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Should North Carolina Require More Efficient Water Heaters in Homes? A Cost-Benefit Analysis

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Abstract

In 2011 the residential sector in the United States, both directly (e.g. on-site gas appliances) and indirectly (e.g. power plant emission), emitted 1,162 million metric tons of carbon dioxide. Residential electricity consumption, of which 14% came from water heaters, accounted for 70% of total carbon dioxide emissions associated with the residential sector. Heat Pump Water Heaters (HPWH) are two to three times more efficient than Electric Resistance Water Heaters (ERWH) that are common in homes. Currently, North Carolina only requires electric water heaters with tanks larger than 55 gallons to be the more efficient HPWH for new homes. This study addresses the question, what costs and savings can be expected by requiring HPWH in all new residential construction? To estimate costs and savings differences in short term economic costs, long term economic savings, and carbon emissions reductions were examined. Data from the U.S. Census Bureau, the U.S. Energy Information Administration, and the U.S. Department of Energy were analyzed to estimate changes in upfront costs and reduced energy demand, which lead to lower electricity bills and carbon emissions over time. Results suggest that requiring HPWHs would lead to a 10-year savings of $125 million for North Carolina residents, as well as 10-year reductions in carbon dioxide emission of around 435,900 metric tons.

1. Introduction

In 1949 the U.S. residential sector was associated with about 321 million metric tons of carbon dioxide emissions, both directly (e.g. onsite gas appliances) and indirectly (e.g. power plant emission), only about 20% of which was from the electricity consumption of the home. Seven decades later, in 2011, the residential sector was (directly and indirectly) responsible for 1,159 million metric tons of carbon dioxide emission in the United States, approximately 70% of which was from electricity consumption[21]. Total emissions from residences had tripled over the 62-year period. This increase was correlated with the substantial increase in the use of electrical appliances in residences, as emissions from other home energy consumption in households stayed relatively steady. In fact, the residential sector's associated emissions from 2011 where greater than those in 1949 by 761 million metric tons of carbon, while emissions from other home energy consumption only increased by 79 million metric tons of carbon dioxide. This indicates that considerable attention should be given to residential electricity use in order to reduce collective carbon dioxide emissions in the United States.

Concerns about climate change among residents, nonprofits, and local governments alike have risen in the United States with this increase in electricity consumption and carbon dioxide emissions. In many cases, the promotion and requirement of energy efficiency has been effective in combating these concerns[6,9,13]. Energy efficiency not only reduces a home's carbon footprint, but also an individual's electricity bill. This increase in the overall energy efficiency of homes and their appliances has the potential to lead to reductions in carbon dioxide emissions and energy demand, but at the higher upfront costs for appliances, and often installation, as heat pump water heaters (HPWH) tend to be more expensive than electric resistance water heaters (ERWH)[3]. To offset increases in upfront costs in the residential sector, savings can be experienced two-fold: (1) in long-term savings experienced by a reduction in electricity bills and (2) in the rebates offered for many of these appliances. Shapiro and Puttagunta have predicted that converting all ERWHs to HPWHs in America could result in $7.8 billion in consumer savings annually just in-home water heating operating costs. In addition, energy consumption for water heating could reduce energy use by 0.70 quads (i.e. 205,149,758,333 kWh) annually[3]. The savings from this shift would result in substantial economic and environmental benefits.

The U.S. Energy Information Administration found that in 2015 water heaters accounted for 19% of residential electricity consumption in NC, the second largest residential electricity consumer behind space heating (31%)[20]. With stringent regulatory requirements for more energy efficient water heaters, residential electricity use could be significantly reduced. HPWHs are hybrid systems that can use both, or either, a vapor compression cycle to transfer heat from the surrounding environment into the water tank (heat pump) and electric coils for direct water heating, for example when surrounding environmental conditions are below operating temperatures[1,14]. Transferring heat using a vapor compression cycle for heating has a much larger energy factor (a measure of efficiency) than directly using electricity for heating[10,11]. HPWHs have been proven to be up to 63.7% more efficient in Houston, Texas, (a warmer climate) and up to 40.2% in Chicago, Illinois, (a cooler climate) demonstrating, despite HPWH's lower efficiency performance in cooler environments, they still perform more efficiently than ERWHs[12].

Regulatory approaches prove to be more effective than voluntary approaches in promoting the adoption of energy efficient appliances in residential homes. Voluntary approaches are not as effective because the price of energy is often too low to incentivize investment in improving the energy efficiency of buildings[28]. States have the authority to set energy efficiency standards for appliances installed in residential homes in the state's building code under a section titled "energy conservation code". The State can set these standards to require stricter energy ratings of new appliances. Home rule states, such as Colorado, allow local governments to set their own laws, and thus building code, as they see fit. North Carolina is a Dillion's rule state, meaning the local government cannot set their own building codes and must default to the state's rules. This leaves the authority to the federal and NC state governments to address tightening the energy code requirements for residential appliances (e.g. water heaters).

In NC homes, water heaters consume more electricity than any other appliance in homes, except for space heating[20]. Currently, minimum efficiency ratings are set for each type of water heater in residential units allowing for the use of a range of different water heaters (e.g. tankless, electric, natural gas, and solar) with different efficiency requirements. In 2015, the U.S. federal government effectively required all electric tank water heaters larger than 55 gallons to be HPWH, as they are the only product that can meet the EF requirement set by the 2010 regulation[22]. This regulation was proven to be significant in increasing the momentum behind and production of HPWH[11]. Extending the reach of this regulation to include all residential water heaters, and not just the largest ones, may have substantial environmental and economic implications, such as reduced carbon dioxide emissions and long-term savings for residents. This paper examines the differences in short term economic costs, long term economic savings, and carbon dioxide emissions reductions that could be realized by requiring HPWH in the North Carolina Building Code for all new residential units.

2. Methods

The purpose of this study was to evaluate the impact of requiring HPWH in all new North Carolina residential housing units. To do so, four major calculations were made: change in energy consumption, change in carbon dioxide emissions, upfront cost, and electricity bill reductions on an annual basis. These calculations focus on new residential construction in North Carolina for 2017 and 2018, which both provided the most recent data available at the time of the study. For each estimate the most up-to-data data were used. This analysis assumes all new residential units would otherwise be built with ERWH, unless required to be built with HPWH under existing regulation. This assumption is unrealistic in some respects, as it excludes the possibility of water heaters (e.g. natural gas or solar) other than HPWH or ERWH being purchased. While not all water heaters are electric, over 70% of the water heaters purchased in North Carolinas census region are which makes this a good first approximation that provides the upper bound of the benefits[25].

2.1 Water Heater Database

To gain the most up-to-date information on water heaters, a database of water heater model name, model numbers, price, and estimated yearly energy use was created. This database was created using the market price of water heaters on Home Depot and Lowe's websites. The estimated yearly energy was collected using the information provided by the U.S. Federal Trade Commission EnergyGuides. These guides are found on all appliances. The database consisted of twenty 50-gallon water heaters. 50-gallon water heaters were used for this estimation, instead of all water heaters under 55-gallons, because they are the most commonly installed sized water heaters in homes. All water heaters, including more expensive outliers, were used in averages in order to represent a real-world range of market choices.

Table 1. Water Heater Database

Category:	**Model Name:**	**Model Number:**	**Price:**	**Estimated Yearly Energy Use (kWh)**
HPWH	[a]Rheem Performance Platinum 50 gal. 10-Year Hybrid High Efficiency Smart Tank Electric Water Heater	XE50T10HD50U1	$1,299.00	915
HPWH	[b]A.O. Smith Signature Premier 50-Gallon Tall 10-year Limited 4500-Watt Double Element Electric Water Heater with Hybrid Heat Pump	HP10-50H45DV	$1,199.00	950
Average (HPWH)			$1,249.00	932.5
ERWH	[b]A.O. Smith Signature Premier 50-Gallon Short 12-year Limited 5500-Watt Double Element Electric Water Heater	EG12-50R55DV	$639.00	3,531
ERWH	[b]A.O. Smith Signature Premier 50-Gallon Tall 12-year Limited 5500-Watt Double Element Electric Water Heater	EG12-50H55DV	$531.97	3,493
ERWH	[b]A.O. Smith Signature 50-Gallon Short 6-year Limited 4500-Watt Double Element Electric Water Heater	E6-50R45DV	$399.00	3,531
ERWH	[b]A.O. Smith Signature Select 50-Gallon Short 9-year Limited 5500-Watt Double Element Electric Water Heater	E9-50R55DV	$599.00	3,531
ERWH	[b]A.O. Smith Signature 50-Gallon Tall 6-year Limited 4500-Watt Double Element Electric Water Heater	E6-50H45DV	$499.00	3,493
ERWH	[b]A.O. Smith Signature Select 50-Gallon Tall 9-year Limited 5500-Watt Double Element Electric Water Heater	E9-50H55DV	$649.00	3,494
ERWH	[a]Rheem Performance 50 gal. Medium 6-Year 4500/4500-Watt Elements Electric Tank Water Heater	XE50M06ST45U1	$394.00	3,493
ERWH	[a]Rheem Performance 50 Gal. Tall 6 Year 4500/4500-Watt Elements Electric Tank Water Heater	XE50T06ST45U1	$440.25	3,493
ERWH	[a]Rheem Performance Plus 50 Gal. Medium 9 Year 5500/5500-Watt Elements Electric Tank Water Heater with LED Indicator	XE50M09EL55U1	$529.00	3,493

ERWH	[a]Rheem Gladiator 50 Gal. Medium 12 Year 5500/5500 Watt Smart Electric Water Heater with Leak Detection and Auto Shutoff	XE50M12CS55U1	$619.00	3,531
ERWH	[a]Rheem Performance Plus 50 Gal. Tall 9 Year 5500/5500-Watt Elements Electric Tank Water Heater with LED Indicator	XE50T09EL55U1	$545.74	3,493
ERWH	[a]Rheem Performance Plus 50 Gal. Medium 9 Year 4500/4500-Watt Elements Electric Tank Water Heater with LED Indicator	XE50M09EL45U1	$528.51	3,493
ERWH	[a]Rheem Gladiator 50 Gal. Tall 12 Year 5500/5500 Watt Smart Electric Water Heater with Leak Detection and Auto Shutoff	XE50T12CS55U1	$619.00	3,531
ERWH	[a]Rheem Performance Plus 50 Gal. Tall 9 Year 4500/4500-Watt Elements Electric Tank Water Heater with LED Indicator	XE50T09EL45U1	$583.12	3,493
ERWH	[b]Rheem Marathon 50 Gal. Tall 4500/4500-Watt Elements Non Metallic Lifetime Electric Tank Water Heater	MR50245	$1,192.01	3,569
ERWH	[a]Rheem Marathon 50 Gal. Short 4500/4500-Watt Elements Non Metallic Lifetime Electric Tank Water Heater'	MSR50245	$1,325.99	2494
ERWH	[a]Rheem Gladiator 50 Gal. Medium 12 Year 4500/4500 Watt Smart Electric Water Heater with Leak Detection and Auto Shutoff	XE50M12CS45U0	$580.64	3531
ERWH	[a]Rheem Gladiator 50 Gal. Tall 12 Year 4500/4500 Watt Smart Electric Water Heater with Leak Detection and Auto Shutoff	XE50T12CS45U0	$598.38	3531
Average (ERWH)			$626.26	3,457

[a] presents data retrieved from The Home Depot's website (homedepot.com). [b] presents data retrieved from Lowe's website (lowes.com). The "number-Year" denoted in under the *Model Name* column represents the length of the warranty for each water heater. All data was retrieved from these websites on 10/19/2019.

2.2 Estimating the Number of HPWH

Estimating the real-world number of housing units that would require the installation of HPWH must rest upon many assumptions. There is insufficient data on what types of water heaters new residential units have installed. Therefore, the results of this model were calculated using a range of percentages (p) of total residential units in North Carolina with water heaters 55 gallons or smaller. In other words, p is the percentage of residential units that would not already be required to have a HPWH under the 2010 regulation. Twenty scenarios were calculated using different p (0-100% at 5% increments). Hypothetically, if p was 0% that would mean all new residential housing units in NC would be built with water heaters with a tank larger than 55 gallons, meaning they already are required to have a HPWH. Thus, there would be no additional benefit by requiring all new residence to have a HPWH (as they would already be required to have a HPWH). If p was 100%, then this would mean that all new residential units would be built with water heaters a tank 55 gallons or smaller. This would mean that under the current regulation, none of these homes would be required to install a HPWH. Therefore, if all new residential units were required to have HPWH, the *p*=100% hypothetical is the scenario that would achieve maximum benefits. These *p*'s were multiplied by the total number of new residential units permitted in NC in 2018 (71,691 units)[18] to model what these costs and benefits might look like for residence of NC. All four major calculations were broken up this way in order to show the benefits of requiring HPWH at different levels of HPWH adoption.

The most likely range of *p* was determined to be 60-74%. This was calculated using the most recent *Characteristics of New Housing* data from the United States Census Bureau to determine how many bathrooms each housing unit had. This data was specifically on the number of bathrooms in new housing units constructed in 2017[17]. New housing units with three or more bathrooms were assumed to already have a HPWH, as they would likely need a water heater larger than 55 gallons, which is already required under existing regulation. New housing units with fewer than three bathrooms were assumed to have a water heater smaller than 55-gallon. Therefore, they would be newly required to have a HPWH if all water heaters were required to be HPWH in NC.

There are two general types of residential units defined by the U.S. Census Bureau, single-family housing units and multi-family housing units. Single family housing units are defined as fully detached, semidetached (semiattached, side-by-side), row houses, and townhouses. Multi-family units are essentially apartment complexes and duplexes (i.e. sharing common spaces or facilities)[19]. For multi-family units, the number of housing units built with "three plus" bathrooms was too small to warrant its own category repeating. The U.S. Census Bureau instead grouped them into a "two or more" bathroom category. The uncertainty in the number of multi-family units with "three plus" bathrooms causes an increase in the uncertainty in the results. This uncertainty in results is present because there are not data on how many new homes have each kind water heater, thus, to estimate how many water heaters there are it must be known how many new residential units there are. To estimate specifically how many small water heaters there are, it must be known what kind of water consumption these housing units might experience. Thus, we used the percentage of new housing with various number of bathrooms to best estimate this information. Therefore, if there is uncertainty in the number of bathrooms in a housing unit, there is uncertainty in the results of this study. Since the data does not clearly define the number of multifamily housing units with "three plus" bathrooms, a "most likely range of *p"* was created in order to mitigate this uncertainty in the results. The lower bound of this range, 60%, is the scenario where all of the "2 or more" bathroom category for multi-family homes are built with three or more bathrooms, representing the least-likely case scenario. The upper-bound of this range, 74%, is where no new multi-family housing units are built with three or more bathrooms.

These upper and lower bounds of the likely range were calculated by using data from both the *2014 Universe*[18] and the *Characteristics of New Housing*[17] census data sets. The *2014 Universe* data set provided the number of new residential units permitted in 2018, for both single-family and multi-family residential units. The *Characteristics of New Housing* census data provided the percentages of single-family homes built with less than "three plus" bathrooms (63% across the U.S. in 2017), and the number of new multi-family units built with less than "two plus" bathrooms (55% across the U.S. in 2017). Since the percent of single-family homes is already in the form needed for the analysis, the 63% was simply multiplied by the 51,248 new single-family homes permitted in 2018 to estimate the number of single-family homes in NC with small water heaters. 32,386 single-family residential units are estimated to have a small water heater. For the multi-family units, it can be assumed that at least the 55% of multi-family homes with less than two bathrooms will have small water heaters. Therefore, multiplying 55% by the number of new multi-family units constructed in NC in 2018 (20,443 units), gives us a minimum number of units with small water heaters (11,244 units). We then added the estimated number of single-family units and multi-family units with small water heaters together (43,529 units) and divide it by the total number of new units permitted (71,691 units) to get the low-bound likely percentage, 60%. The upper-bound is done similarly, except we assumed that 100%, not 55%, of the multi-family units have less than three bathrooms (20,443 units). Adding this number of multi-family units and single-family units, and once again dividing them by the total number of new residential units gives us the 74% upper-bound of the range.

The 66%, most likely *p*, was estimated using 2016-2017 *American Housing Survey (AHS)* data from the census[16]. This data provided the number of U.S. housing units completed between 2016-2017 with fewer than three bathrooms (553 thousand residential units), and the total number (841 thousand residential units). The number of units with less than three bathrooms was then divided by the total number of residential units to get the likely percentage of units with less than three bathrooms, 66%. The census expressed uncertainty in both the *American Housing Survey (AHS)* and the *Characteristics of New Housing*, thus both the range of likelihood and most likely values were used to estimate the percentage of new residences that may have been built with less than three bathrooms.

2.3 Reduction in Energy Demand

HPWHs have much higher energy efficiency than ERWHs, which directly leads to a reduction in energy demand. In this analysis, these reductions can be broken into energy demand per housing unit and for the state of North Carolina. This section breaks down how the reduction in energy demand that would result from requiring all water heaters be HPWH is estimated.

2.3.1 reduction in energy demand per housing unit

The estimated reduction in energy consumption that would result from installing a HPWH instead of an ERWH was calculated per housing unit using the following formula:

$$\Delta E = E_{HP} - E_{ER} \tag{1}$$

where ΔE represents change in energy demand per housing unit, E_{HP} represents the average estimated yearly energy use of a 50-gallon HPWH, E_{ER} represents the average estimated yearly energy use of a 50-gallon ERWH. The right-hand side of the equation represents the change in the estimated yearly energy use from installing a HPWH instead of an ERWH, per residential unit. Both E_{HP} *and* E_{ER} were calculated taking the average of the estimated yearly energy use, from Table 1, for corresponding water heater type (HPWH or ERWH). E_{HP} was calculated to be 923.5 kWh and E_{ER} was calculated to be 3457 kWh, therefore the ΔE was calculated to be -2533.5 kWh.

2.3.2 reduction in energy demand for NC

The estimated reduction in energy consumption that would result from requiring HPWH in all new construction in North Carolina, *change in energy demand* (in GWh), was calculated. The change in energy demand for North Carolina (ΔE_{NC}) was estimated using the following formula:

$$\Delta E_{NC} = (p)(n)(\Delta E) \tag{2}$$

where *n* represents the number of new residential units in North Carolina, *p* represents the percentage of residential units that would not already be required to have a HPWH under the 2010 regulation, and ΔE is given by equation 1. By multiplying ΔE, a per household unit, by *(p)(n)*, which describes the number of households experiencing this change in energy demand, the entire annual reduction in energy demand for the state is estimated. The *n* was determined using data on the number of new residential housing units that were permitted in 2018 from the United States Census Bureau[18]. The Census Bureau defines a residential housing unit as “a house, an apartment, a group of rooms, or a single room intended for occupancy as separate living quarters”[19].

2.4 Carbon Dioxide Emissions Reductions

A transition to HPWH would result in a reduction in local emissions from natural gas and coal electricity plants because HPWH are more energy efficient than ERWH. The reduction in carbon dioxide emissions in metric tons per residential unit (ΔC) and for the state (ΔC_{NC}) was estimated based on the reduction ΔE using the following formulas:

$$\Delta C = (\Delta E)(f) \tag{3}$$

$$\Delta C_{NC} = (\Delta C)(p)(n) \tag{4}$$

where f is the 2018 carbon dioxide emissions factor (metric tons of CO_2 emitted by electricity generation and use per MWh produced in North Carolina). The U.S. Energy Information Administration reported, in their *North Carolina Electricity Profile 2018*, this ratio to be 814 lbs of CO_2/MWh (0.369 metric tons of CO_2/MWh) in their 2018 North Carolina Electricity Profile[23]. This formula assumes that the energy demand reduction from anywhere in North Carolina would have the same reduction in carbon dioxide emissions, despite the fact that this reduction is dependent on the energy source used at a residential unit's local power plant, of which there are many in North Carolina.

2.5 Changes in Costs

The short-term costs are costs endured once by a household. In this analysis, these costs are the difference in price of a HPWH and an ERWH. The long-term savings are defined in this model as the annual change in electricity bill, as this is an ongoing savings that will last the lifetime of the water heater. In North Carolina, there is also potential for short term savings in the form of a one-time rebate provided by Duke Energy Carolinas ($350 at the time of this study) for their customers. These calculations are done both with and without this rebate since there is no guarantee it will continue to be offered.

Total statewide upfront costs are determined by three factors, the price of a new water heater, the savings from using a rebate and the number of new residential units. The change in upfront cost may be larger when considering potential increases in installation costs, these cost differences were excluded in this analysis as there was insufficient data. We used the average purchase price for all HPWHs and ERWHs listed in Table 1. As shown in Table 1, the average purchase price of a 50 gallon HPWH is $1,249 and the average price of an ERWH is $626.26. Thus, each residential unit incurs an extra upfront cost of $622.74 when purchasing a HPWH.

To find the total statewide upfront, we multiplied the individual residential unit's upfront cost by the number of new units in the state. As described in Section 2.2, the possible range of new residential units subject to a proposed new WH energy efficiency requirement is between 0 and 71,691 residential units, with the most likely range between 43,015 and 53,051 residential units. Total statewide upfront costs, therefore, are between $27 million and $33 million.

Next, the long-term economic savings of having a HPWH instead of an ERWH was estimated to be the difference in electric bill costs. The total change in electricity bill costs for North Carolina residents was determined using the average retail price of electricity to the residential sector in North Carolina, $0.1157/kWh[24]. This price was then multiplied by energy demand at each *p*. For example, we found the most-likely range of residential units that would newly be required to install HPWH was found to decrease energy demand anywhere from 108 and 136 GWh per year by using the most likely range of *p*. Total statewide annual economic savings, therefore, are between $13 and $16 million.

The change in upfront cost of requiring HPWH in all new residential units was also calculated both with and without the rebate provided by the local electricity utility in NC (*Duke Energy Carolinas*) in order to demonstrate the benefits of the switch to HPWH in multiple scenarios. It was also calculated including the savings from reduced cost of electric bills as explained in the previous paragraph. The change in cost over the 10-year warranty period of the water heater was calculated by multiplying the long-term savings over the lifetime of the water heater, then subtracting out the upfront cost. The lifetime of the water heater is assumed to be the average warranty in years of HPWH. This information was found using Table 1. The warranty of ERWH tends to be less than this.

3. Results and Discussion

The first part of the analysis estimated the change in energy demand that could resulted from requiring HPWH in all new residential units in NC. Figure 1 shows this change in energy demand as a function of the percentage of new home that would newly be required to install a heat pump water heater (*p*) and ΔE. The negative correlation between ΔE and *p* in Figure 1 was to be expected, as a transition from ERWH to HPWH would decrease residential energy demand. The significance of this figure is within the magnitude of these decreases in energy demand, rather than their direction. The maximum reduction in energy demand for NC would be where *p*=100%, when all new units have water heaters with tanks 55 gallons of smaller. This maximum reduction is therefore estimated to be 181 GWh. The minimum reduction would be when *p*=0%, the case where all new residential units have water heaters tanks larger than 55 gallons. Neither of these extreme cases are likely since residential units are can be expected to need a range of water heater sizes to meet the demands of the various load sizes residents may require, but the real-world benefits lie somewhere in between. Table 2 summarizes the results of analysis, looking exclusively at the most-likely range of *p* (i.e. the blue bars in Figure 1 and 2). The most likely range of decreases in energy demand are estimated to be between 108-134 GWh per year (the blue bars in Figure 1), calculated as describe by Section 2.3. The most likely decrease in energy demand, at p=66%, is 120 GWh as displayed in both Table 2 and Figure 1.

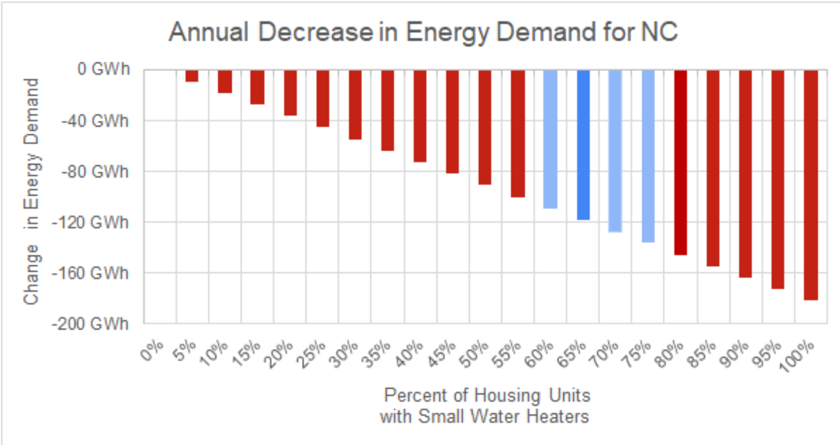

Figure 1. Change in Energy Demand

This graph is modeling the annual decrease in energy demand that could be actualized by requiring HPWH in all new residential units in NC. this figure was calculated using equations 1 and 2 from Section 2.3. small water heaters are 55 gallon or smaller, and therefore not regulated under current NC Building Code. any of these changes in energy demand are possible, but blue bars represent the range of the most likely decrease in energy demand, with the dark blue line representing the most likely exact *p*.

Table 2. Likely Range of Results

Percent of New-Small Units (p)	**Number of New-Small Units (p*n)**	**Change in Energy Demand**	**Change in Carbon Dioxide Emissions**	**Change in Upfront Cost**	**Change in Cost (After Energy Savings)**	**Change in Electricity Bill (per year)**	**Change in Cost (After Rebate and Energy Savings)**	**Lifetime Costs (energy savings)**	**Lifetime Costs (rebate and energy Savings)**
Total Across State:	**Number of housing units**	**(GWh)**	**(thousand metric tons)**	**(Millions of Dollars)**	**(Millions of Dollars)**	**(Millions of Dollars)**	**(Millions of Dollars)**	**(Millions of Dollars)**	**(Millions of Dollars)**
60%	**43014.6**	**-109**	**-40**	**$27**	**$14**	**-$13**	**-$0.9**	**-$99**	**-$114**
66%	**47316.06**	**-120**	**-44**	**$29**	**$16**	**-$14**	**-$1.0**	**-$109**	**-$125**
74%	**53051.34**	**-134**	**-50**	**$33**	**$17**	**-$16**	**-$1.1**	**-$122**	**-$140**
Per Housing Unit:		**(kWh)**	**(metric tons)**	**(Dollars)**	**(Dollars)**	**(Dollars)**	**(Dollars)**	**(Dollars)**	**(Dollars)**
	1	**-2533.5**	**-935**	**$623**	**$330**	**-$293**	**-$20.40**	**-$2,293**	**-$2,643**

This table displays the most likely range of results. *60%* is the minimum percentage of the "most-likely" range, *66%* is the most likely estimate, and *74%* is the maximum percentage of the "most-likely" range within the assumptions of the model. *per Housing Unit* is showing the results at an individual household level. columns 2-8 are first year results, while columns 9 and 10 are estimated cumulative savings after 10 years.

These reductions in energy demand will lead to reductions in carbon dioxide emissions from power plants across the state. Therefore, there is a negative correlation between C_{NC} and p in Figure 2. For the maximum reduction in carbon dioxide emissions, the case scenario where maximum reduction in energy demand is being achieved, 67,062 metric ton of carbon dioxide would be avoided. This is the case where p=100%, when all new units have water heaters with tanks 55 gallons of smaller. The minimum reduction (i.e. 0 newly avoided emissions) would occur when p=0%, the case where all new residential units have water heaters tanks larger than 55 gallons. Similarly to ΔE, neither of these extreme cases are likely and the real-world benefits lie somewhere in between. The most likely range of decreases in carbon dioxide emissions (as described in Table 2 and by the blue bars in Figure 2) is between 40,237-50,296 metric tons of carbon dioxide emissions. The most likely value existing in the range being around 44 thousand metric tons.

Table 2 displays the range of results that would most likely occur if the transition were to be realized. The table gives results for both statewide and per household scales, and additionally gives first-year and lifetime savings. The table shows that at p=66% of new residential units, North Carolina would collectively see a decrease in energy demands of 120 GWh and a decrease in carbon dioxide emissions of 44 thousand metric. As the fifth largest new unit permitting state in 2018, issuing 5% of new housing permits, these results are particularly significant in the state of North Carolina[18]. In North Carolina, Duke Energy Carolinas is a dominate electric utility that offers services territory spans across most of NC and is regulated by the state as a regulated monopoly[7]. Duke Energy Carolinas has an interest in, and has even made efforts in some areas, reducing energy demand in order to avoid the construction of peaker power plants. Construction of these peaker power plants will increase the spending of Duke Energy Carolinas and could be partially shifted onto the consumers[15]. Thus, a reduction in energy demand on this scale could have significant implications for additional monetary savings that were not estimated in this study.

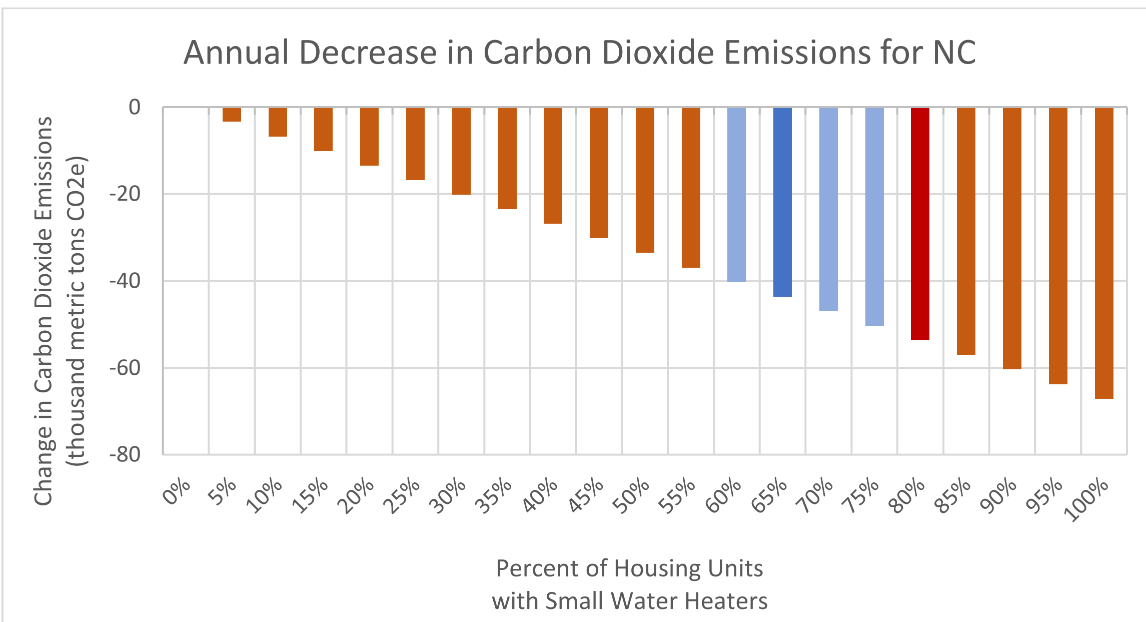

Figure 2. Change in Carbon Dioxide Emissions

This graph is modeling the annual decrease in carbon dioxide emissions in NC that could be actualized by requiring HPWH in all new residential units in NC. this figure was calculated using equations 3 and 4 from Section 2.4. small water heaters are 55 gallon or smaller, and therefore not regulated under current NC Building Code. any of these changes in energy demand are possible, but blue bars represent the range of the most likely decrease in emissions for NC, with the dark blue line representing the most likely exact p.

The magnitude of the estimated cost, Figure 3, also displays promising results. In Figure 3, the red bar shows the change in upfront cost of purchasing a HPWH instead of an ERWH. The blue bar shows the first-year change in cost after including savings from reduced cost of electricity bills, which reduces the cost by more than 50%. Most interestingly, the green bar shows the first-year change in cost after both the rebate and savings from reduced cost of electricity bills. The difference between the red and blue bar is the savings in electricity bills. The difference between the green and blue bars is both the savings energy savings and savings from the rebate. Therefore, the difference between the blue and green lines is the savings from the rebate. The negative green bar, representing an overall savings, is significant as it shows that within the first year the cost of the water heater is completely negated, therefore saving North Carolina residence a within the first year. The maximum savings for the first year of ownership, after an annual savings in electric bills and the $350 rebate per residential unit, would be $1.5 million (where *p*=100%). This scenario, where *p*=100%, is unlikely. The most-likely range of savings would be anywhere from $0.9-1.1 million for the state. For individual households, these savings would be $20.40 within the first year, and $2,643 for the lifetime of the water heater (Table 2). These savings were calculated as described in Section 2.5.

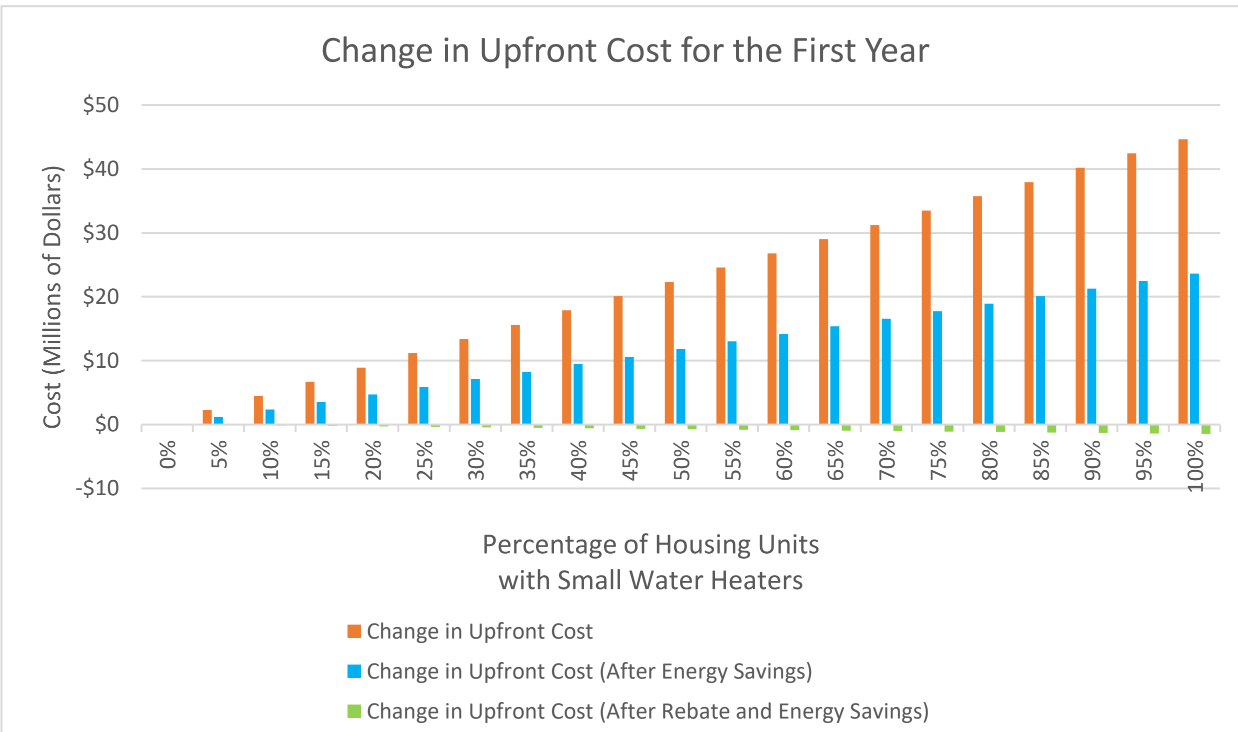

Figure 3. Costs

This graph shows net costs within the first year; it does not show the lifetime savings potential. the red is displaying the collective change in upfront cost for residents in NC, this amount is only accounting for the increase in price from buying a HPWH instead of an ERWH. the blue bar is the change in upfront cost including the reduction in cost from the continued annual savings in electricity bills that result from the energy efficiency improvement from having a HPWH instead of an ERWH. the green bars, going in the negative direction, represent the change in upfront cost including both these energy savings and the savings if all residents took advantage of Duke Energy Carolinas' $350 rebate the one-time rebate.

Across the state, the results show a maximum lifetimes savings of $190 million (when *p*=100%). The most likely range of lifetime savings across the state would be between $114-140 million (Table 2), calculated as described in Section 2.5. Figure 4 models these lifetime savings using the most likely percentage of homes with small water heaters, *p*=66%. The blue line is the estimated change in cost after the reduction in electricity costs, modeling a cumulative change in cost to be a savings of $109 million for residents in NC ($2,293 per housing unit). The green line displays the change in cost of installing a HPWH after both the savings form the Duke Energy Carolinas rebate and the reduction in electricity costs modeling a cumulative net savings of $125 million for residents in NC ($2,643 per housing unit). The red line displays the change in upfront cost as a short-term cost, a cost only incurred within the first year. This is important conceptually as the savings from requiring a HPWH, as oppose to an ERWH, will continue to accumulate, while the increase in cost will only occur once. It should be noted that this increase in upfront cost, $623 (Table 2), would be included in the overall cost of purchasing a new home, thus homeowners will not likely feel the financial burden in the same way that an existing home owner upgrading their system may feel. Additionally, Figure 4 shows that the change in upfront cost of the HPWH is completely negated in the first or second year of use. The entire cost of the HPWH, $1,249 (Table 1), would be negated in 3-4 years (with and without the rebate), leading to a net savings of $1,758-$2,051 over a ten-year period per household. These findings are significant as they demonstrate the positive impact requiring HPWH in all new residential homes could have on both individuals and the environment at a low cost.

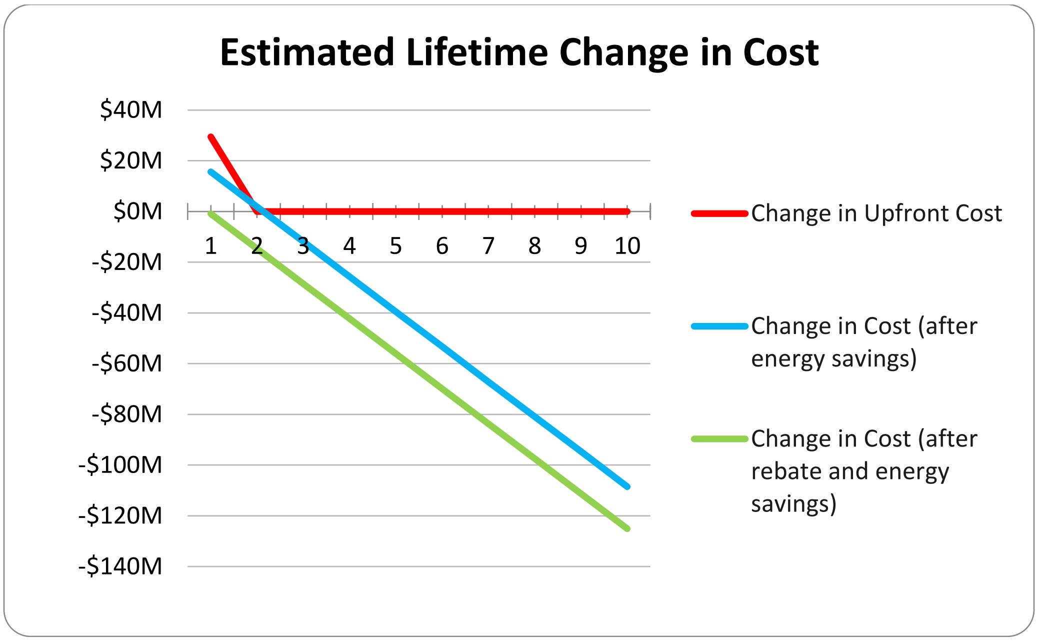

Figure 4. Estimated Lifetime Cost

This graph is showing the cumulative lifetime net costs of purchasing a HPWH. the lifetime of a HPWH was estimated to be 10-years as that is the typical warranty on HPWH, therefore the lifetime savings likely are an underestimation since the water heater can be expected to outlast the warranty. *the change in cost (rebate and energy savings)* is a net saving within the first year. *the change in cost (energy savings)* becomes offsets the increase in upfront cost within the second year. *change in upfront cost* is continuously zero after the first year. this figure is at *p*= 66%, therefore the scenario where 47,316 new housing units are built with HPWH.

4. Conclusion

Requiring HPWH in all new residential housing units would benefit North Carolina residents. This analysis found that this requirement would have substantial implications for energy demand and carbon dioxide emissions reduction. These annual reductions are on the order of a decrease in energy demand of 120 GWh and a decrease in carbon dioxide emissions of 44 thousand metric tons of carbon dioxide tons across the state. For each residential unit, the decrease is 2,533.5 kWh and 0.9 metric tons of carbon dioxide. Despite the increase in upfront cost for consumers (as HPWH are more expensive than ERWH), savings such as reductions in resident's electricity bills negate the increase in expenses and lead to significant savings over the lifetime of the water heater. This analysis found that the lifetime savings of installing a HPWH, as oppose to an ERWH, would be around $125 million dollars for NC residents ($2,643 per housing unit) and would result in a lifetime avoidance of 435 thousand metric tons of carbon dioxide emissions. Further, this study found that the upfront cost increase could be negated within the first two years of installation. In tandem, these results are enough to justify the implementation of requiring all water heaters to be HPWH. If left up to the consumer or building contractor, the $623 increased cost per residential unit may be enough to dissuade purchase of the HPWH, and long-term benefits of the appliance may not be considered in the consumer choice. This analysis implies that the requirement of HPWH should be adopted in North Carolina's Building Code.

Though the number of HPWH being manufactured has increased since the 2010 requirement, they are still not being produced at a scale to meet the demand of the state residents *if* HPWH were required in all future construction. Therefore, it is also recommended that the implementation of the requirement be staggered like the current requirement. Additionally, it is important to recognize that this model assumes that all water heaters are tank water heaters, which, in reality, is not the case. Further investigations that compare the emissions, cost, and energy efficiency between tankless water heaters and HPWH (and associated emissions from their respective power plants) are necessary. It may be inefficient to require all residents to have a tank water heater (such as a heat pump), as they are not the most energy efficient option under certain circumstances. Lastly, this paper does not posit that HPWH are the best option for residential heating. Solar heating should be allowed as an alternative heating source, as it has no associated emissions. Further research that examines the risks (installation costs and heating time) versus rewards of solar heating is also necessary. In the same vein, the impacts of using tankless water heaters on all the factors considered in this study should also be further investigated. They were not considered in this study because they use natural gas and cannot be replaced by renewable energy sources like electrical water heaters can. There are a multitude of water heaters and ways to supply energy to them, and the environmental and economic implications of each should not be overlooked or underestimated.

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