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Willingness to Pay for Renewably-Sourced Home Heating in the Fairbanks North Star Borough

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Abstract: Space heating is a necessity in Alaska; however, the use of heating fuels carries both economic and environmental costs. In the Fairbanks North Star Borough (FNSB), Alaska, most households utilize heating fuel oil as a primary source for home heating and firewood as a secondary source. In the FNSB, wood-burning devices are the principal source of fine particulate matter with a size of 2.5 microns or less, ($PM_{2.5}$), but firewood is less expensive when compared to heating fuel oil. The FNSB has been designated as a nonattainment area for $PM_{2.5}$, which has been linked to negative cardiopulmonary impacts and other adverse health consequences. Electric thermal storage heaters (ETSH) could help solve the $PM_{2.5}$ problem by displacing firewood used for residential space heating. We use dichotomous choice contingent valuation (DC-CV) to estimate willingness to pay (*WTP*) for an ETSH program which would allow FNSB residents to offset 100 gallons of heating fuel oil annually. Certainty correction is used to control for the presence of hypothetical bias. We find median *WTP* is USD 33.98 without certainty correction and USD 9.75 with certainty correction. Our results indicate that implementation of a special ETSH electricity rate based on the *WTP* estimate may lead to broader adoption of ETSH for space heating, which could improve air quality, reduce fuel poverty, and reduce the carbon footprint of residential space heating.

Keywords: contingent valuation; willingness to pay; home heating; air quality

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1. Introduction

The winter air quality in Alaska's Fairbanks North Star Borough (FNSB) does not meet the U.S. Environmental Protection Agency's National Ambient Air Quality Standard (NAAQS) for fine particulate matter with a size less than or equal to 2.5 microns ($PM_{2.5}$), posing a public health risk due to its association with negative impacts on cardiopulmonary health [1]. It is both expensive and necessary to heat homes in the FNSB during the winter. Most households use high-cost heating fuel oil as their primary heating fuel. Wood is a common secondary heating fuel because it is relatively less expensive when compared to heating fuel oil [2]. Unfortunately, wood burning is also the borough's largest source of $PM_{2.5}$ [3]. The choice to burn wood is often financially motivated, so determining residents' willingness to pay (*WTP*) for alternative heating fuels is an essential step in finding an affordable way to meet the demand for home heating while also improving air quality in the borough.

One way to assess *WTP* is contingent valuation, which is a survey method used to estimate the value of goods, services, and environmental amenities not usually exchanged in economic markets. Replacing wood fuels with cleaner alternatives generates positive externalities such as reduced air pollution. Contingent valuation is a useful tool to elicit an accurate measure of value in instances where a proposed program is expected to generate social benefits not reflected by traditional prices.

Elevated $PM_{2.5}$ levels resulting from residential wood-burning are a widespread issue elsewhere in the United States, including in Arizona, California, Georgia, Idaho, Montana, Pennsylvania, Utah, and Washington, as well as abroad in Australia, New Zealand, Chile, Canada, Sweden, Denmark, Finland, and Norway [4–16]. Some communities have had success with woodstove change-out programs aimed at reducing $PM_{2.5}$. The Wood Heater Replacement Program in Launceston, Australia, reduced particulate matter by nearly 30% over a ten-year period by providing public funds to homeowners to switch their primary heat source from wood burning to heat pumps powered by renewably-generated electricity [17]. Several programs aimed at reducing $PM_{2.5}$ emissions and ambient concentrations in the FNSB have been implemented in the past few years, including a wood stove change-out program [18]. These initiatives do not eliminate wood usage, but they aim to reduce the emissions from wood burning.

This study provides the first estimate of *WTP* for electric thermal storage as a specific space heating option. Electric thermal storage heaters (ETSH) combine thermal storage and electric space heating and could be used to displace firewood for home heating. ETSH use electric resistance coils to transfer heat to ceramic bricks housed in an insulated cabinet. The hot bricks store the heat for up to 24 h. To use the stored heat, the operator turns on the unit's fan, which blows air over the hot bricks. The heated air is then discharged into the living space. ETSH have been used in the United Kingdom since the 1940s and are an economically viable option in locations with low off-peak time-of-use electricity rates [19]. Time-of-use rates incentivize households to shift the timing of their electricity use to off-peak hours when the marginal cost of generating electricity is lower. A special reduced time-of-use rate for ETSH could help reduce fuel poverty by making ETSH an economically viable option for households that currently burn firewood for space heating. Alternatively, ETSH can be charged when there is excess renewable energy being produced. In the Yukon Kuskokwim region of Alaska, the Chaninink Wind Group communities use ETSH installed in homes as a dispatchable load controlled by the electric utility to improve grid stability. Excess wind energy is diverted to residential ETSH systems at a discounted price, yielding cost savings for customers and reducing curtailment for the utility [20]. This study investigates the possibility of implementing a similar program based in the FNSB. Although the FNSB generally has a poor wind resource during the winter months, other regions of the state connected to the FNSB via the regional electricity grid have a strong wind resource in the winter, which makes ETSH a viable option for the region [21].

The Golden Valley Electric Association (GVEA), a member-owned cooperative, is the electric utility serving the FNSB. GVEA is one of six electric utilities that operate on the Railbelt electric grid, which spans from the Kenai Peninsula in Southcentral Alaska to Fairbanks in the Interior [22]. GVEA currently generates over 90% of its electricity from fossil fuels but also has renewables in its energy mix [23]. The utility operates a 25 megawatt (MW) wind farm and a 0.5 MW solar farm and also purchases renewably-generated electricity over the Railbelt electric grid [24]. The utility is interested in adding additional renewables. GVEA plans to retire a 50 MW coal-fired power plant by 2025 and aims to replace it with new wind generation and energy storage and to increase power purchases from Southcentral electric utilities [23]. An ETSH program dispatching excess renewably-generated electricity to residential ETSH units would complement their strategy.

With increases in renewable electricity generation, matching supply and demand for the electrical grid is both crucial and complex. This has led to research to develop strategies to balance electricity demand. Recent evidence suggests that, in the US, 50% of participants were willing to accept USD 9.50 per month over the summer to participate in a smart thermostat program designed to reallocate electricity demand [25]. Respondent's attitudes and preferences around environmental and institutional perspectives impacted participation in the smart thermostat program and may also affect participation in an ETSH program. Additionally, a recent preference analysis for peer-to-peer electricity trading in South Korea, estimates that prosumers (both producers and consumers of electricity) have a *WTP* of approximately USD 55.68 per month for a peer-to-peer electricity trading program [26]. Consistent with these findings, the increased use of ETSH could incentivize electric utilities to integrate more renewable energy.

2. Background

Since 2009, the FNSB has been classified as a nonattainment area for exceeding the $PM_{2.5}$ NAAQS [27]. The nonattainment area is shown in Figure 1. The FNSB experiences frequent episodes of poor air quality in the winter due to low temperatures, valley-like topography, high latitude, and lack of wind, which combine to produce temperature inversions where a layer of dense, cold air is trapped close to the ground by the less-dense, warmer air above it [28]. During a temperature inversion, pollutants emitted into the stagnate inversion layer get trapped close to the ground leading to an increase in $PM_{2.5}$ concentrations. Exposure to elevated $PM_{2.5}$ levels is correlated with negative health outcomes [29]. Wood smoke from heating devices is the largest contributor to $PM_{2.5}$ air pollution in the FNSB [3]. ETSH use could help solve the borough's $PM_{2.5}$ problem by displacing a portion of the firewood currently used for residential space heating.

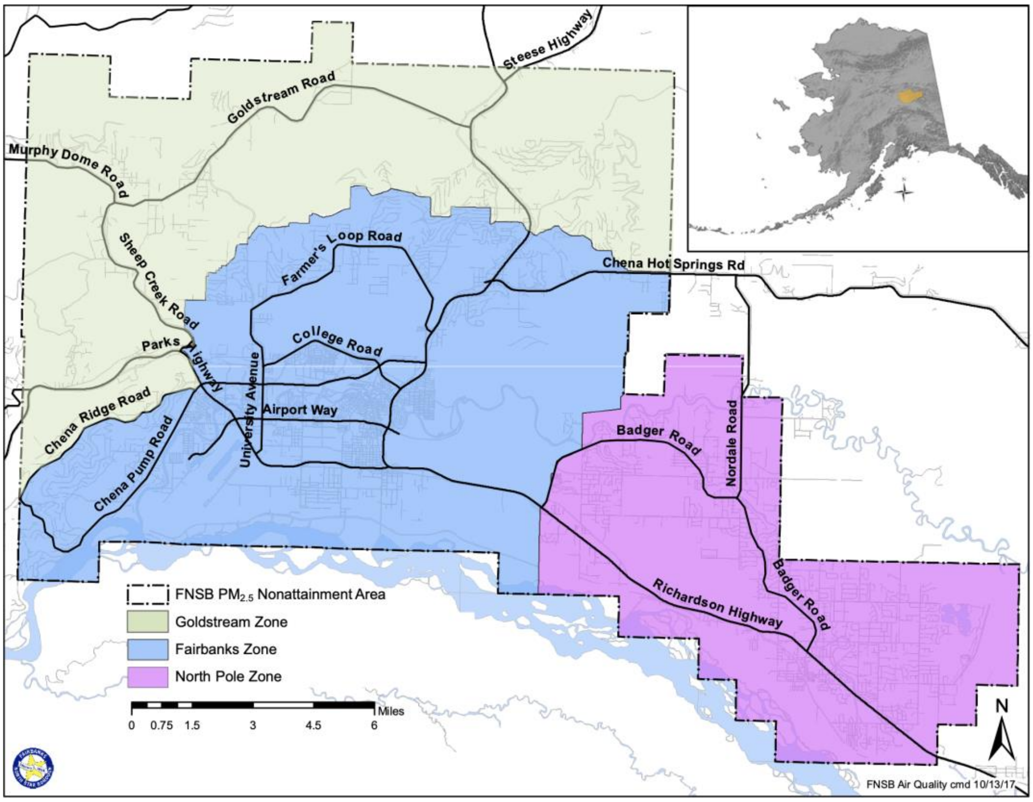

Figure 1. Map of the FNSB with the nonattainment area outlined. A map of Alaska is inset with the FNSB shaded in gold for spatial reference (adapted from FNSB Air Quality burn restriction zones map, 2017).

ETSH use may also reduce fuel poverty within the borough while providing a secondary heating source for residential space heating if charged with discounted electricity. Fuel poverty occurs when a household spends a disproportionately large percentage of its income on residential energy services (e.g., space heating, cooking, electricity, and domestic hot water) [30]. In cold climates, homes require more energy for space heating than comparable homes in more moderate climates. Space heating accounts for 77% of total residential energy costs in the FNSB [31]. Heating fuel oil is the most used fuel, accounting for 73% of wintertime heating use. To reduce heating costs and provide redundancy, many FNSB households use wood to supplement heating. Although wood is relatively less expensive than heating fuel oil, it is the most significant contributor to the area's elevated ambient $PM_{2.5}$ concentrations. Recent estimates indicate that wood burning accounts for over 95% of the $PM_{2.5}$ emissions linked to space heating in the region [2]. This leaves FNSB households in the position of choosing between lower-cost residential space heating and healthy air quality.

Alaska's remoteness, limited transportation infrastructure, and sparse population contribute to high energy prices [32]. Additionally, much of the housing stock in the FNSB was built in the 1970s and 1980s during and immediately following the construction of the Trans-Alaska Pipeline [31]. Many homes were built without regard for the subarctic climate [31]. The combination of high energy prices, an energy-inefficient housing stock, and a cold climate results in high household energy expenditures in the FNSB.

3. Literature Review

Willingness to pay for renewable energy has been investigated in many other locations using contingent valuation techniques. In Myanmar, estimates of household *WTP* for a 10% solar power share, biomass share, or hydropower share are USD 1.92, USD 1.13, and USD 1.17, respectively [33]. In South Korea, consumers are willing to pay 31.9% more to substitute natural gas with renewable methane [34]. In Vermont, solar power has been identified as a preferred public investment option over wind and energy generated through cow manure [35]. Likewise, in Arizona, the average household *WTP* for investment into the research and development of solar energy is estimated to be USD 17 [36].

There are also several studies investigating consumer preferences and *WTP* for home heating in Europe. A recent examination finds that ETSH and wood pellet boilers were the least favored home heating alternatives for the Finnish population; comfort of use is identified as a highly significant factor affecting heating system decisions [37]. Comfort level is also identified as a key decision-making factor for heating and cooling systems in the Spanish residential sector followed by economic criteria such as savings and initial investment [38]. Recent estimates of *WTP* for a residential hybrid system providing heating, cooling, and domestic hot water in Spain, Portugal, and Greece find that the majority of respondents in all three countries were willing to pay EUR 6000 for installation of the system [39]. When compared with the cost of installation, approximately 5–10% of respondents would be expected to actually install the system. This finding, however, is sensitive to differences between estimated payback period and acceptable payback period as 30–40% of respondents would likely invest in the system given shorter payback periods. In Ireland, a discrete choice experiment examining preferences for renewable home heating systems indicates that upfront cost, bill saving, installation hassle, environmental sustainability, and comfort of use increase the uptake of new systems [40]. In a separate study from Ireland, findings suggest that consumers are willing to pay for heat pumps but their *WTP* does not cover the high upfront costs of the technology [41]. In Germany, a discrete choice experiment used to investigate *WTP* for home heating finds that district heating from renewables is the most preferred home heating option and that households are willing to pay a premium of about EUR 5 per m^2/a over fossil fuel district heating [42].

Willingness to pay and consumer preferences for home heating have also been investigated in South Korea. One study investigated consumer preferences for renewable heat obligation policies using a discrete choice experiment. The results suggest that an increase in heating expenses was the most important attribute to consider in policy creation, followed by maintaining a stable heating supply [43]. When heating expenses increased in the scenario, the adoption rate for renewable heat decreased. Another study used contingent valuation to elicit *WTP* for the introduction of a power-to-heat system and found that the average *WTP* was USD 3.59 per year [44]. Another article investigated the price premium for renewable heat and found that residential consumers were willing to pay 5% more for renewable heat compared to heat produced by fossil fuels [45]. One study investigated the renewable heat incentive program created by the South Korean Government [46]. The program's goal is to increase the proportion of renewable heat from 1% to 20% by 2040. Using contingent valuation, researchers estimated the mean household *WTP* for the renewable heat incentive program is USD 5.35 per year.

Comfort of use and cost of installation have been identified as key decision-making factors in consumer choices for home heating. The ETSH program described in the *WTP* question largely avoids these barriers to adoption—e.g., a simple flip of a switch by the homeowner releases warm air into the room and the cost of installation is covered by the program (participants are only asked to pay the cost of the electricity used to charge the ETSH). These features of the ETSH program provide an opportunity to focus solely on estimating the *WTP* for the renewably-sourced electricity for alternative heating. To date, a review of literature has not identified any studies of a similar nature focused on energy in Alaska.

4. Estimation Method

Estimation of *WTP* was conducted using a probit model using maximum likelihood techniques. In this formulation, the probit model assumes there is an underlying *WTP* function described as:

$$WTP_i = x'_i\beta + \mu_i \quad (1)$$

where x_i is a vector of explanatory variables, β is a vector of estimated coefficients, and μ_I is the random error term (assumed to be independent and normally distributed with a mean of zero and a standard deviation of σ). The *WTP* function is not directly observable, instead, we observe latent *WTP* as represented by an indicator, y_i, which takes a value of 1 when the respondent indicated a "yes" to the payment level and a value of 0 when the responded indicated a "no" to the presented payment level. Define $Payment_i$ as the randomly assigned payment amount presented to respondent *i* in the *WTP* question. The random error is equal to the probability that the respondent's unobserved *WTP* is greater than the payment amount, so the probability of a "yes" vote given the explanatory variables is

$$Pr(y_i = 1 \mid x_i) = Pr(WTP_i > Payment_i) = Pr(x'_i\beta + \mu_i > Payment_i) = Pr(\mu_i > Payment_i - x'_i\beta) = Pr(z_i > [Payment_i - x'_i\beta]/\sigma) \quad (2)$$

z_i is the standard normal random variable. The likelihood function for the standard probit model with *n* observations is:

$$logL = \sum{}^{n}{}_{i=1}(WTP_i log\,[1 - \phi([Payment_i - x'_i\beta]/\sigma)] + (1 - WTP)_i log[\phi([Payment_i - x'_i\beta]/\sigma)] \quad (3)$$

The median *WTP* is the fiftieth percentile of the *WTP* distribution and can be calculated when the random error term is equal to zero. Median *WTP* is given by:

$$M(WTP_i) = \alpha x_i/\beta \quad (4)$$

where α is a parameter, such as income, that provides an upper bound on *WTP*. We estimate median *WTP* following Hanemann (1984) and utilize the Krinsky–Robb (1986) procedure to simulate the 95% confidence interval for the estimates [47,48].

5. Survey Design

We assessed *WTP* using a dichotomous-choice contingent valuation survey following the best-practice recommendations outlined in Johnston et al. [49]. We received informal feedback on the *WTP* question from an interdisciplinary group of energy researchers at the Alaska Center for Energy and Power (ACEP) at the University of Alaska Fairbanks (UAF). Additionally, the *WTP* question was pre-tested with focus groups recruited using an advertisement on ACEP's social media accounts. The *WTP* question was refined after each focus group based on the feedback provided by participants. In total, four focus groups ($n = 2$, $n = 3$, $n = 3$, and $n = 4$; respectively) were conducted between March and April 2022. Focus group participants were offered a USD 45 electronic gift card for their participation. A pilot survey was sent to 100 households within the FNSB in May 2022. The final response rate of the pilot survey was 5%.

Invitations to complete the survey were mailed to a stratified random sample of 5400 households drawn from the FNSB property tax database. The strata were proportioned based on the population size of the borough's census tracts. Households received a contact postcard with information about how to access the online survey. The survey was administered using the Qualtrics platform. A reminder postcard with the same information was sent two weeks later and a final reminder postcard was sent in mid-September 2022. An advertisement for the survey was placed on the local public radio station and ran from August through September 2022. Additionally, a flier advertisement was placed in the local Sunday paper in August 2022. Households that completed the survey were offered a USD 25 electronic gift card. Responses were collected from 29 July to 1 December 2022. The final response rate is 6.59% with 356 completed surveys. The survey included questions about the physical attributes of the respondent's home, household energy use, heating costs, household electricity usage, home heating sources and expenditures, energy cost burden, and respondent demographics. It included a block of Likert-scale questions to determine respondents' participation in environmental behavior such as turning off the lights when leaving the room. The *WTP* question was followed by a certainty scale question following Champ and Bishop [50] and a set of questions used to identify potential protest behavior.

5.1. WTP Question

For the dichotomous-choice question, respondents were first provided with basic facts about home heating in the FNSB. Next, they were provided with information about the function and use of ETSH as a secondary heat source in Western Alaska. This was followed by a list of the pros and cons of ETSH use for home heating. Respondents were then presented with a description of a program similar to those in Western Alaska where the electric utility would pay for the ETSH, a separate electric meter, and installation. In the hypothetical program, participating homeowners would be able to use renewably-sourced heat from the ETSH to displace approximately 100 gallons of heating fuel oil annually and would be asked to remain in the program for five years. After that time, the participants could remain in the program or have the ETSH removed for free. Program participants would be billed monthly to charge the ETSH with electricity and would have to allow the electric utility to control when the ETSH is charged. Respondents were then asked if they would choose to participate in the program.

The survey question was: "Given your limited household budget, would you choose to opt-in if participating in the ETSH program increased your monthly electric bill by \$X for the next five years? (\$X per month $\times$ 12 months = \$Y total per year to displace 100 gallons of heating fuel oil per year)". \$X is the randomly assigned payment amount. There were eight different payment amounts ranging from USD 3.00 to USD 135.00 per month which were determined using the feedback provided through the focus groups and pilot test. Alberini suggests that the optimal survey design has five to eight different payment amounts [51]. The payment amount displaces heating fuel oil because heating fuel oil is the most common offset to wood heating in the FNSB. Heating oil cost equivalents by payment amount are found in Table 1. Contingent valuation can provide an estimate to inform anticipated policy before the details and effects of the policy are known [52]. When designing an ETSH program, using an estimated median *WTP* for electricity derived from the hypothetical program should yield a more effective program.

Table 1. Heating Oil Cost Equivalent for Payments Amounts.

Payment Amount	Heating Oil Equivalent (Price per Gallon)
USD 3.00	USD 0.36
USD 15.00	USD 1.80
USD 30.00	USD 3.60
USD 40.00	USD 4.80
USD 55.00	USD 6.60
USD 70.00	USD 8.40
USD 80.00	USD 9.60
USD 135.00	USD 16.20

Figure 2 shows the votes by payment amount for the 341 respondents who completed the entire survey and answered the *WTP* question. As the payment amount increases, the ratio of “yes” votes to “no” votes generally decreases.

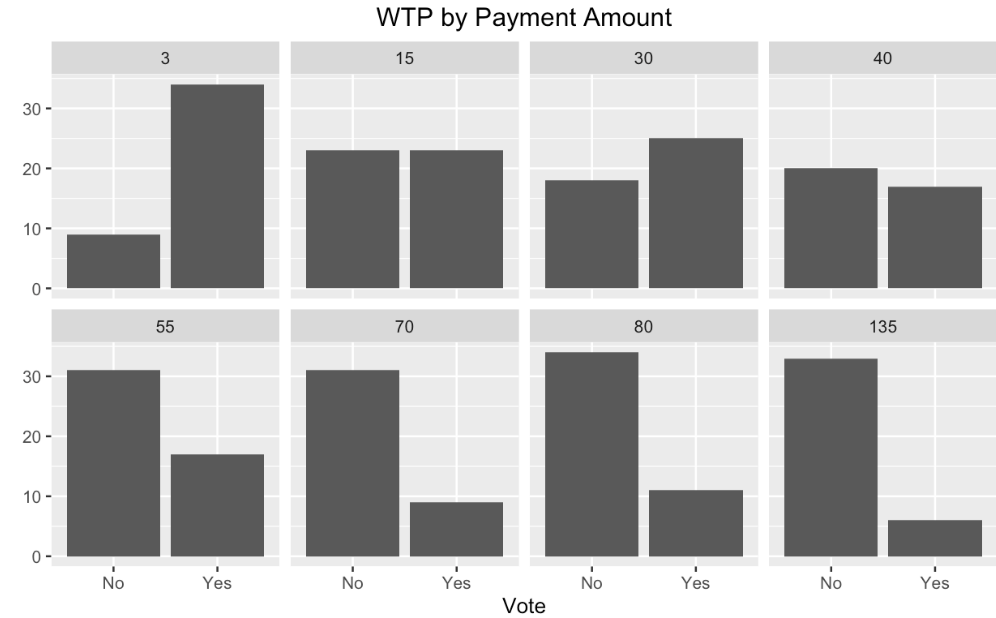

Figure 2. Number of respondents *WTP* by payment amount.

5.2. Respondent Uncertainty

Following the *WTP* question, respondents were asked to rate their level of certainty on a scale of 1 = “very uncertain” and 10 = “very certain”. Certainty questions have been used to explain the difference between values estimated from hypothetical questions and actual behavior [53,54]. The average level of certainty following a “no” was 5.19, and the average level of certainty following a “yes” was 7.29. If a respondent indicated no, they were also asked to provide their primary reason why; these responses are presented in Table 2. Certainty responses were used to address the potential for hypothetical bias in the *WTP* responses. Results are presented with the full data as well as with *WTP* “yes” responses coded as “no” for certainty levels of less than 7.

Table 2. Responses to Survey Question 24: Please indicate your primary reason for voting “No”.

Primary Reason for Voting “No”	Number of Respondents (256)	Percent (100)
I do not want to participate in the ETSH program.	29	11.3
The ETSH program is not that important to me.	7	2.7
I cannot afford to pay extra to heat my home.	49	19.1
It is unfair to expect me to pay for renewable energy.	5	2.0
The ETSH program is not the solution to reducing air pollution.	4	1.6
The electric utility should be paying for renewable energy.	11	4.3
The monthly cost of the ETSH program is too high.	69	27.0
Other	82	32.0

5.3. Respondent Demographics

Table 3 presents the distribution of respondents for sociodemographic variables such as gender, age, education level, and income level. Respondents were also asked about the price per gallon of heating fuel oil on their last fuel bill. The average price per gallon reported was USD 4.47. At a price per gallon of USD 4.47, displacing 100 gallons should save the resident USD 447 annually, or USD 37.25 per month.

Table 3. Distribution of Respondents by Sociodemographic Variables.

Item		Number of Respondents (356)	Percent (100)
Gender	Male	186	52.2
	Female	145	40.7
	Prefer not to say	13	3.7
Age	18–29	17	4.8
	30–39	60	16.9
	40–49	69	19.4
	50–59	60	16.9
	60 and over	135	37.9
Education	High school	25	7.0
	Some college	37	10.4
	Trade/technical/vocational	18	5.0
	Associate degree	28	7.9
	Bachelor's degree	127	35.7
	Master's degree and over	107	30.0
Annual Household Income	USD 45,000 and less	32	8.9
	USD 45,001–65,000	55	15.4
	USD 65,001–85,000	63	17.7
	USD 85,001–105,000	55	15.4
	USD 105,001–150,000	65	18.3
	USD 150,001–200,000	35	9.8
	USD 200,001 and more	28	7.9

6. Results

Several explanatory variables were used in the *WTP* function. Table 4 shows summary statistics and definitions for variables included in the estimated models. Model estimates are based on 315 usable observations where respondents provided answers to all explanatory variables.

Table 4. Definitions and Summary Statistics of Variables.

Variable	Definition	Mean	Std. Dev.
Payment	Randomly assigned payment amount (USD2022) Payments varied from USD 3, 15, 30, 40, 55, 70, 80, 135	USD 54.09	39.50
Comfort	Dummy for question: "Can you maintain a comfortable temperature in your home during the coldest days in winter?" (0 = no; 1 = yes)	0.91	0.29
Age: Over 65	Dummy for the respondent being 65 or older	0.31	0.46
Household Members	Number of members in the household	2.76	2.44
Education [1]	Number assigned to respondent's education level, increasing with increased education (range from 1–11)	7.67	1.89
Household Annual Income [1]	Number assigned to the respondent's household annual income level, increasing with increased income (range from 1–50)	20.27	11.12
Primary Fuel: Heating Fuel Oil	Dummy for respondent using heating fuel oil as their primary fuel source for home heating (0 = no; 1 = yes)	0.83	0.38
Political Identification [1]	Dummy for respondent's political affiliation being slightly conservative, conservative, or extremely conservative (0 = no; 1 = yes)	0.31	0.46
Environmental Organization	Dummy for respondent being a member of a conservation or environmental organization (0 = no; 1 = yes)	0.16	0.37
Environmental Behavior [1]	Average of six Likert-scale questions about environmental practices based on the overarching question: *"How often do you perform the following in your daily life?"*	3.02	0.52

[1] More information is available about these questions in Table A1 (Appendix A).

The *WTP* values are derived using a probit model and represent the monthly *WTP* for the electricity to run the ETSH device. Two separate models are estimated. Model 1 presents estimates without any certainty correction. Model 2 presents results from the certainty-corrected payment response data. The certainty correction follows the approaches suggested by Champ and Bishop [50] and applied by Mueller [36]. In Model 2, "yes" responses with a certainty score of less than seven have been recoded as a "no" response. Confidence intervals are derived using the Krinsky–Robb procedure with 5000 random draws [48]. The coefficients for both models as well as median *WTP* estimates and their 95% confidence intervals are presented in Table 5.

Table 5. Maximum Likelihood Estimation Results.

Variables	**(1)** **Model 1**	**(2)** **Model 2**
Payment	−0.0149 *** (0.00230)	−0.0144 *** (0.00247)
Comfort	−0.521 * (0.281)	−0.660 ** (0.282)
Age: Over 65	−0.284 (0.181)	−0.150 (0.189)
Household Members	−0.00495 (0.0594)	−0.0479 (0.0634)
Education	0.0701 (0.0448)	0.104 ** (0.0480)
Household Annual Income	0.00206 (0.00798)	0.00345 (0.00825)
Primary Fuel: Heating Fuel Oil	0.377 * (0.207)	0.483 ** (0.225)
Political Identification	−0.414 ** (0.179)	−0.403 ** (0.190)
Environmental Organization	0.407 * (0.219)	0.522 ** (0.223)
Environmental Behavior	−0.312 ** (0.156)	−0.182 (0.163)
Intercept	1.205 (0.736)	0.255 (0.774)
Observations	315	315
Log Likelihood	−178.81	−161.98
Pseudo R^2	0.1639	0.1706
Lower bound of 95% confidence interval (USD)	20.94	−11.46
Median *WTP* (USD)	33.98	9.75
Upper bound of 95% confidence interval (USD)	44.01	22.70

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

There are several interesting outcomes reflected by the estimated models. The signs of the estimated coefficient indicate whether the variable in question is associated with an increase or decrease in the likelihood of observing a "yes" response to the payment level presented in the *WTP* question. As program cost increases the likelihood of observing a "yes" response should decline. In this case, the ETSH program cost is inversely related to likelihood of observing a "yes" as reflected by the negative and statistically significant (0.01 levels) coefficient on the payment variable. Median *WTP* estimates are USD 33.98 (Model 1) and USD 9.75 (Model 2). The substantial difference between the median *WTP* estimate from each model reflects the impact of the certainty correction. In treating relatively uncertain "yes" responses (e.g., 5 or 6) as a "no" the *WTP* distribution shifts leftward potentially reducing hypothetical bias in the estimate. In both models, homeowners who indicated they use heating fuel oil as the primary fuel source are more likely to select "yes" at each payment level than those who do not. Homeowners who use heating fuel oil as their primary heating fuel likely have a better understanding of the costs and benefits of the program given the potential cost offset associated with avoiding the use of 100 gallons of heating fuel oil. Likewise, respondents who indicated they were members of an environmental organization are also more likely to select "yes" at higher payment levels. Interestingly, the estimated coefficient on the Comfort variable is negative and statistically significant (0.1 levels). Again, the Comfort variable indicates that the respondent does not have difficulty maintaining a comfortable temperature in their home during the winter months. A respondent's ability to maintain a comfortable temperature in their home depends on a number of factors including their income level as well as housing characteristics such as home size and energy efficiency of the home. Regardless of the reason, it seems intuitive that *WTP* for the ETSH program would be lower for homeowners who do not face challenges maintaining a comfortable temperature in their homes because they do not feel the need to pursue heating alternatives.

Wood burning has been a significant political issue in Fairbanks; in both models, respondents who identify as conservative-leaning are less likely to opt-in to the program. For the certainty corrected model, education was statistically significant (0.05 levels), and the coefficient was positive. Approximately 16% of respondents are involved in an environmental or conservation organization. Membership in such organizations is associated with a higher likelihood of observing a "yes" response to presented payment levels given the positive and statistically significant coefficient in both models. The environmental behavior coefficient was negative in the models, indicating that respondents who regularly engage in energy conservation efforts were less likely to opt-in to the ETSH program at each payment level. The environmental behaviors described in the survey are also cost-saving choices and may be capturing consumer preferences unrelated to the environment.

7. Discussion

The models highlight a number of considerations that may be used to guide the development of an ETSH program for the FNSB. Although an ETSH program in the FNSB has the potential to both improve local air quality and promote the increased integration of renewable energy into the electrical grid, the large proportion of "no" responses at lower payment values, as well as the lower levels of certainty associated with these responses, suggests that survey respondents felt trepidation about the proposed program. This point emphasizes the importance of careful program design and public outreach to educate residents about ETSH technology, the program, and how such technology can be utilized to both improve air quality and promote the further integration of renewably-sourced electricity into the grid.

Another notable conclusion to draw from this analysis is the importance of correctly pricing the electricity to be utilized so that it is financially feasible for homeowners to participate in an ETSH program. As seen in Table 1, cost concerns drove many of the "no" responses to the *WTP* question. An ETSH program is not financially practical for homeowners at the current residential rate charged by the local electrical utility. At the current rate of USD 0.22/kWh, it costs approximately USD 886 per year (USD 74/month) to offset the energy equivalent of 100 gallons of heating fuel oil. This far exceeds the median *WTP* estimate of USD 33.98 per month from Model 1, which is equivalent to a rate of USD 0.10/kWh, and the median *WTP* estimate of USD 9.75 per month from Model 2, which is equivalent to a rate of USD 0.03/kWh. This finding speaks directly to the need for subsidized rates in order to make the program financially viable for homeowners.

The surveys were mailed to a stratified random sample of households in the borough. Our sample demographics indicate that the average survey respondent was slightly more educated, wealthier, and older than the average resident of the borough [55]. We find that there is a small population interested in the program and that educating more residents about the program would likely positively impact interest in the program.

Future research should examine the reasons why respondents selected "no" in order to develop a program that appeals to more residents in the borough. More information about the geospatial distribution of "no" responses can also provide information for the outreach component of an ETSH program. In the political science literature, voting behavior is correlated across space [56]. Given the tendency for people to locate themselves near others with similar views, identifying and understanding more about regions with concerns about a possible ETSH program can contribute to the design of a more successful program. To this end, an attribute-based approach such as a choice experiment can be utilized to understand preferences for different program attributes that can be targeted to increase participation. Regional variability in air quality may also affect willingness to participate. The Hurst Road air quality monitoring site in the City of North Pole has historically had the highest $PM_{2.5}$ concentrations in the FNSB [27]. Residents from North Pole who experience worse air quality in the winter may be more likely to participate due to their winter experiences. Finally, testing the proposed ETSH program values in a real-world setting would provide more information about the accuracy of the *WTP* values, the potential of ETSH to improve air quality while expanding the use of renewable energy, and its ability to decrease fuel poverty in the FNSB.

This paper contributes to the existing body of research on *WTP* for renewable energy and home heating in several ways. We provide a *WTP* estimate for renewably-sourced electricity for alternative heating in Alaska that can help to inform future research on renewable energy use in the region. We find that the average household in the FNSB is willing to pay approximately USD 33.98 a month to participate in the ETSH program and displace approximately 100 gallons of heating fuel oil each year. Implementation of a special ETSH electricity rate based on the *WTP* estimate may lead to broader adoption of ETSH for space heating, which could improve air quality, reduce fuel poverty, and reduce the carbon footprint of residential space heating. We also find large deviations in *WTP* estimates when using uncertainty coding. Understanding possible overestimates of *WTP* has relevant policy implications for the program and for other similar renewable energy initiatives. This research has public health and policy implications for any community interested in reducing $PM_{2.5}$ air pollution resulting from wood burning for space heating.

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Appendix A

Possible answers to survey questions as shown to the respondent for some explanatory variables used in the model are listed below in Table A1.

Table A1. Survey Question Details for Some Explanatory Variables.

Variable	Answer Options
Education	(1) No schooling completed; (2) Elementary school to 8th grade; (3) Some high school, no diploma; (4) High school graduate, diploma; (5) Some college credit; (6) Trade/technical/vocational training; (7) Associate degree; (8) Bachelor's degree; (9) Master's degree; (10) Professional degree; (11) Doctorate degree
Household Annual Income	(1) Less than USD 10,000; (2) 10,001–15,000; (3) 15,001–20,000; (4) 20,001–25,000; (5) 25,001–30,000; (6) 30,001–35,000; (7) 35,001–40,000; (8) 40,001–45,000; (9) 45,001–50,000; (10) 50,001–55,000; (11) 55,001–60,000; (12) 60,001–65,000; (13) 65,001–70,000; (14) 70,001–75,000; (15) 75,001–80,000; (16) 80,001–85,000; (17) 85,001–90,000; (18) 90,001–95,000; (19) 95,001–100,000; (20) 100,001–105,000; (21) 105,001–110,000; (22) 110,001–115,000; (23) 115,001–120,000; (24) 120,001–125,000; (25) 125,001–130,000; (26) 130,001–135,000; (27) 135,001–140,000; (28) 140,001–145,000; (29) 145,001–150,000; (30) 150,001–155,000; (31) 155,001–160,000; (32) 160,001–165,000; (33) 165,001–170,000; (34) 170,001–175,000; (35) 175,001–180,000; (36) 180,001–185,000; (37) 185,001–190,000; (38) 190,001–195,000; (39) 195,001–200,000; (40) 200,001–205,000; (41) 205,001–210,000; (42) 210,001–215,000; (43) 215,001–220,000; (44) 220,001–225,000; (45) 225,001–230,000; (46) 230,001–235,000; (47) 235,001–240,000; (48) 240,001–245,000; (49) 245,001–250,000; (50) Above 250,000
Political Affiliation	(0) Extremely liberal, liberal, slightly liberal, moderate; (1) Slightly conservative, conservative, extremely conservative
Environmental Behavior (Questions)	(Q1) Turn off the lights when leaving a room, (Q2) cut down on heating to limit energy consumption, (Q3) only run full loads when using washing machines or dishwashers, (Q4) wash clothes using cold water rather than hot water, (Q5) switch off standby mode of appliances/electronic devices, (Q6) air dry laundry rather than using a clothes dryer.

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