When should we electrify space heating?

[Parth Vaishnav, Carnegie Mellon University, +1 (412) 268 9919, parthv@cmu.edu]
[Adilla Mutia Fatimah, Carnegie Mellon University, afatimah@andrew.cmu.edu]
[Meghana Kavakuntala, Carnegie Mellon University, mkavakun@andrew.cmu.edu]

Overview

Most discussions of deep decarbonisation of the energy system assume that space heating will be electrified, and that—since resistive heating is inefficient—air source or geothermal heat pumps will be used to achieve this electrification [1,2]. A number of studies have quantified the reductions in energy use and CO_2 emissions that would accrue from such a shift [3,4]. [5] quantify the greenhouse gas and criteria pollution reductions achieved by using a ground source heat pump to heat a house that is off the natural gas grid, and which would otherwise have to use oil. That also calculate that, although the heat pump is more expensive to install than an oil-fired furnace, the former results in lower monthly energy bills and pays for itself relatively quickly. However, we are not aware of any studies that perform a broad environmental and private benefit-cost analysis for heat pumps across the United States. In our study, we calculate the benefits of using heat pumps at over 900 locations in the continental United States. We account for differences in the local electricity mix, energy prices, and climatic conditions. Further, we estimate how the balance of benefits and costs will evolve as the grid gets cleaner and the climate gets warmer.

Methods

Our analysis draws on a dataset of air source heat pumps maintained and updated by the [6]. We restrict our analysis to centrally-ducted air source heat pumps with a capacity of 25,000 btu and below, as these are identified as being of the right size for a reasonably efficient home [7]. The NEEP dataset includes information about the coefficients of performance of various heat pumps at external termperatures of 5, 17, and 47°F. We derive a linear relationship between the temperature and the coefficient of performance (COP) of the heat pumps, and use the relationship to estimate the COP of the heat pump at temperatures other than the ones for which empirical estimates are available. The demand for natural gas for space heating, expressed in kW, for each hour of a typical meteorological year (TMY) for a typical ("Base case") residential building was obtained for over 900 locations in the U.S. from a DOE dataset [8]. The hourly temperature at these locations for the year 2010 was obtained from the National Oceanographic and Atmospheric Administration (NOAA). The correlation between temperature and COP was used to estimate the COP for the heat pump for each hour of the year. It was assumed that, if this demand were to be met by a heat pump, the electricity requirements of the heat pump would be equal to the required heating output divided by the COP. Where the original heating requirement exceeded the capacity of the heat pump, it was assumed that the difference would be made up by the combustion of natural gas. We estimate total fuel consumption for two cases. A base case, in which it is assumed that all heat is provided by natural gas. A hybrid heat pump case, in which heat is provided by an air source electric heat pump, with natural gas combustion providing auxiliary heat (at 90% efficiency). The calculation is repeated for each hour for each location, and summed to estimate fuel and energy consumption for the year. In calculating the fuel costs, we assume the State annual average price of natural gas for the residential sector for 2016 [9] for natural gas. We used the EASIUR model to estimate the monetary value of the location-dependent damages from these emission [10]. For electricity, we assume the State annual average price of electricity. For natural gas, whether used as the sole source of heat in the base case, or as an auxiliary fuel source in the hybrid heat pump case, we used $PM_{2.5}$, SO_2, and NO_x emission factors from [11]. For electricity, we used techniques developed in [12] and applied in [13] and the accopmapnying datset [14] to calculate location-dependent marginal emissions from the hourly electricity consumption. While these damages and emissions factors are calculated based on the current electricity mix, we also run the anslysis that any electricity used for speace heating comes from natural gas. For this, we calculate emissions factors for natural gas-fired plants from the [15]. Finally, we assume that damages from CO_2 emissions are \$40 per tCO_2 [16]. Finally, we estimate the net benefits of a shift to air source electric heat pumps by subtracting the monetized fuel cost, air quality (from SO_2, NO_x, and $PM_{2.5}$), and CO_2 damages associated with the "hybrid heat pump" case from the "baseline" case.

Results and Conclusions

A shift to electric heat pumps with the current electricity mix is likely to result in lower energy use, but higher heating bills and emissions of criteria pollutants in most parts of the country. A shift to natural gas, made assuming that electricity prices do not change and that the average heat rate of power plants stays roughly the same, would not change energy use or fuel costs by much but would result in CO_2 emissions reductions everywhere. This environmental benefit would, however, be substantially offset by a rise in criteria pollution. In future work (likely ready for presentation at the USAEE Annual Meeting), we will estimate how much cleaner the grid needs to get before a shift to heat pumps produces a net benefit, weight our location-based results by the number of households, and run the analysis for a case where a "hybrid" approach is not required; that is, where heat pumps can supply all the required heat. We will also test the sensitivity of our conclusions to factors such as value of COP assumed.

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