Estimating the Emissions Benefits of Switching to Heat Pumps for Residential Heating

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Overview

This analysis provides an estimate of the oxides of nitrogen (NOx), sulfur dioxide (SO_2), and carbon dioxide (CO_2) reductions that result from two scenarios where fossil fuel-burning residential furnaces are replaced with electrified heat pumps. The analysis was completed as a test case for the state of Connecticut to evaluate the use of the National Renewable Energy Laboratory (NREL) ResStock model and to gauge the value of completing additional analysis using the tool. The analysis provides estimated reductions in emissions resulting from replacement of natural gas and #2 fuel oil (residential oil) furnaces with heat pumps. Increases in electricity-related emissions from the use of heat pumps are estimated and included in the results. The analysis found significant reductions in NOx, SO_2, and CO_2 can be achieved by using heat pumps for residential heating.

Background

The majority of space heating systems in the Northeast are fueled by natural gas or residential heating oil. Improvements in cold weather heat pumps, along with state and local incentives have allowed for expanded use of the systems in the region. In some states, heat pumps are used for space heating in 10 percent of new construction and use of the systems is expected to grow over time. Significant work is being done by states to estimate the energy and GHG emissions savings associated with reducing energy consumption in buildings. This analysis is intended to add to those efforts.

In addition to reducing GHG emissions, the replacement of residential and commercial heating systems with alternatives such as variable speed air source heat pumps (VSHP) and ground source heat pumps (GSHP) can reduce criteria pollutants, including NO_X and SO_2. Other pollutants, such as methane, particulate matter, and volatile organic compounds are also emitted by furnaces and could be reduced through replacement with heat pumps, but the impact on these pollutants has not been evaluated in this analysis. Nor was the potential reduction in emissions associated with the use of VSHP for air conditioning in warmer months evaluated. Both of these analyses could be done in a follow-on study. In addition, an estimate of emissions reductions as the electricity grid transitions to greater levels of renewables could also be evaluated in a follow-on analysis.

Method

For this analysis, NESCAUM relied on existing model runs of ResStock conducted by NREL and published on their website.[1] As a test case, two scenarios were chosen for the state of Connecticut. These included: 1) transitioning home furnaces currently fueled with residential fuel oil to VSHP; and 2) transitioning home furnaces currently fueled with natural gas to VSHP.

In both scenarios, the energy, fuel, and CO_2 emission benefits resulting from reduced combustion of residential oil and natural gas was available in ResStock output tables found in an NREL report. The NREL tables also provided the additional amount of electricity used by heat pumps (in megawatt hours or “MWh”) that replaced the conventionally fueled furnaces. Table 1 shows the type of fuel switch assumed, the number of homes switched, fossil fuel reductions, and the additional electricity for the two scenarios.

Table 1. Scenario Descriptions

Scenario	**Type of fuel switch**	**Number of homes switched**	**Additional electricity generated**	**Reduction in residential fossil fuel consumption**
1	Residential oil furnace to heat pump	21,931 to 221,821	+157,000 to +1,341,000 MWh	-3 to -20 TBtu
2	Residential natural gas furnace to heat pump	41,874	+235,000 MWh	-3 TBtu

The ResStock model provides two outputs for each scenario: 1) economic potential; and 2) technical potential. In the technical potential case, all the furnaces that can be switched to VSHP are switched regardless of cost. Economic potential is similar to technical potential but must meet cost-effectiveness criteria. Specifically, a switch from a fossil fuel heating system to VSHP must meet the criteria of being net present value (NPV) greater than zero. In other words, the cost to purchase and own the VSHP must be less than the cost to purchase and own a fossil fuel heating system. More detail on the criteria for these scenarios are available from NREL.[2]

Estimating NO_X and SO_2 Emissions Resulting from Fuel Oil and Natural Gas Combustion

The ResStock model provides total change in energy consumption in British thermal units (Btu). NESCAUM estimated the volume of natural gas and residential oil through a simple conversion to standard cubic feet (scf), where 1 scf equals 1,020 Btu, and to gallons, where 1 gallon of fuel oil equals 138,500 Btu. NESCAUM multiplied relevant emission factors from EPA AP42 tables to convert scf of natural gas and gallons of fuel oil to NO_X, SO_2, and CO_2 emissions. Table 2 lists the emission factors for converting fuel volume to NO_X, SO_2, and CO_2 emissions.

[1] Residential Energy Efficiency Potential by State https://public.tableau.com/shared/SM9R5YT4N?:display_count=yes&:showVizHome=no.

[2] Energy Efficiency Potential in the U.S. Single-Family Housing Stock https://www.nrel.gov/docs/fy18osti/68670.pdf.

Table 2: Emission Factors for Fuel Oil and Natural Gas Furnaces

Pollutant	Emission Factors for Fuel Oil Furnaces	Emission Factors for Natural Gas Furnaces
NO_X	0.10815 (lbs./MMBtu)	94 (lbs./Mmcf)
SO_2	142 (lbs./1,000 gallons) 0.0015% sulfur content	0.6 (lbs./Mmcf)
CO_2	2230 (lbs./1,000 gallons)	120,000 (lbs./Mmcf)

Estimating Emissions from the Current Electricity Generating Mix

NESCAUM estimated emissions associated with the additional electricity use for the scenarios using emission factors in pounds per MWh (lbs./MWh) obtained from the Independent System Operator New England (ISO NE) 2021 air emissions report.[3] For this analysis, marginal electricity-related emission rates were used as opposed to annual average emission factors. Specifically, NESCAUM used the locational marginal units (LMUs) time weighted emission factors for 2019 from the ISO NE 2021 report shown in Figure 1. In this ISO NE case, the electricity generation mix is largely natural gas (49%), with small contributions from other fossil fuel emitting plants and wood and wood derived fuels. The remainder of electricity generation comes from non-emitting sources like renewable and nuclear energy. The ISO NE marginal electricity emission factors shown in Figure 1 were used to calculate the emissions from additional electricity generation required by implementing VSHP in Connecticut.

Figure 1: ISO NE 2019 Annual Time Weighted Marginal Emission Rates (lbs./MWh)

	LMU Marginal Emission Rates					
	Time-Weighted			Load-Weighted		
	2018 Annual Rate	2019 Annual Rate	Percent Change 2018 to 2019	2018 Annual Rate	2019 Annual Rate	Percent Change 2018 to 2019
	(lbs/MWh)	(lbs/MWh)	(%)	(lbs/MWh)	(lbs/MWh)	(%)
All LMUs						
NO_X	0.17	0.10	-41.2	0.20	0.11	-45.0
SO_2	0.11	0.02	-81.8	0.13	0.03	-76.9
CO_2	655	648	-1.1	745	719	-3.5
Emitting LMUs						
NO_X	0.28	0.15	-46.4	0.27	0.15	-44.4
SO_2	0.17	0.04	-76.5	0.16	0.04	-75.0
CO_2	1,005	970	-3.5	971	943	-2.9

Results

Scenario 1: Residential Oil Furnace Replaced with VSHP

Scenario 1 evaluates a switch of 21,931 (in the economic case) to 221,821 (in the technical case) of Connecticut homes fueled by residential oil to VSHP. Heating-related NO_X emissions from the 21,931 to 221,821 homes were estimated to decreases the most, between 9 percent and 57 percent from the original residential heating oil emissions. This is equivalent to 154 to 1,015 tons of NOx for the heating season. CO_2 emissions decreased between 6 percent to 43 percent,

[3] ISO NE, "2019 ISO New England Electric Generator Air Emissions Report," 2021.

equivalent to 164,630 to 1,149,624 tons per heating season. SO_2 emissions decreased by approximately 3 percent to 8 percent, or one to two tons per heating season. The change in tons of pollutants in the minimum and maximum cases are provided in Table 3.

Table 3. Scenario 1 Emissions Changes from Baseline (Tons and Percent)

		Minimum (Economic)			**Maximum (Technical)**		
		NO_X	**CO_2**	**SO_2**	**NO_X**	**CO_2**	**SO_2**
Baseline	*Residential Oil (tons)*	1,795	2,673,013	26	1,795	2,673,013	26
Scenario 1	*Electricity (tons)*	1,633	2,457,515	24	713	1,088,923	11
	Residential Oil (tons)	8	50,868	1	67	434,484	13
Difference, Scenario 1-Baseline		-154	-164,630	-1	-1,015	-1,149,624	-2
Change (%)		-9%	-6%	-3%	-57%	-43%	-8%

The economic case of scenario 1 increases electricity generation by 157,000 MWh/year and the technical case increases electricity generation by 1,341,000 MWh/year. Residential fuel oil consumption is predicted to decline by 3 TBtu/year (economic potential) to 20 TBtu/year (technology potential). Gallons of fuel oil consumed in the baseline case equaled 242 million gallons for the heating season. Fuel oil reductions equaled 19 million gallons in the economic case and 115 million gallons in the technical case, again for the entire heating season.

<u>Scenario 2: Gas Furnace Replaced with VSHP</u>

Scenario 2 evaluates a relatively small percent of households switching to VSHP from natural gas furnaces. This scenario only assumes technical feasibility, as the NREL ResStock report finds the economic potential to result in zero change in residential gas or electricity consumption. Five percent (41,874 homes) are switched to VSHP from natural gas in this scenario. NO_X emissions from electricity and residential gas combined decrease by approximately 126 tons per heating season from the baseline scenario. CO_2 emissions decrease by 100,331 tons, and SO_2 emissions increase by 1.5 tons per year. These changes are shown in Table 4.

Table 4. Emission Changes for Scenario 2 (short tons), Range of All Emission Factors

		NO_X	**SO_2**	**CO_2**
Baseline	*Residential Gas*	1,512	9.7	1,930,260
Scenario 2	*Electricity*	11.8	2.4	76,140
	Residential Gas	1,373	8.8	1,753,789
	Total	1,386	11.1	1,829,929
Difference, Scenario 2-Baseline		**-126**	**+1.5**	**-100,331**
Percent Change		**-8.7%**	**<+15%**	**5.2%**

According to the NREL ResStock output, this scenario increased electricity generation in the state by 235,000 MWh/year with a residential natural gas savings of three TBtu/year. In this scenario, residential natural gas consumption declines by ~12 percent. As with scenario 1, emission factors in lbs./MWh were gathered from the ISO NE emissions data tables to calculate emissions for NO_X, SO_2, and CO_2.

Summary

A transition of 21,931 homes (in the economic case) to 221,821 homes (in the technical case) heated by residential fuel oil to VSHP would result in a NO_X emissions savings of approximately 154 to 1,015 tons per year and a CO_2 reduction of 164,630 to 1.15 million tons per year. Transitioning 41,874 households from natural gas furnaces to heat pumps would result in a NO_X savings of approximately 126 tons per year and a CO_2 savings of 100,331 tons per year. With the current electricity generating mix, there would be a slight decrease in SO_2 emissions in both residential oil scenarios and a slight increase in SO_2 emissions in the natural gas scenario. Further work to evaluate emissions from electricity generation in future years is needed given the ongoing shift away from high emitting electric generating units. How quickly this shift occurs will significantly impact the results of an analysis of heat pump-related emissions reductions.

This analysis evaluated emission reductions only for the State of Connecticut as a test case for the analysis. A follow-on analysis could evaluate emission reductions in additional states since the ResStock model provides outputs for all of the Ozone Transport Commission states.

Finally, additional reductions could be realized through the use of heat pumps for air conditioning in the warmer months since heat pumps are more energy efficient than are conventional air conditioning units. A further analysis could evaluate the impact on summertime NOx emissions due to electricity use reductions.