SURVEYING THE EDGES: HOMEOWNERS' PERSPECTIVES ON RESIDENTIAL ENERGY EFFICIENCY AND RENEWABLE ENERGY IMPROVEMENTS IN OHIO

Qian Chen,[1] Eric Romich,[2] Andrew Cruse,[3] Andrea Gorzitze,[4] Hongsen Shi,[5] and Lingying Zhao[6]

ABSTRACT

While energy costs, home size, and home age in Ohio fall into an average range for the United States as a whole, homes in Ohio are well below the average price, making homeowners particularly cost sensitive when considering investments on energy savings features. In addition, Ohio is the seventh largest emitter of carbon dioxide in the nation, suggesting that reducing energy use can have an outsized environmental impact. These not only pose a tremendous challenge but also an urgency to home energy conservation in Ohio. This study examines residential consumers' understanding of and attitudes toward various energy efficiency measures (EEMs) and renewable energy systems (RESs) through a questionnaire survey with a sample size of 519 Ohio homeowners. The survey results not only revealed Ohio homeowners' knowledge gap but also identified barriers to implementing these improvements. The findings can assist in developing high-quality, well-tailored education and outreach programs to help homeowners make informed energy saving decisions. They can also help guide local policy decisions and the development of effective initiatives or incentive programs. This study suggests that it is imperative to fill the knowledge gap among homeowners, educate them about reasonable expectations on return on investment, and increase their awareness of non-energy benefits that could be achieved through home energy efficiency and renewable energy improvements.

KEYWORDS

home energy, homeowner, questionnaire survey, energy efficiency, renewable energy, Ohio

1. Associate Professor (corresponding author), Department of Food, Agricultural & Biological Engineering (FABE), The Ohio State Univ., chen.1399@osu.edu.
2. Associate Professor, Department of Extension, The Ohio State Univ., romich.2@osu.edu.
3. Assistant Professor, the Knowlton School of Architecture, The Ohio State Univ., cruse.40@osu.edu.
4. Grants Development Specialist, FABE, The Ohio State Univ., gorzitze.1@osu.edu.
5. Ph.D. Candidate (Graduate Research Assistant), FABE, The Ohio State Univ., shi.546@osu.edu.
6. Professor, FABE, The Ohio State Univ., zhao.119@osu.edu.

INTRODUCTION

In the United States (U.S.), residential homes consumed approximately 22% of the total energy and contributed 21% of total carbon dioxide emissions (EIA, 2012). Reducing residential energy use will have a significant impact on the environment and national energy security. Nationwide, Ohio was ranked No. 22 in total energy consumption per capita. However, its per capita residential energy consumption ranking was disproportionately high, i.e., 11th in the nation. Of the net energy used by Ohio's residential sector, approximately 55% and 36% come from natural gas and electricity, respectively, followed by 5% from petroleum and 4% from renewables including biomass, geothermal, and solar (EIA, 2018a). Further, in the state, 58% of electricity is generated by coal-fired power plants, making Ohio the seventh largest emitter of carbon dioxide nationally. While electricity produced by natural gas and nuclear energy accounts for 24% and 15%, respectively, only 3% comes from renewables (i.e., wind, hydroelectric, and solar) (EIA, 2018b). These facts suggest that reducing residential energy consumption in Ohio is not only needed but can have an outsized impact on carbon emissions. Also, the use of renewable energy in Ohio is very limited, leaving huge room for improvement.

Ohio homes are approximately the same size as but slightly older than the national average. The average home price in Ohio ranks 46th out of 51 states. In 2016, the average home price in Ohio was $117,300, well below the average $317,200 price in the mid-west and the $360,900 national average (Statistic Brain Research Institute, 2017; U.S. Census Bureau, 2017). Also, compared with some other metropolitan areas (e.g., San Francisco Bay Area) with double-digit annual percentage increases in house price, major metro areas in Ohio such as Columbus only experienced a moderate annual increase (e.g., around 6%) in the past several years (Esswein, 2014; U.S. HUD, 2016). The relatively low housing price and slow annual growth would likely make Ohio homeowners price sensitive when it comes to spending on home energy efficiency measures (EEMs) and renewable energy systems (RESs) due to the limited resale values.

Additionally, a lack of transparency in the retrofit market regarding measurable outcomes makes it difficult to convince owners of the positive payback and benefits associated with retrofits (PGL, 2011). Especially, the non-energy benefits (i.e., health and comfort, lower maintenance costs, increased asset values, creation of new jobs, and environmental benefits) from energy efficiency investments have not been made widely known (Mulholland et al., 2011; Norton et al., 2016). In addition, many single-family homeowners are uncertain about how best to tackle energy efficiency improvements and obtain financial resources to implement such improvements, which usually cost more with a retrofit than in new construction (Sutherland, 1991). As pointed out by PGL (2011), there are an insufficient number of retrofit programs that target the older sector of the housing market. Given the low home prices and high carbon emissions, Ohio makes a valuable case study for how to improve residential energy efficiency.

Although many players (e.g., government, marketing and finance, homebuilders, manufacturers/suppliers, etc.) are involved in developing new energy efficient homes or retrofitting old homes, homeowners are apparently one of the most important stakeholders that directly make purchase decisions (Chen et al., 2011). Understanding and addressing the real and perceived barriers to homeowner energy decisions is a necessary step to improve home energy conservation, which would reduce both utility costs and carbon emissions. An early focus-group study among recent and potential home buyers investigated their perceptions, attitudes and acceptance of energy efficient homes (Northwest Energy Efficiency Alliance, 2009). The result showed that energy-efficiency and environmental considerations were seldom at the forefront of homeowners' minds when purchasing a new home. When reminded of energy efficiency, participants were more likely to choose technologies they were familiar with, such as insulation, windows, and heating and cooling systems. Another home energy efficiency study surveyed a utility's hard-to-reach customers and found that they often lacked information and knowledge about energy efficiency opportunities. An increase in customer awareness and adoption of the recommended EEMs (mostly "no cost" and "low cost" options) was recorded after the completion of the survey (Southern California Edison, 2006).

By taking a different approach, Chen et al. (2011) conducted a series of workshops among representatives from various players in the homebuilding industry including architects, manufacturers/suppliers, homebuilders, utilities, real estate agents, lenders, government agencies, etc. to learn about their perceived barriers to energy efficient homes. A consensus among participants was that U.S. homeowners often lack the knowledge (i.e., building science, benefits of EEMs, payback calculations, etc.) to make informed decisions. Furthermore, from green building experts' perspectives, Darko et al. (2017) identified the principal barriers to adopting green building technologies in the U.S. commercial and residential sectors to be resistance to change, a lack of knowledge, and costs associated with implementing such measures.

National surveys have been conducted to garner additional information from a larger number of consumers or homeowners. In an online survey of public perceptions of energy use and savings, most of the 505 participating households believed that curtailment such as turning off lights and turning down thermostats is more effective in reducing energy use than making energy efficiency improvements in their homes, e.g., improving lighting and using efficient home appliances. This suggests that well-designed efforts to improve public understanding of energy use and savings could result in significant savings (Attari et al., 2010). Another survey of 2,500 consumers on their thoughts of energy efficiency found that they usually do not fully understand the energy-efficiency potential of the appliances they purchased and often underuse rebates and incentives (Frankel et al., 2013). A poll of 1,418 homeowners on their choices and attitudes toward clean-energy technologies, including solar photovoltaic (PV) systems, LED light bulbs, electric cars, green home construction, etc., was conducted in 2014 (Clean Edge, Inc., 2014). The survey results revealed that while environmental considerations among homeowners are increasing, economics still drive most purchasing decisions and homeowners perceive price barriers to clean-energy technologies.

Besides the main barriers identified above, there are other factors (i.e., policies, financial incentives, personal and contextual influences such as attitudes, behaviors, housing characteristics and demographics, etc.) that affect homeowners' energy decisions (Wilson et al., 2015). As pointed out by Frankel et al. (2013), despite increasing homeowners' awareness of energy efficiency and progress of home energy conservation, an improved understanding of consumers' behavior and better ways to engage them are often required to reach the next level in energy savings. Also, it is important to understand market segmentation in order to more clearly target information about EEMs to the population for which it would be most effective.

The aim of this paper is to present and analyze Ohio homeowners' perspectives on residential energy efficiency and renewable energy improvements based on the empirical data collected through a questionnaire survey of 519 homeowners. The presented study had four specific objectives: 1) To understand Ohio homeowners' current energy use, energy cost, and existing energy efficiency and renewable energy applications; 2) to assess homeowners' knowledge, attitudes, and opinions related to energy-efficiency technologies, opportunities, and challenges; 3) to gauge their level of interest in adopting EEMs and RESs in homes or at the community level; and 4) to offer insights for developing and delivering relevant education and outreach programs that can meet homeowners' needs and help address perceived barriers. This effort was a key component of a university-funded education and outreach project that aims to better educate Ohio homeowners about healthy, energy efficient, and sustainable housing technologies. The findings of this study can also help guide local policy decisions (e.g., policies on community solar) and the development of initiatives or incentive programs.

RESEARCH METHODOLOGY

This research adopted a questionnaire survey approach to generating empirical data regarding Ohioan's home energy use, cost, knowledge, attitudes, perceptions, and interest and adoption levels of energy efficiency and renewable energy technologies. This approach allows large populations to be assessed in a cost-effective way with relative ease (Jones et al., 2013).

Questionnaire design and data collection

Questionnaire construction began in December 2015. The research team met several times to discuss the objectives of this survey, formulate the questions and response options, and determine the order of questions within the questionnaire. The 29 questions developed in this process fall into three parts:

- Part I: aims to collect the characteristics of homes owned by survey respondents, their average monthly energy costs, and general factors that would affect their purchasing decisions.
- Part II: intends to ascertain the survey respondents' knowledge in common residential EEMs, the implementation rates, their attitudes toward investing on EEMs, and potential barriers they face.
- Part III: uses questions similar to Part II to collect data on home RESs.

Then, the 29-item questionnaire was presented in front of the project Stakeholder Advisory Group for comments and suggestions. The Advisory Group was formed to guide the education and outreach project by helping shape the survey instrument, propose program topics, and assess the project outputs. It consisted of green home owners and representatives from utility companies/cooperatives, non-profit organizations that are devoted to promoting energy efficiency and renewable energy in Central Ohio, state government offices, and local schools/school districts. Finally, the final research protocol, the questionnaire, and informed consent correspondence were submitted to the university's Office of Responsible Research Practices in January 2016 for review. The project received approval on March 2, 2016.

A modified version of the Dillman Tailored Design Method was used to guide the internet and email data collection (Dillman et al., 2014). The target population for this study was Ohio homeowners and the sample frame was purchased from a private vendor, Qualtrics LLC., who was responsible for distributing the survey and managing the data on the Qualtrics server. The sample frame for the survey included 20,000 homeowners age 18+ living in Ohio. A Qualtrics panel project manager randomly selected respondents for the survey from the sampling frame. Each sample from the panel base was proportioned to the general population and then randomized before the survey was deployed. The Qualtrics project manager sent an email invitation to potential respondents inviting them to participate in the survey, informing them that the survey is for research purposes only; how long the survey is expected to take; and they may unsubscribe at any time.

Data was collected during summer 2016. The survey yielded a total of 944 panel responses for the study. To ensure quality data, Qualtrics verified the respondents' computer's IP address, incorporated attention screeners, and time quotas on the surveys. Specifically, respondents who finished the survey too quickly (i.e., using less than one third of the average survey completion time calculated based on the pilot study), did not answer the attention screener question correctly, or were not resident homeowners of Ohio were screened out and removed from the study. Table 1 lists the number of total surveys received and the number of surveys removed from the study due to attention filters, non-Ohio residence, renters, and those refusing to participate. The total sample size included 519 completed surveys.

Data analysis

Tracking and coding of surveys was conducted by the Qualtrics project manager. Personal identifiers were permanently removed from the dataset so respondents could not be identified. In addition, all data was reported in aggregate. The panel sample and response data were both housed and managed on Qualtrics server systems. Descriptive statistics were used to provide simple observations and summary about the energy use, cost, attitudes, and opinions of Ohio homeowners regarding energy efficiency and renewable energy development. Basic statistical analysis including frequencies, percentages, means, modes, medians, ranges, standard deviations, and variance were utilized to analyze and summarize the data using a combination of Excel and Qualtrics Data Reporting software. Cross-tabulation and the Pearson's Chi-Square Test were adopted to assist researchers in understanding and identifying the relationship between different variables. Cross-tabulation was also used to prepare data for subgroup comparison.

In this study, subgroup comparison was made between urban and rural homeowners as well as homes with different values. This research tested the normality of data in each subgroup for individual questions using the Shapiro–Wilk test. It was found that the data does not fit the normal distribution, which violates the assumption of commonly used parametric methods such as Analysis of Variance (ANOVA), the Inference Concerning Two Means with a t-distribution test (ICTM-t), and the Two-proportion Z-test. Therefore, the non-parametric Kruskal-Wallis (K-W) test was adopted to determine if statistically significant differences in homeowners'

TABLE 1. Ohio Homeowner Survey Responses.

Items	Number of surveys
Total Qualtrics survey responses	944
Removed due to attention filters	260
Not an Ohio resident	44
Renters (non-homeowners)	57
Declined to participate	64
Completed surveys included in the study	519

perceptions exist between independent subgroups. Then, the joint ranking approach was used to decide which subgroup has a higher value by comparing the average ranks for two groups.

RESULTS AND DISCUSSIONS

Characteristics of survey participants and housing characteristics

The 519 survey respondents in the study were geographically diverse, representing 72 of Ohio's 88 counties (Figure 1). Combined, 65% of the respondents identified their home as located in a city or suburb, while 35% of the respondents owned homes in small towns, countryside, or on farms (Figure 2).

Most respondents (89%) owned a detached home, while 4% owned condominiums, 2% owned a semidetached home or apartment, and 4% had some other arrangement. Combined, 67% of the homes had an estimated value of less than $150,000 (Figure 3). The average home size was 1,760 square feet, supporting an average of 2.86 occupants.

When asked to estimate what year their home was built, around 85% of the respondents indicated that their homes were built before the year 2000 (Figure 4). Roughly, a third of the respondents indicated they have lived in their homes for more than 15 years (Figure 5), which would allow home energy improvements with longer payback periods.

When the respondents were asked if they have any plans to purchase another home in the future, only 27% of them indicated "yes," while 28% answered "unsure" and 45% said "no" (Figure 6). The 142 respondents that indicated they had plans to purchase another house in the future were asked to rank various factors that influence their purchasing decisions with "0" being no influence and "5" being the highest influence. As shown in Figure 7, factors that may influence homeowners' purchasing decisions fall into three tiers. Those among the highest influence include location (scoring 4.62 out of 5), price (4.50), and house size (4.35). Housing style, utility cost, and energy efficiency were deemed important as well by receiving a score of 3.75, 3.58, and 3.51, respectively, but ranked slightly lower than the first-tier influencing

FIGURE 1. Survey respondents by zip code.

FIGURE 2. Survey respondents by location type.

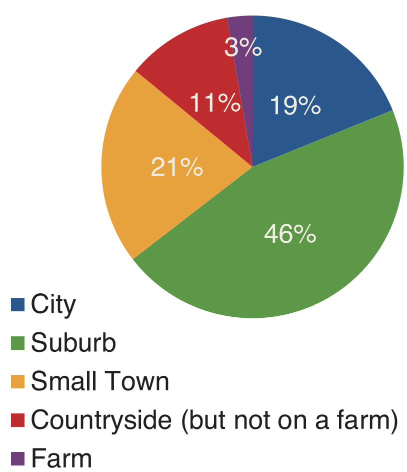
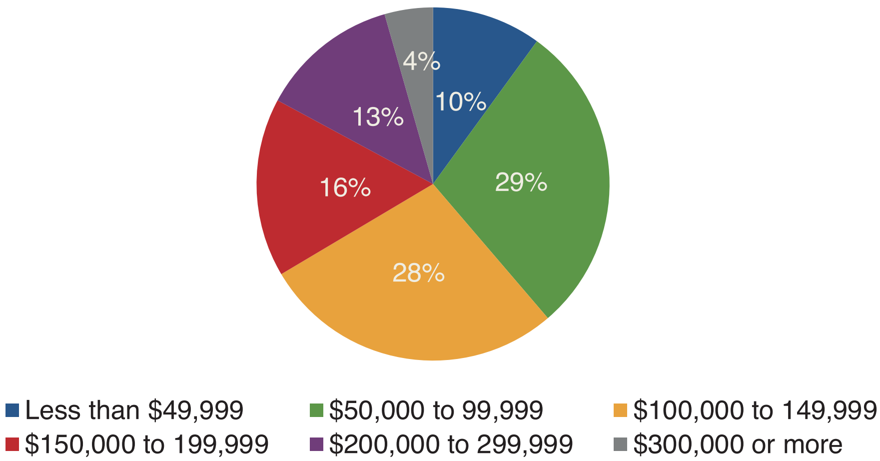


FIGURE 3. Estimated market value for homes included in the survey.



factors. Low importance (1.54) was given to the "other" response option with the most commonly listed answers as lot size and school district.

Energy efficiency

Respondents were asked to estimate their typical summer and winter utility bills for various energy sources. The results are displayed in Table 2. Among 518 homeowners who reported their average monthly electric consumption, only 460 reported data for at least one type of heating fuels, i.e., natural gas, propane, or fuel oil. The difference is mainly attributable to the number of homes that may only use electricity as the energy source (i.e., all-electric homes). The data confirmed that homes using propane and fuel oil incurred much higher winter energy bills. Being energy efficient would help lower these households' energy burden more significantly. Additionally, it was found that natural gas usage was reported by approximately 91%, 81%, and 72% of homeowners from cities, suburbs, and small towns, respectively. In contrast only 29% and 7% of homeowners from countryside and farms, respectively, reported usage

FIGURE 4. The construction year of their homes.

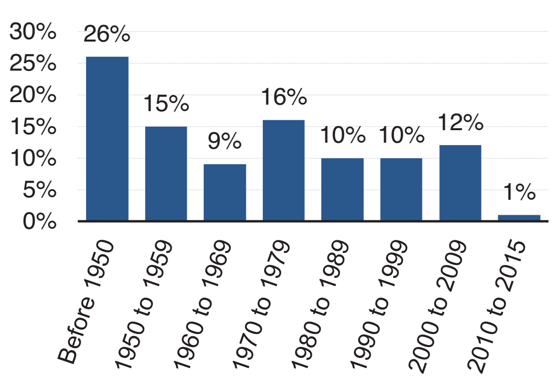


FIGURE 5. Duration staying in their homes.

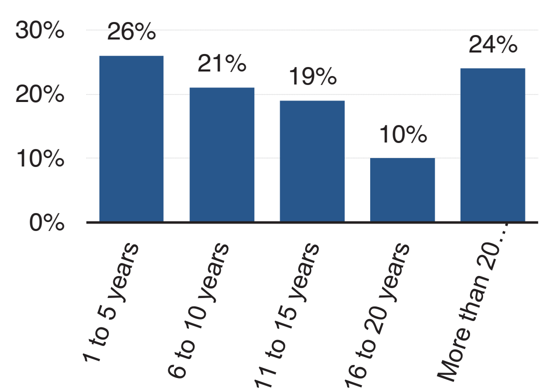


FIGURE 6. Plans to purchase another home.

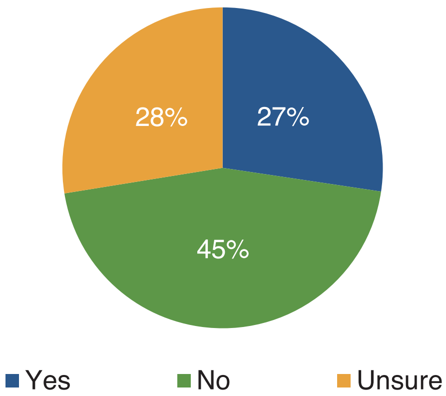
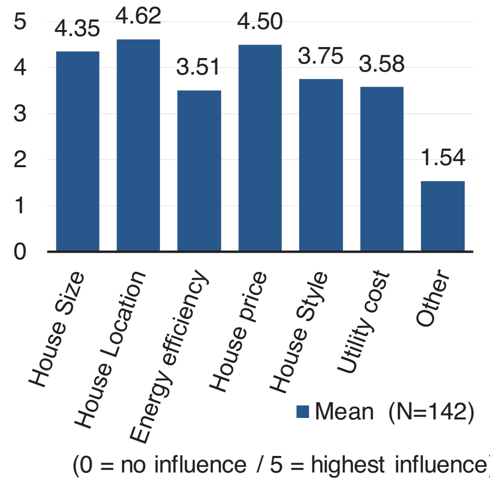


FIGURE 7. Factors influencing purchase decision.



of natural gas, showing that these rural locations had much lower accessibility to this energy source. Accordingly, around 34% of homeowners from the countryside and farms had to rely on propane and around 13% of them used fuel oil for heating and other purposes (e.g., domestic hot water). Thus, it can be inferred that energy efficiency improvements would likely offer greater financial benefits to homeowners at these rural locations.

When asked if in the past year, they had taken any steps to reduce their energy bill, most respondents (65%) indicated "yes" while about one third (32%) said "no." Three percent of the homeowners indicated they were "unsure" (Figure 8). Furthermore, approximately 30% of the respondents indicated they were "very likely" to take steps to reduce their household energy bill this year, while 39% indicated they were "very likely" to do so within the next five years (Figure 9). Only about 5% and 7% of homeowners surveyed in this study indicated that they were unlikely to take any steps to reduce their energy bills within this year and the next five years, respectively.

To assess the current level of awareness and understanding of various energy efficiency technologies, respondents were asked to rank their level of knowledge for different energy efficiency technologies. The results show that respondents were most knowledgeable about energy efficient lighting (with an average score of 3.34), and least knowledgeable about passive house

TABLE 2. Estimated typical summer and winter energy bills.

Energy source	Sample size	Average summer bill (Aug.)	Average winter bill (Jan.)
Electric	518	$140.77	$150.56
Natural gas	367	$60.90	$101.03
Propane	54	$129.76	$248.98
Fuel oil	39	$113.77	$235.85

FIGURE 8. Steps taken to reduce energy costs in the past year.

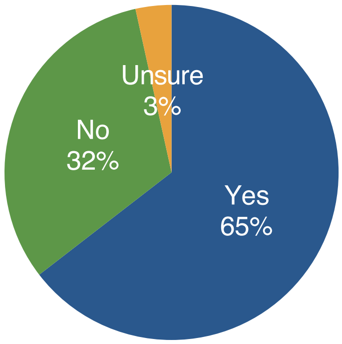
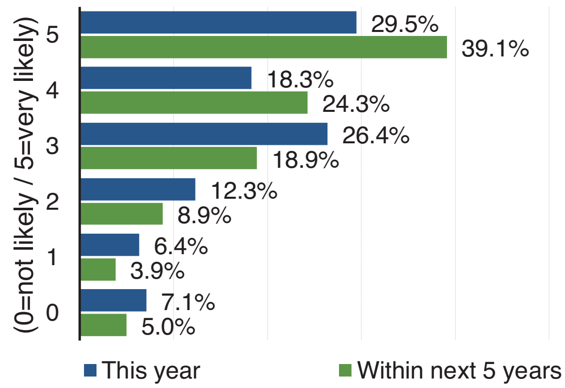


FIGURE 9. How likely to take steps to reduce energy costs in the future.



design (with an average score of 1.11) (Figure 10). Overall, the respondents only had a moderate level of knowledge about most EEMs listed.

Respondents were asked how much potential barriers keep them from upgrading the energy efficiency of their home with "0" being not a barrier and "5" being a very significant barrier. As shown in Figure 11, the most significant potential barrier they identified was the cost of energy efficiency improvements (with an average score of 3.78), followed by other projects with a higher priority (2.94) and uncertainty about the long term energy cost savings (2.74). Lack of knowledge about applicable EEMs and no time to research technologies ranked in the middle.

"My home is already energy efficient" received the lowest average score of 1.75, showing that this was not a significant barrier. However, it was noticed that, while 129 or 25% of respondents gave "my home is already energy efficient" a 0 rating, the remaining 390 or 75% somehow chose scores ranging from 1–5, suggesting that they more or less considered it a barrier.

To understand the rationale behind respondents' perception that their homes are already energy efficient, the researchers compared the answers given to this question with results from two other most related questions: typical summer and winter utility bills and EEMs already installed in homes (reported later in this paper). While no obvious relationship was found between respondents' rating for this question and the amounts of their average energy bills, it seems that respondents choosing a score between 1–5 for this question did have higher

FIGURE 10. Respondents' level of knowledge on the listed energy efficiency technologies.

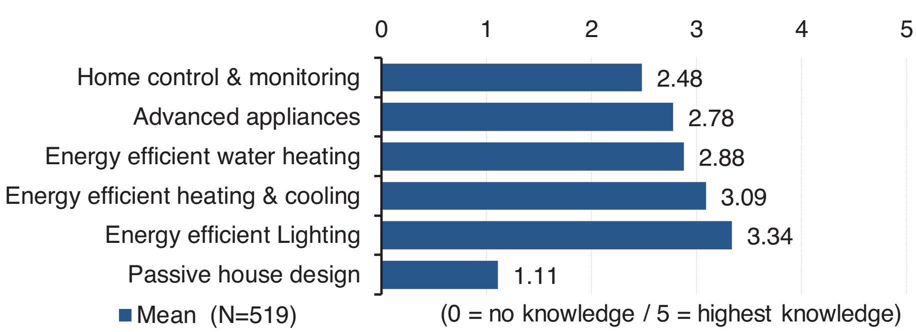
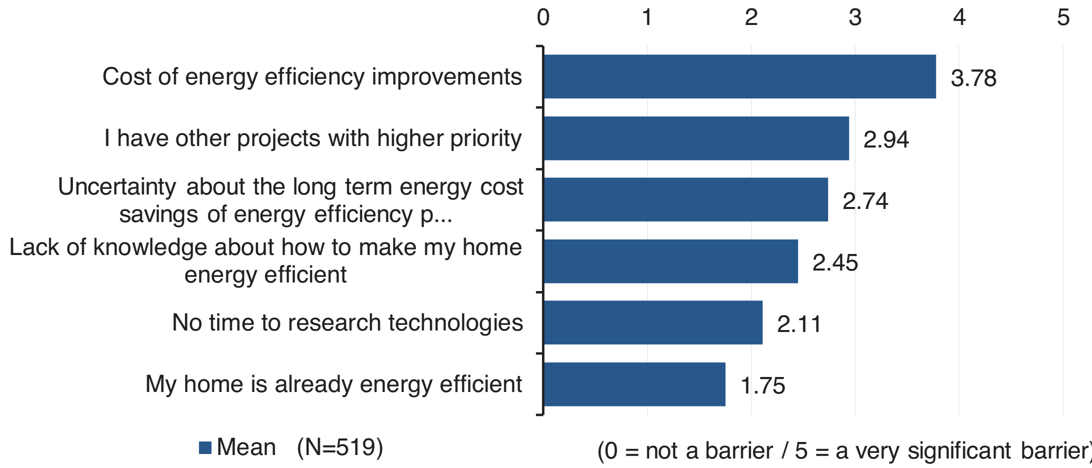


FIGURE 11. Potential barriers to energy efficiency upgrades.



implementation rates for most of the listed EEMs than those giving a 0 rating, e.g., 44% implementation rate versus 17% for efficient heating and cooling systems, 38% versus 19% for additional insulation materials, and 39% versus 21% for high performance windows. On average, they also had more EEMs installed in their homes than respondents giving a 0 rating (i.e., 3.02 versus 1.96 EEMs per home). The Pearson's Chi-Square Test confirmed a strong correlation ($p < 0.001$) between the EEM implementation rates and homeowners' positive perception of home energy efficiency. To avoid any potential negative impact from homeowners' misperception of home energy efficiency, this study suggests providing a relatively simple home energy rating system for homeowners to adopt, which will help them reach more accurate perceptions of whether their homes are already energy efficient. Some simple and straightforward home energy ratings such as the Home Heating Index (HHI), Home Energy Index (HEI), and Home Electrical Energy Index (HEEI) could be potential candidates (Zimmerman, 2009).

When asked what the target payback period was they would consider investing in an energy efficiency project, approximately 17% of respondents selected less than 1 year, 48% selected 2 to 5 years, while 22% were not interested regardless of the payback (Figure 12). Only about 13% of respondents allowed longer payback periods (6–15 years). This would present great challenges in promoting EEMs that require medium to long-term payback periods among homeowners. When asked to consider potential benefits that influence homeowners to upgrade the energy

FIGURE 12. The target payback period for energy efficiency projects.

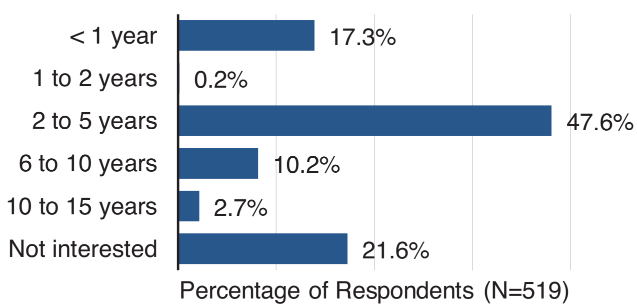
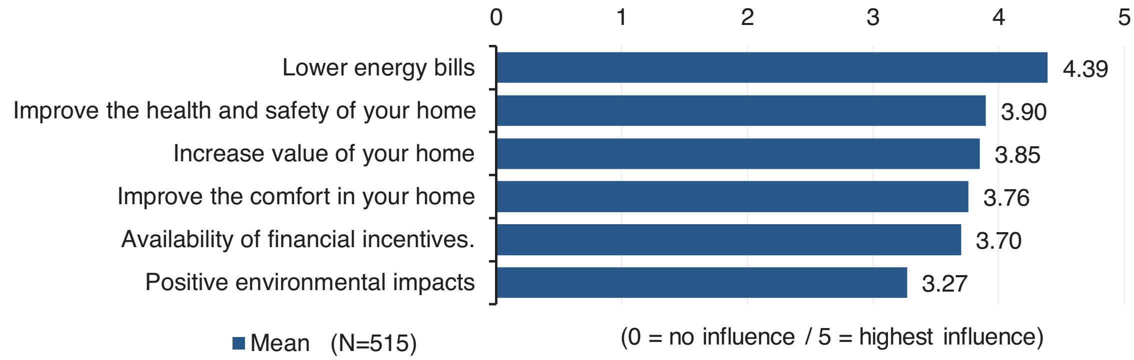


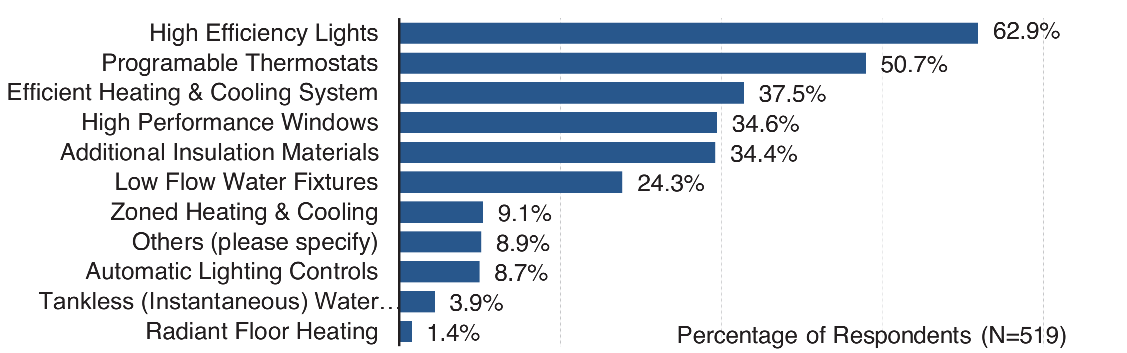
FIGURE 13. Potential benefits of home energy efficiency upgrades.



efficiency of their home with "0" being no influence and "5" being the highest influence, respondents showed a good level of awareness of various listed benefits. As they were most motivated by lower energy bills (with an average score of 4.39), improving the health and safety of their home and increasing value of their home were also deemed high by them (with average scores of 3.90 and 3.85, respectively) (Figure 13).

Respondents were asked which EEMs were already installed in their homes. High efficiency lights were the most common EEM, with 63% of respondents having them installed already. Programmable thermostats were installed in 51% of homes. High performance windows, energy efficient heating and cooling systems, and additional insulating materials were present in a little over one third of all homes surveyed. Almost a quarter of respondents had low flow water fixtures in their homes. The least common EEMs were radiant floor heating, tankless water heater, zoned heating and cooling, and automatic lighting controls, which were reported by fewer than 10% of the respondents. In addition, 9% of respondents reported having additional features in their homes that were not mentioned in the survey (Figure 14). Some consistencies exist between this finding and the result from the national survey, where high efficient lighting (LED light bulbs), smart thermostat, and double or triple pane windows were also ranked among top purchases the homeowners made (Clean Edge, Inc., 2014). This is likely due to the low costs or high familiarity associated with these options. It can be seen from Figure 14, there is still room

FIGURE 14. Energy efficiency features already installed.



for improving the implementation of many EEMs, especially those with lower prices, shorter payback periods, or covered by incentive programs.

Results from the energy efficiency survey suggest that consumers are motivated by economic considerations. For example, the most significant potential barrier of energy efficiency upgrades was the cost of energy efficiency improvements, while the uncertainty of the long-term energy cost savings was the third highest barrier. Similarly, the highest ranked potential benefit was related to lowering energy bills. When assessing energy efficiency features already installed in homes, cost once again appears to drive behavioral change. For example, high efficiency lighting, which is commonly viewed as a low cost rapid return investment, was the most common energy efficiency technology already installed in homes. Finally, 65% of homeowners in this study indicated they want a target payback period less than five years to consider investing in an energy efficiency project.

One immediate measure that could help ease these economic concerns of homeowners is to utilize various incentive programs provided by governments, utilities, and third parties, which subsidize the cost of home energy efficiency improvements and renewable energy applications. A website from Ohio State University Extension (2018) tracks renewable energy and energy efficiency incentive programs available to Ohio residents. These include federal loans/grants, tax credits/exemptions, rebates from governments or utilities, etc. Particularly, various energy efficiency incentives range from as low as $10 to over one thousand dollars covering technologies and products related to lighting, thermostats, power strips, boilers, furnaces, heat pumps, windows/doors, insulation, etc. As revealed by Frankel et al. (2013), homeowners often underuse rebates and incentives when purchasing energy efficient appliances. A survey of residents in Southeast U.S. states showed that residents who are aware of utility energy efficiency programs are more likely to participate (Craig, 2016). A similar finding was generated by Southern California Edison (2006). Therefore, it is reasonable to assume that increasing the awareness of these incentive programs among Ohio homeowners would have a similar effect.

In terms of lack of knowledge, past research found that it is often not easy for homeowners to obtain accurate and complete information about the energy efficiency investments they are interested in as well as the costs and payoffs of potential alternatives. Their search and information costs may be expensive with a single, infrequent purchase under most circumstances (Sutherland, 1991). Therefore, free or low-cost educational programs offered by governments, utilities or third parties would be a great resource for homeowners to learn useful and relevant information. This can help mitigate the "lack of knowledge" barrier.

Renewable energy

When asked to indicate the level of knowledge about RESs on a scale from 0 (no knowledge) to 5 (highest level of knowledge), respondents indicated that they had the most knowledge about wind turbines (2.19), followed by geothermal (1.74) and solar hot water (1.54). As illustrated in Figure 15, respondents had the least knowledge of solar PV (0.93) and biomass boiler systems (0.71). Overall, there was a lack of knowledge in residential renewable energy technologies. When asked to assess what payback periods were considered acceptable, 41% of respondents indicated that two to five years was acceptable. Eleven percent found less than one year acceptable, and 16% of respondents expect a payback period of 6 to 10 years. Fewer than 5% of respondents are willing to wait for 10 to 15 years. The remaining 27% were not interested in installing RESs at all (Figure 16). The distribution was quite similar to that for EEMs.

FIGURE 15. Current level of knowledge about RESs.

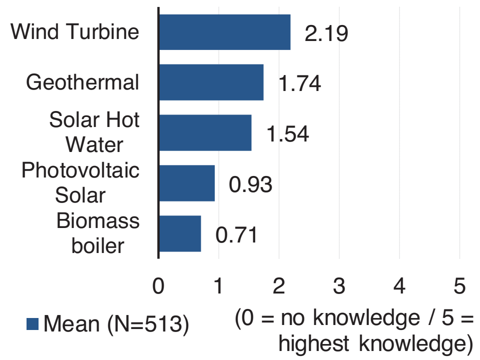
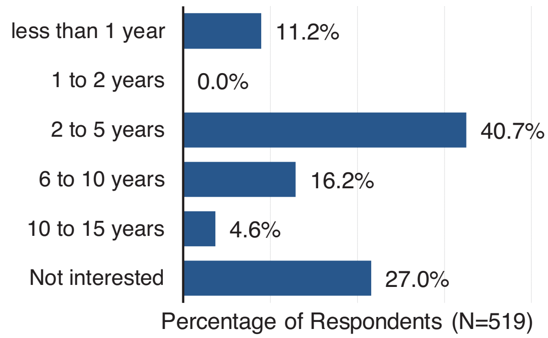
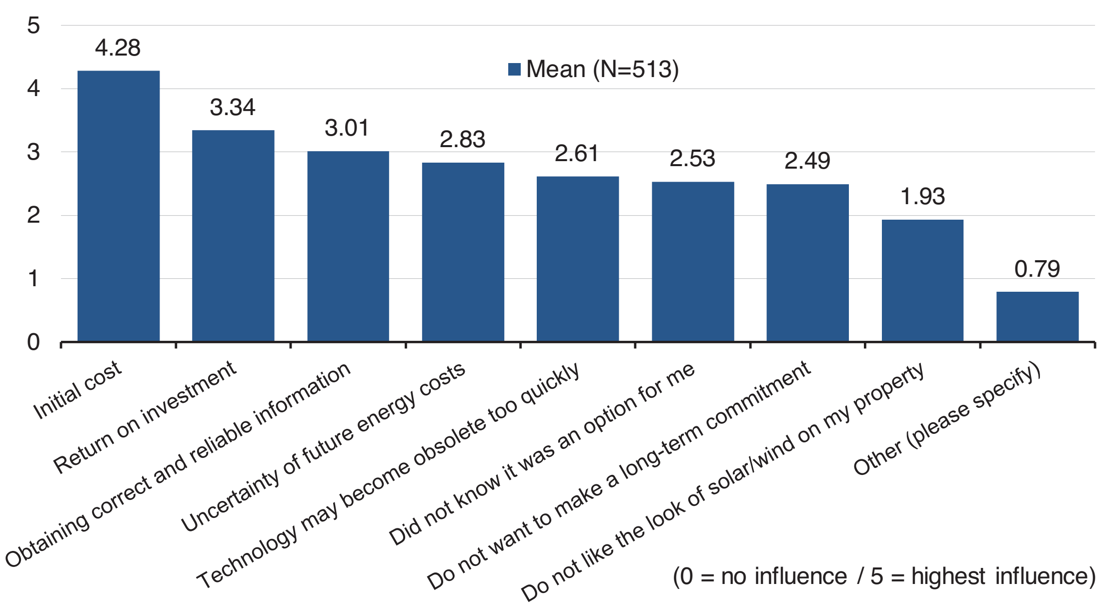


FIGURE 16. Acceptable payback period for RESs.



Respondents were asked to rate on a scale from 0 (no influence) to 5 (highest influence) how much certain barriers influenced their decision to install RESs. As shown in Figure 17, the leading barriers were financial. These include initial cost as the strongest (4.28), followed by return on investment (3.34), and uncertainty of future energy costs (2.83). Except for obtaining correct and reliable information (3.01), other factors fell into a mid-range, including a concern that the technology may become obsolete too quickly, not knowing that renewable energy was an option for them, not wanting to make a long-term commitment and not liking the look of solar/wind on their property. The national survey presented earlier (Clean Edge, Inc., 2014) also identified expensive initial cost as the top reason that prevents homeowners from installing

FIGURE 17. Barriers to installing a RES.



solar power (selected by 50% of respondents). It was noted that despite strong and widespread support for renewables, zero up-front costs and ongoing cost savings are two top factors that would convince homeowners to install a solar PV system. There seems a large gap to fill even with the recent price drop for home solar PV applications.

Of 513 survey respondents, only five percent already had a RES installed on their home (Figure 18). Seven, or 28% of them had a geothermal system installed, followed by solar thermal and wind turbine, adopted by 24% (or six) and 12% (or three) of the respondents, respectively (Figure 19). The implementation of PV and biomass boiler was very low, i.e., each implemented by 4% or one of 25 respondents. Those choosing the "other" option mentioned solar powered lighting, outdoor wood burner water heater, etc. Of these 25 renewable energy applications, 18 were in urban locations (city and suburb), and seven were associated with homes in small towns, countryside, and farms. While more solar thermal (all of six) and geothermal (five out of seven) applications were in urban homes, the location of other installed RESs is not worth discussing due to the small sample size. Overall, the implementation of RESs, especially PV systems, was extremely low among Ohio homeowners, compatible with the lower knowledge level of PV (an average score of 0.93 out of 5) when compared with wind turbine, geothermal, and solar hot water.

Of the same respondents who had installed a RES, 68% were either "satisfied" (40%) or "very satisfied" (28%). Twenty percent of respondents (20%) were "neutral" while the remaining 12% were "dissatisfied" or "very dissatisfied" with their investment decision (Figure 20a). Respondents were asked whether they are saving money on their energy bill as a result of a renewable energy installation, and 84% of the respondents answered "yes" while 16% said "no" (Figure 20b). When asked whether they are more conscious of their energy use after installing a RES, 80% of them said "yes" while 20% said "no" (Figure 20c).

Figure 21 shows the identified barriers respondents encountered when installing a RES (multiple responses were allowed). About two-thirds of respondents (64%) said they faced one or more barriers, which include Home Owners' Associations (28%), problems with installation (24%), availability of solar panels (24%), inspections and permitting (4%), and other (4%). Thirty-six percent of respondents answered that they did not encounter any barriers.

FIGURE 18. Homes with a RES installed (N = 513).

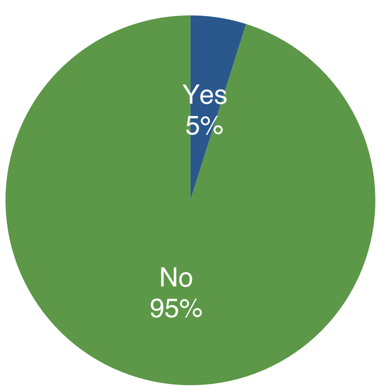


FIGURE 19. Types of renewable technology installed (N = 25).

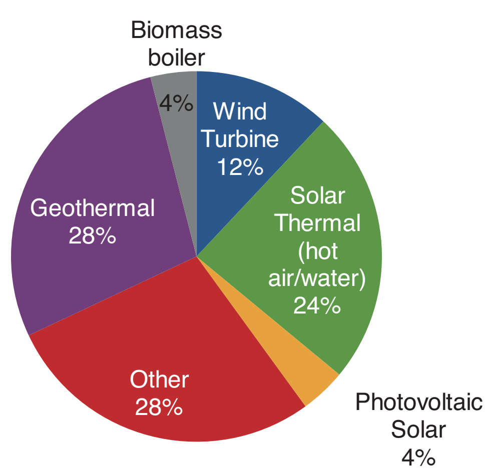
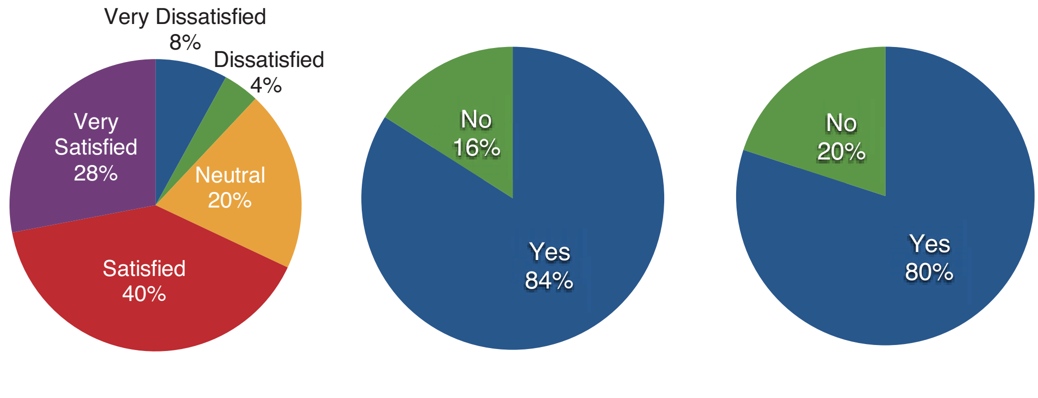


FIGURE 20. Respondents' perceptions on the RES installed.



a. Homeowner's satisfaction with their investment decision

b. Saving on the homeowner's energy bill

c. More conscious after installing the RES

The concept of community solar or shared solar has been gaining popularity in recent years. Community solar increases homeowners' access to clean solar energy when they face feasibility problems (e.g., renting, unsuitable roof space, etc.) or other obstacles. This study explored Ohio homeowners' interests in community solar projects. The results (see Figure 22) show that while 30% of survey respondents confirmed their interests in participating in a community solar project; 58% indicated that they may be interested. Only 12% said "no" to this question, which is lower than 26% who said that they are not interested in RESs regardless of the payback period. Of the 30% of respondents who were interested in a community solar farm, slightly less than half (43%) said they would be interested in one panel and a similar percentage (46%) said they would be interested in two to five panels. The remainder of respondents was interested in six panels or more.

As shown in Figure 23, most respondents (77%) pointed out that they were willing to pay less than $500 for a 250-watt panel from a community solar project given that a 250-watt

FIGURE 21. Barriers encountered during the installation of a RES.

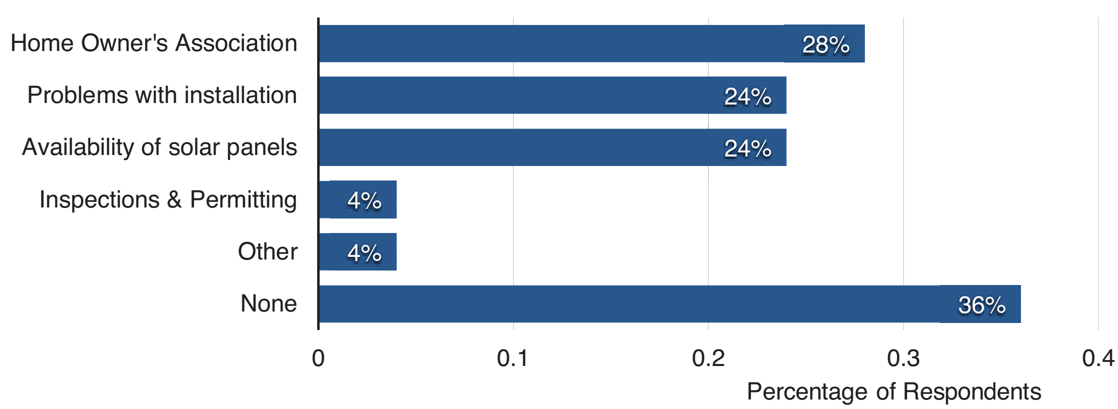


FIGURE 22. Respondents' interests in community solar projects (N = 511).

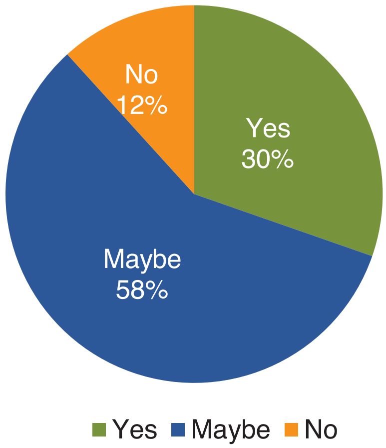
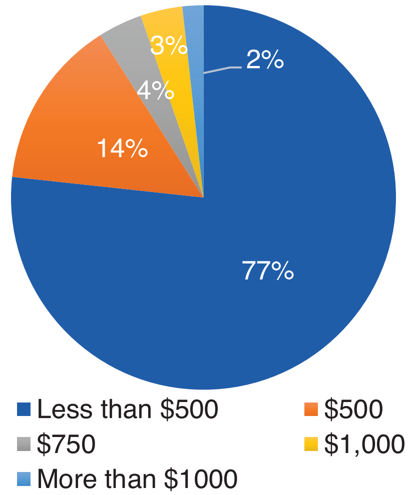


FIGURE 23. Price homeowners are willing to pay for a 250-watt solar panel (N = 511).



panel could generate an approximate average annual energy savings of $38 for a typical Ohio household, estimated based on the current cost of electricity and future escalation rates. This means that the majority of respondents could accept a payback time of less than 13 years. In addition, 14% of respondents were willing to spend $500 for the 250-watt panel, a payback time slightly over 13 years. Then, respondents' willingness to participate was reduced significantly when costs become higher. The big discrepancy between respondents' low acceptance rate for home RESs with a longer payback period in an early question (i.e., approximately 16% and 5% for payback ranging from 6–10 and 10–15 years, respectively, as shown in Figure 16) and the higher acceptance rate in this question was likely caused by the lower initial cost of participating in a community solar project (could be lower than $500) and the reduced risk associated with smaller investments.

Survey data on RESs show that overall Ohio homeowners lack knowledge in residential renewable energy technologies, with the least knowledge of solar PV and biomass boiler systems. The low level of knowledge of PV is somewhat surprising, as PV solar represents 96% of Ohio's 2,541 renewable energy facilities certified with the Public Utilities Commission of Ohio (Public Utilities Commission of Ohio, 2017). Results from the study suggest that consumers are motivated by economic considerations. For example, the most significant potential barrier of installing RESs was the initial cost of the RES, while the uncertainty of the return on investment was the second highest-rated barrier. In total, 52% of homeowners in this study indicated that they want a target payback period less than five years and up to 67% can accept a payback period less than 10 years before considering investment in a renewable energy project. Around 26% are not interested in RESs regardless of the payback period. However, some of these respondents may have interests in investing in community solar.

While historically, PV has been considered one of the costliest renewable energy technologies, the costs have come down significantly in recent years. Specifically, the National Renewable Energy Laboratory (NREL) 2017 U.S. Solar Photovoltaic System Cost Benchmark report shows the costs to install residential solar PV systems in the U.S. has decreased from $7.24 per watt (DC) in 2010 to $2.80 per watt (DC) in 2017 (Fu et al., 2017). As a result, the NREL website lists PV as the lowest cost option compared to wind, biomass, and ground source heat pump (geothermal) technologies (National Renewable Energy Laboratory, 2016). Therefore, in addition to increasing Ohio homeowners' overall knowledge about RESs, it is vitally important to keep them updated on the latest advances, e.g., the significantly reduced initial cost for implementing a solar PV system. Promoting community solar in Ohio also seems promising.

Subgroup comparison

Homeowners with homes under $150,000 vs. worth $150,000 or more

In the original survey, homeowners were asked to indicate their homes' value based on six categories: (1) *less than $50,000*, (2) *$50,000~$99,999*, (3) *$100,000~$149,999*, (4) *$150,000~$199,999*, (5) *$200,000~$299,999*, and (6) *$300,000 or more*. In this statistical study, samples were divided into two subgroups as *homes under $150,000* (N = 345) and *homes for $150,000 or more* (N = 174). The following significant differences between the two subgroups were identified using a significant level of 0.05:

- Overall, homes with an estimated value of $150,000 or more are newer, with the median year of construction being 1985 than homes under $150,000 with the median year of construction being 1955 ($p = 0.0000$).
- Owners having a higher value home cared more about house style in making their purchasing decision ($p = 0.0020$).
- Compared to owners having a home under $150,000, owners with a higher value home indicated a higher level of knowledge on three energy efficiency technologies, including energy efficient water heating ($p = 0.0327$), advanced appliances ($p = 0.0009$), and home control and monitoring ($p = 0.0033$). They also allowed slightly longer payback periods for EEMs ($p = 0.0109$). However, more of these owners perceived their homes to be already energy efficient, which is a potential barrier preventing them from upgrading their homes for energy efficiency ($p = 0.0013$). Further analysis also suggested that this perception might be attributable to the higher implementation rates of various EEMs in these homes although the Chi-Square Test could not confirm a statistically significant relationship between these two variables. For example, the survey data showed that 73%, 64%, 45%, and 43% of higher value homes had installed high efficient lighting, programmable thermostats, efficient heating and cooling systems, and high performance windows, respectively, which were 16%, 21%, 12%, and 13% higher than the corresponding implementation rates of such EEMs in lower value homes. On average, higher value homes had 3.22 EEMs per home while lower value homes had 2.50 EEMs per home.
- In terms of renewable energy, owners having a higher value home indicated a higher level of knowledge about solar hot water ($p = 0.0091$) and geothermal ($p = 0.0376$). More of them indicated having installed a RES on their homes ($p = 0.0477$). But at the same time, they view "do not like the look of solar/wind on their property" more likely as a barrier to the implementation of home RESs.

Urban vs. rural homeowners

This study also conducted a statistical comparison between two subgroups as *Urban* (including homes located in *City* and *Suburb*) (N = 335) and *Rural* (including homes located in *Small*

Town, *Countryside*, and *Farm*) (N = 184). The following significant differences between these two subgroups were identified using a significant level of 0.05.

- Homes located in an urban environment are usually newer with the median year of construction being 1975 than homes in a rural setting with the median year of construction being 1965 (p = 0.0124). In general, the estimated home values provided by survey respondents for the urban home group are higher than that for the rural home group (p = 0.0079).
- Urban homeowners more likely have a plan to purchase another home in the future (p = 0.0117).
- Compared to homeowners from a rural area, urban homeowners indicated a higher level of knowledge on passive house design (p = 0.0095), advanced appliances (p = 0.0196), and home control and monitoring (p = 0.0001). They also had less belief that their homes are already energy efficient (p = 0.0187). Thus, this potential barrier would have less effect on these urban homeowners. However, in this case, no big difference was identified between these two subgroups in the implementation rates of most listed EEMs, suggesting that there might be other factor(s) causing the difference in perception.
- Of all the homeowners who had invested in a RES, urban homeowners (N = 18) were more satisfied with the decision than rural homeowners (N = 7) (p = 0.0187).

The results from subgroup comparison provide valuable insights into how the education and outreach programs can be tailored to address the knowledge gap and potential barriers faced by the intended audience categorized based on their housing characteristics, which will improve the effectiveness of such programs on influencing homeowners' energy decisions (Frankel et al., 2013).

CONCLUSIONS

By taking a questionnaire survey approach this research explored homeowners' perspectives on current home energy use, energy cost, energy efficiency, and the implementation of EEMs and RESs in Ohio households. It also assessed homeowners' interests in becoming more energy efficient and adopting renewable energy, as well as related barriers.

The survey study found that 65% of the 519 respondents had already taken steps to reduce their energy bill in the past year, while 68% of them were very likely to do so in the current year or within the next five years, showing Ohio homeowners' high involvement in moving toward home energy efficiency. Also, respondents had a good level of awareness about various benefits that could result from home energy efficiency upgrades, especially the health, safety, and comfort benefits. In contrast, survey respondents only had a moderate level of knowledge about most listed EEMs, with the least knowledge of passive home design (with a score of 1.1 out of 5). In terms of RESs, their implementation rates among survey respondents were extremely low. Overall, there was a lack of knowledge about these systems (shown as the low scores ranging from 0.71–2.19). As lack of knowledge, no time to research, and obtaining correct and reliable information were considered potential barriers to the implementation of EEMs and RESs, it is necessary to improve homeowners' knowledge about these technologies through high-quality, up-to-date, and well-tailored education and outreach programs (e.g., based on different housing characteristics or demographics).

This study also found that respondents were most motivated by economic considerations. Initial costs and return on investment ranked the highest among various barriers. For both EEMs and RESs, more than half of the respondents would only consider payback periods of less than five years. Given that such a short payback may not be feasible for most EEMs and RESs when no significant subsidies are available, there is a great need to not only close the knowledge gap among homeowners but also educate them about reasonable expectations on return on investment, the non-energy benefits that could be achieved through energy efficiency improvements, and available incentive programs that help reduce the implementation costs, so homeowners are more willing to invest on home energy efficiency and renewable energy projects.

This research not only provided a new understanding of Ohio homeowners' perspectives on residential energy efficiency and renewable energy improvements, but also generated some valuable insights into how to address major barriers identified in this survey through education and outreach programs. This work can also provide insights to help guide local policy decisions (e.g., policies on community solar) and the development of effective initiatives or incentive programs. Since this study focused on Ohio homeowners, whose perspectives were affected by many local factors as well as demographics, the findings may not be generalized to other populations from different geographical locations. Thus, similar studies will need to be performed to generate useful information applicable to other particular states or regions.

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REFERENCES

Attari, S.Z., DeKay, M.L., Davidson, C.I., and Bruin, W.B.D. (2010). Public perceptions of energy consumption and savings. *Proceedings of the National Academy of Sciences*, 107(37), 16054–16059.

Chen, Q., Kinzel, G., Zimmerman, A., Potter, S., and Lichtensteiger, M. (2011). Barriers and impediments to a holistic approach to promoting super-energy-efficient (SEE) homes. *Journal of Green Building*, 6(1), 93–103.

Clean Edge, Inc. (2014). *U.S. homeowners on clean energy: A national survey*. Partner with SolarCity. <https://cleanedge.com/reports/US-Homeowners-on-Clean-Energy-A-National-Survey-2015> (Sept. 19, 2018).

Craig, C.A. (2016). Energy consumption, energy efficiency, and consumer perceptions: A case study for the Southeast United States. *Applied Energy*, 165(March), 660–669.

Darko, A., Chan, A.P.C. Ameyaw, E.E., He, B.-J., and Olanipekun, A.O. (2017). Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. *Energy and Buildings*, 144(June), 320–332.

Dillman, D.A., Smyth, J.D., & Christian, L.M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method*. 4th edition. Hoboken, N.J: Wiley & Sons.

Energy Information Administration (EIA). (2012). *Annual energy review 2011*. DOE/EIA-0384[2011], U.S. Department of Energy, Washington, D.C.

EIA. (2018a). *State energy consumption estimates 1960 through 2016*. U.S. Department of Energy, Washington, D.C. <https://www.eia.gov/state/seds/sep_use/notes/use_print.pdf> (Aug., 30, 2018).

EIA. (2018b). Ohio state profile and energy estimates. U.S. Department of Energy, Washington, D.C. < https://www.eia.gov/state/?sid = OH#tabs-4> (Aug. 30, 2018).

Esswein, P.M. (2014). Ten markets where housing prices have risen the most. Kiplinger. <https://www.kiplinger.com/slideshow/real-estate/T010-S001-12-cities-where-home-prices-have-risen-most/index.html> (Dec. 10, 2017).

Frankel, D., Tai, H., and Heck, S. (2013). Using a consumer-segmentation approach to make energy-efficiency gains in the residential market. McKinsey & Company Research Study, New York City, NY.

Fu, R., Feldman, D.J., Margolis, R.M., Woodhouse, M.A., and Ardani, K.B. (2017). *U.S. solar photovoltaic system cost benchmark: Q1 2017*. Technical Report: NREL/TP-6A20-68925, National Renewable Energy Laboratory, Golden, CO.

Jones, T.L., Baxter, M.A.J., and V Khanduja, V. (2013). A quick guide to survey research. *Annals of the Royal College of Surgeons of England*, 95(1), 5–7.

Mulholland, D., Rosenberg, J., and Hogan, K. (2011). Assessing the multiple benefits of clean energy: A resource for states. U.S. Environmental Protection Agency, Washington, D.C.

National Renewable Energy Laboratory. (2016). *Distributed generation renewable energy estimate of costs*. <https://www.nrel.gov/analysis/tech-lcoe-re-cost-est.html> (Nov. 10, 2017).

Northwest Energy Efficiency Alliance. (2009). *Home buyers focus groups: Market research report*. NEEA/#09-201, prepared by Curtis Research Associates.

Norton, R.A., Brown, B.W., Malomo-Paris, K., and Stubblefield-Loucks, E. (2016). Non-energy benefits of energy efficiency and weatherization programs in multifamily housing:

The clean power plan and policy implications. Presented at *2016 ACEEE Summer Study on Energy Efficiency in Buildings*, 16 pages.

Ohio State University Extension. (2018). *Energize Ohio*. <https://energizeohio.osu.edu/incentives> (Sept. 14, 2018)

Preservation Green Lab (PGL). (2011). *The greenest building: Quantifying the environmental value of building reuse*. Prepared by Frey et al. Seattle, WA. <https://living-future.org/wp-content/uploads/2016/11/The_Greenest_Building.pdf > (Jan. 10, 2018).

Public Utilities Commission of Ohio. (2017). Ohio's alternative energy portfolio standard certified renewable energy facilities. <www.puco.ohio.gov/emplibrary/files/util/RatesAnalysis%5CRenCERT%20Internet%20Files%5CApproved%20Facilities%20Summary.pdf> (Nov. 10, 2017).

Southern California Edison. (2006). Home energy efficiency survey. <http://www.californiaenergyefficiency.com/calenergy_old/sce/2503.pdf> (Jul. 28, 2010).

Statistic Brain Research Institute. (2017). Average home sale price. From: Statistic Sources & References. <https://www.statisticbrain.com/home-sales-average-price/> (Jan. 10, 2018).

Sutherland, R.J. (1991). Market barriers to energy-efficiency investments. *The Energy Journal*, 12(3), 15–34.

U.S. Census Bureau. (2017). Median and average sales price of house sold by region. <https://www.census.gov/construction/nrs/pdf/pricerega.pdf> (Jan. 10, 2018).

U.S. Department of Housing and Urban Development (U.S. HUD). (2016). Comprehensive housing market analysis: Columbus, Ohio. Office of Policy Development and Research, U.S. HUD, Washington, D.C. <https://www.huduser.gov/portal/publications/pdf/ColumbusOH-comp-16.pdf> (Dec. 23, 2017).

Wilson C., Crane, L., and Chryssochoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research & Social Science*, 7(May), 12–22.

Zimmerman, A. (2009). MPG for homes: Improving the energy performance of homes and households. *Home Energy*, May/June, 28–30.