil	Electricity	All Fuels
2013	$30,959	$1,166	$3,735	$35,861
2014	$30,571	$1,152	$3,688	$35,412
2015	$30,189	$1,137	$3,642	$34,968
2016	$29,810	$1,123	$3,596	$34,530
2017	$29,437	$1,109	$3,551	$34,098
First five years	$150,967	$5,688	$18,213	$174,868
Lifetime	$577,771	$24,045	$45,658	$647,474

Table 7.9 shows the calculation for the average amount of avoided emissions and the average value per housing unit served by the WAP program. The estimated avoided emissions per housing unit at the national level is 0.000760 short tons with a lifetime value of $7.53.

Table 7.9 Quantity and Value of Avoided Emissions for VOC Per Housing Unit – National

Year	Units	Aggregate Short Tons	Short Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
2013	85,931	3.58	0.000042	$35,861	$0.42
2014	85,931	3.58	0.000042	$35,412	$0.41
2015	85,931	3.58	0.000042	$34,968	$0.41
2016	85,931	3.58	0.000042	$34,530	$0.40
2017	85,931	3.58	0.000042	$34,098	$0.40
First five years	85,931	17.90	0.000208	$174,868	$2.03
Lifetime	85,931	65.34	0.000760	$647,474	$7.53

8. SUMMARY OF ENVIRONMENTAL BENEFITS

Table 8.1 furnishes information on the 2008 WAP program emissions impacts, both in tons of avoided emissions and in the estimated social value of emissions. The table shows that the aggregate value of avoided emissions is over $250 million and that the average value per housing unit is $2,932. SO2 emissions account for 55 percent of the benefits and CO2 equivalents account for 34 percent. The other emissions represent about 10 percent of the aggregate value.

Table 8.1 Quantity and Value of Avoided Emissions by Type of Emissions Aggregate and Per Housing Unit - National

Type of Emissions	Housing Units	Aggregate Tons	Tons Per Unit (All Fuels)	Aggregate Value (2013 Dollars – All Fuels)	Value Per Housing Unit (2013 Dollars – All Fuels)
CO_2 Equivalents	85,931	2,246,174*	26.14	$85,380,036	$994
SO_2		3,275**	0.0381	$139,164,170	$1,619
NOx		1,825**	0.0212	$19,133,849	$223
PM 2.5		106**	0.001234	$7,605,273	$88
VOCs		65**	0.000756	$647,474	$8
TOTAL		N/A	N/A	$251,930,802	$2,932

*Metric Tons
**Short Tons

Table 8.1 understates the aggregate impact of the 2008 WAP program because the evaluation was not able to develop savings estimates for large multifamily buildings treated outside New York City. A total of 97,965, units were treated by the WAP program in 2008. However, the evaluation was able to estimate energy savings for only 85,931 units. So, the actual avoided emissions from the 2008 WAP program are likely to be 10 to 15 percent higher than the estimates in Table 8.1.

Table 8.2 shows how each fuel contributes to the aggregate value of savings for each type of emissions. Natural gas and propane account for about 22 percent of the value of avoided emissions, fuel oil accounts for about 49 percent, and electricity accounts for about 29 percent.

Housing units with fuel oil main heat account for about 15 to 20 percent of WAP housing units. However, they represent almost one-half of the benefits of avoided emissions for a number of reasons. Fuel oil has higher SO_2 emissions per MMBtu than other fuels, is a ground source pollutant (i.e., is emitted at the level where it has the greatest health impact), and is emitted in areas where the social cost is highest.

Natural gas and propane account for the social cost of about one-half of greenhouse gas emissions (i.e., CO_2 equivalents) and NO_x emissions, and almost 90 percent of the VOC emissions. About two-thirds of housing units treated by the WAP program are heating by natural gas or propane.

Electricity generation accounts for a significant share of all of the listed emissions, except for VOCs. Electricity accounts for the almost 40 percent of the value of avoided PM 2.5 emissions, 34 percent of the value of avoided emissions of CO_2 equivalents, and 28 percent of value of avoided emissions of SO_2. About 15 to 20 percent of homes treated by the WAP program use electricity as their main heating fuel.

Table 8.2 Value of Avoided Emissions by Type of Emissions and Fuel Type Aggregate Value – National

Type of Emissions	Natural Gas and Propane	Fuel Oil	Electricity	Aggregate Value - All Fuels
CO_2 Equivalents	$41,883,785	$14,238,989	$29,257,261	$85,380,036
SO_2	$214,453	$100,077,299	$38,872,419	$139,164,170
NOx	$10,595,490	$5,392,188	$3,146,173	$19,133,849
PM 2.5	$2,105,017	$2,504,465	$2,995,791	$7,605,273
VOCs	$577,771	$24,045	$45,658	$647,474
TOTAL	$55,376,516	$122,236,986	$74,317,302	$251,930,802