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Drivers and barriers to public acceptance of future energy sources and grid expansion in the United States

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ABSTRACT

With the coming of the 21st century in the U.S., reliance on fossil fuels, in particular coal, decreased while renewable energy sources increased their contribution to the U.S. energy portfolio. The factors behind this emerging trend toward a decreased reliance on coal are many, including economic as well as policy goals. Nationally, support is strong for the general transition to renewable energy, but this support can decline at the local level particularly if renewable energy is perceived as have negative local economic impact, impeding implementation. However, some look at this as part of a transition to a new economic power structure. Due to a lack of research on identifying public preferences for energy production in the United States, the authors conducted a national survey to identify drivers and barriers of acceptance of different types of electrical energy production. Results show that nationally, most Americans support decarbonization of the energy sector, especially if wind and solar photovoltaic facilities are located at least 5 miles (8 km) from their home. This is also supported by strong preference for an energy mix containing a larger percentage of energy produced by renewable energy sources. Environmental sustainability, economic viability, and social acceptance were of roughly equal importance in pairwise comparison of policy objectives. Results also demonstrate the importance of analyzing socio-demographic characteristic's role regarding acceptance of renewable energy sources. The information is useful for policy makers to better implement renewable energy development and improve acceptance of such technologies at the local level.

1. Introduction

Decarbonization of the electrical energy sector is necessary to combat CO_2 emissions via low-carbon technologies, such as nuclear power plants, natural gas, and coal fired power plants with carbon capture and storage (CCS) and increased use of renewable energy sources (RES) [1]. This study assesses the American publics' energy generation preferences. We hope to identify drivers of RES acceptance to better inform policy makers on RES implementation and barriers to its implementation. In particular, the study aims to answer the following research questions (RQ):

1. How well does the general population understand the technologies associated with the transition to a RES focused energy sector, and what are their opinions of the various options? (RQ1)
2. How does the acceptance of various options for electrical power generation on a national level differ from the local acceptance of individual power technologies? (RQ2)
3. What are the main factors driving local acceptance of various energy technologies? (RQ3)
4. How strongly should different objectives be weighted in decisions related to national or local energy policy, and how important is subjective valuation and social acceptance compared to traditional objectives of energy policy, namely economic viability, environmental sustainability, and reliability of supply? (RQ4)
5. To which extent are the answers to the above questions related and are they correlated with socio-demographic characteristics? (RQ5)

Previous work established that the success or failure of RES implementation depends heavily on the public's willingness to accept these innovations [2,3]. Without public acceptance, RES are unlikely to achieve the necessary level of replacing traditional fossil-fueled electrical power generation in order to significantly inhibit global warming [4].

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Abbreviations

CCS	Carbon capture and storage
RES	Renewable energy sources
HVPLs	High voltage power lines
PV	Photovoltaics
RQ	Research Question
NIMBY	Not in My Back Yard

There is a significant gap in the literature regarding renewable energy preferences of U.S. citizens. Some studies analyze preferences for individual technology types (see Literature Review). Given the current uncertainty in policy direction in the United States and an unknown level of acceptance of RES technologies nationally and locally, the objective of this paper is to identify public perception towards RES and associated technologies across the United States. The results will help policy makers determine best methods to overcome local opposition to deployment of RES based on socio-demographic information. Technologies specifically tracked are wind turbines, coal fired, solar, biomass, and natural gas power plants. Given that a transition to RES will require decentralization of the grid, acceptance of above- and belowground power lines is also explored. Certain RES will also require battery storage devices or load shifting via automated demand response and the survey includes questions regarding these technologies.

The basis of this study is a nationally representative survey distributed across the U.S. (Section 2) which identifies significant trends to understand the acceptance and preference of various types of electricity production sources and associated infrastructure (Section 4). Sections 5 and 6 conclude with a discussion on policy implications, limitations of this study, and recommendations for future work.

1.1. Literature review

The public gives high importance to environmental concerns when considering energy initiatives and generally favors new energy technologies [5–7]. Economics, social concerns, and reliability of supply are important priorities regarding sustainable power generation [6]. Although general public acceptance tends to support implementation of RES, resistance is experienced at the local level [8–10]. However, some look at this as part of a transition to a new economic power structure, although there is still debate whether this will affect local control's influence on a renewable energy future [11]. The reasons behind this resistance vary and often go beyond technical and economic challenges [12]. Resistance may also be politically motivated if projects go beyond the state or local level [13]. Negative attitudes worsen if impacts are not framed properly [14]. Often, rejection of a technology stems from lack of knowledge [15,16]. Low perceived level of knowledge can discourage stakeholders from participation in discussion and decisions about future energy technologies and how public funds should be spent, impeding development of RES. If self-knowledge is perceived as adequate to assess a technology, people may make uninformed judgements and do not rely on established expertise [17]. Often, people will rely on their own knowledge due to a lack of trust about judged risks and benefits from experts, even if their own knowledge may be limited. It is also important to note that it is difficult to change people's minds once decisions are made, so it is important to give them information as soon as possible [18].

Currently, there are limited studies regarding energy preferences for the U.S. and most of these studies are for individual technology types or focused in specific locations. One U.S. study confirmed the significance of perceived cost regarding acceptance of solar PV, as well as perceived maintenance requirements, environmental concerns, and aesthetics [19]. A study in Pittsburgh, Pennsylvania identified that participants favored energy efficient technologies over traditional low carbon technologies such as wind and PV [20]. Participants in two study sites in Utah, both containing large amounts of fossil fuel resources, saw RES as a threat to the current local economy [8]. Aesthetics of solar panels also affected public opposition due to negative impact on the landscape. Availability of financial programs and incentives also influences public perceptions of solar PV. In the western U.S., opposition to wind power is moderate with negative impacts on aesthetics, wildlife, and economics as large drivers or opposition [13,21]. A national study throughout the U.S. found that regarding outcomes of energy policy, environmental quality, energy costs, job creation, and greenhouse gas emissions are most important to citizens [5].

Grid expansion is necessary for the implementation of RES technology. The literature suggests a negative perception of landscape impact via high voltage power lines (HVPLs) and pylons. General acceptance of HVPLs is typically higher than if installed locally, and the predictors of national and local acceptance also differ [22,23]. Educational attainment, trust in the operation of the national grid, general attitudes toward HVPLs, and perceived impact on the landscape quality and place where the infrastructure is proposed are significant factors explaining public preferences, although environmental concern was not a significant predictor [24]. People also do not necessarily associate additional power lines with the expansion of RES. Those who do associate HVPLs with the energy transition tend to associate more benefit and less risk regarding HVPLs [23]. Literature suggests a misconception exists about aboveground and belowground HVPLs. Typically, people prefer underground power lines, as they perceive fewer negative effects on landscape aesthetics. Upon informing stakeholders that underground lines can still cause landscape changes, their acceptance of HVPLs decreased, reducing perceived difference between aboveground and belowground powerlines [25].

Typically, general acceptance by the public of RES but rejection locally is attributed to NIMBYism. NIMBYism is defined as people who might be in favor of a technology or development, but who oppose this when it is in their own localized (and often self-defined) personal area. NIMBYism is often attributed to selfish motives, stating that individuals oppose technologies to maximize their own individual utility, although the idea that people act with selfish motive is not typically true [26,27]. The idea that local rejection is purely due to NIMBYism is a stretch, and it requires further investigation as it leaves the cause of opposition unexplained. When faced with a choice to seem more open minded, stakeholders will adjust their motivations for resistance to RES out of fear of being branded as NIMBY [28,29].

One suggestion to increase local public acceptance of RES and grid expansion is allowing the public to have greater stake in the new installations through shared ownerships. A study in 2016 found that developers want shared ownership to achieve positive public relations, avoid protest, raise funds, prevent regulation, and reduce risk of planning refusal, whereas community actors want shared ownership to increase financial gain of local communities and empower local people to gain new knowledge and skills [30]. A case study in Germany compared two samples and the one involving a co-ownership had higher levels of acceptance of wind turbines installed nearby than wind farms owned by commercial companies [31]. A study in Ireland, however, found that public acceptance of energy infrastructure development actually decreased as the public's level of involvement increased [32].

A decrease in public acceptance even with an increase in levels of public involvement is thought to stem from a lack of trust that leads to lower levels of perceived justice. Constituents can feel as though there is a lack of equality in decision-making. There are also feelings that developers are motivated by financial gain and may exaggerate the project benefits, thereby creating feelings of distrust [18,30,33]. One way to combat this is to involve local investors and developers [34]. Another option is to involve the public in decision making to create trust between developers and communities [35–37].

2. Material and methods

2.1. Survey structure

A nationally representative survey of the United States was created using Qualtrics. The survey responses were randomized to prevent order effects. A total of 2550 valid survey responses were collected, with the distribution across the country representing the relative population percentages by region. As is standard with panel data, the distribution across regions was guaranteed to be representative of the U.S. population as a whole, although other parameters such income and education level could not be guaranteed to be randomized based on the procedures set by the survey organisation (Qualtrics) and their method for obtaining survey responses which was to solicit voluntary participation in this particular survey from a pool of potential respondents. It is generally not possible to ensure a (1) randomized sample among the population (2) that would include distribution across the population for location, age, gender, (3) as well as exposure to all the different RES technologies. Thus, this survey focused on having at least a representative distribution among the geographic regions in the U.S. This population size and distribution across regions is sufficient to be representative of a 95% confidence interval in the survey results with an approximate 2.5% margin of error. Screening questions were included to qualify or disqualify responses [38,39]. Refer to question 51 in the supplemental material for the screening question. Since respondents were given the option to choose "Not Specified/I don't know" for some questions, the sample size for individual questions may differ per question. However, although this study survey covers a broad range of topics and perspectives, based on the given geographic representative distribution we can assume that these survey results represent a general synopsis of the general population feelings as of the time of the survey.

The survey questions are broadly grouped into five categories, as outlined in Table 1. The questions used were based on a similar survey done in Germany [3], and summary details about that survey are included in the supplemental material. That prior survey indicated that gender and ethnicity differences were not significant effects based on the results of a Confirmatory Factor Analysis [2]. Thus, this survey does not compare or report differences in responses by gender or ethnicity. This also helped keep the survey length from being too long. Refer to the supplemental material to see the details of the survey.

The panel is demographically representative of age, gender, and region of their residence in the United States. Table 2 maps the population of the survey respondents.

Table 1
Overview of survey questions categories and research questions used.

Research Questions	Survey Question Categories
1) How well does the general population understand the technologies associated with the transition to a RES focused energy sector, and what are their opinions of the various options?	Category 1: - Attitudes and perceptions related to technological change and public participation - Preferences to accept different future power generation mixes
2) How does the acceptance of individual power systems differ on a national level differ from local acceptance?	Category 2: - Subjective overall valuation of individual technologies and minimum distance assessment to accept technologies locally - Comparison to selected questions in category 1
3) What are the main factors driving the local acceptance of technologies?	Category 3: - Impact assessment of technologies w.r.t. different compensation schemes - Willingness to accept blackouts w.r.t potential personal impacts
4) How should different objectives be weighted in decisions related to energy policy and how important do people rate their subjective valuation/acceptance in comparison to traditional objectives of energy policy?	Category 4: - Pairwise comparison aimed at rating importance of wider policy objectives
5) Are the answers to the above four questions related and are they related to sociodemographic[1] characteristic or personal attitudes?	Category 5: - Socio-demographic characteristics - Comparison to selected question in category 1

[1] Sociodemographic characteristics define groups by sociological and demographic factors. Such factors in this study are listed in Table 2.

3. Theory and calculation

Results of individual preferences are mapped in QGIS version 3.2.1. Population-level descriptions are built based on the results of two-step cluster analyses performed using SPSS version 24. A two-step cluster analysis is well-suited to complex datasets and is capable of handling categorical and continuous variables simultaneously. The algorithm's phased approach assesses cluster membership first as a series of combinations then as a distance calculation based on the pre-cluster results, rather than as an *a priori* requirement. The results are that the clusters are more homogenous. The research team employed Bayesian Information Criterion (BIC) to assess cluster membership.

The Analytical Hierarchy Process [3] was applied to the final section of questions in the survey to analyze the relative importance of economic viability, environmental sustainability, social acceptance, and reliability of electric supply. Each question was a pairwise comparison of two of these four topics. The analysis determines the relative importance of each of these factors using a 9-point scale [40]. This procedure can lead to inconsistent preference statements and must be checked for consistency using a consistency ratio. If the preference statement value is greater than that of the consistency ratio value (0.10), it is removed from the data analysis due to that inconsistency. Over half of the responses (n = 1612, 63.2%) had a preference statement greater than that

Table 2
Socio-demographics of the survey on a national level.

Total Survey Population n = 2550			
Value Label	N	% of Survey Sample	% of U.S. Population
Region			
West	588	23.1%	23.6%
Midwest	563	22.1%	21.0%
South	936	36.7%	37.7%
Northeast	463	18.2%	17.8%
Age			
18–34	383	15.0%	23.3%
35–44	268	10.5%	12.5%
45–54	360	14.1%	13.0%
55–64	650	25.5%	12.9%
65 or older	889	34.9%	15.6%
Highest Achieved Degree			
Did not complete high school	25	1.0%	11.0%
High school diploma	454	17.8%	28.9%
Some post-secondary education, but no degree	597	23.4%	18.9%
Post-secondary degree	1051	41.2%	29.8%
Graduate-level degree	423	16.6%	11.4%
Rented or Owned Dwellings			
Own	1785	70.0%	63.6%
Rent	654	25.6%	36.4%
Other	75	2.9%	–
Not specified	12	0.5%	–
Annual Household Income			
< $50,000	1075	42.2%	45.5%
$50,000-$100,000	939	36.8%	30.0%
> $100,000	405	15.9%	24.6%
Prefer not to answer	126	4.9%	–
Political Viewpoint			
Conservative	978	38.4%	26.0%
Liberal	699	27.4%	30.0%
A moderate or centrist	873	34.2%	41.0%

of 0.10 and were removed from that part of the analysis.

4. Results

This section summarizes and compares survey results for national versus regional results. Significant deviation from national trends is noted. The first section of the survey asks participants to identify the effect of RES technologies on the key parameters of: change of landscape; noise; health; economy; climate concerns; employment; air quality; water quality; and odor. Not all of these issues were questioned for each RES technology, as some were not relevant (e.g., water quality and wind turbines). The most important feature of this section is that participants may rank their perceptions of the different technologies as positive or negative. The assessment is made for energy production using wind turbines, coal fired plants, solar power, biomass, and natural gas power plants, as well as associated energy technologies such as above- and underground transmission lines, battery storage, and automated demand control devices.

4.1. Wind turbines

Nationally, wind turbines are positively assessed (88%) (Fig. 1(a)), with impact on health (43%), climate concerns (55%), the economy (60%), and local employment (48%) being the strongest drivers of support. Some participants felt as though there was a negative impact on change of landscape (37%) and neither a positive nor negative influence on noise (30%). Over 20% of participants responded “no experience or limited knowledge” regarding influence on noise (21%), impact on health (21%) and local employment (23%). The Midwest deviates from this tend as 20% responded as “no experience or limited knowledge regarding influence on the economy (20%).

4.2. Coal fired power plants

A majority of survey participants’ overall assessments of coal fired power plants were negative (69%) (Fig. 1(b)), with the key factors being change of air quality (69%), climate concerts (61%), landscape (54%), water quality (53%), and impact on health (35%). Participants felt there was a positive influence on the economy and local employment. There were no regional deviations from this trend, although Fig. 1(b) shows that respondents in three states (Wyoming, West Virginia, and New Mexico) have overall positive opinions on coal fired power plants. These positive views are likely connected to the predominance of the coal industry in these three states.

4.3. Solar power (PV) plants

Fig. 1(c) shows a national trend for an overall positive assessment for solar PV technology (90%). This technology was felt to have a positive influence on climate concerns (67%), the economy (66%), impact on health (59%), local employment (59%), although a plurality felt that there was a positive impact on the change of landscape (34%). There was not a significant number of responses answering “no experience or limited knowledge” for this technology.

The Midwest was the only region that deviated from this trend, as a plurality of the respondents felt that solar panels would have no effect on change of landscape (32%). This was also close to the number of participants in this region that felt solar panels have a positive influence on change of landscape (30%). Wyoming’s slightly negative opinion about solar PV is possibly based on economic concerns, given the coal industry’s large presence in the state’s economy.

4.4. Biomass power plant

Nationally, participant’s overall assessment of biomass power plants is positive (Fig. 1(d)). Biomass power is the technology which is the least understood (at least by the survey respondents). A number of respondents reported “no experience or limited knowledge” to the topics of change of landscape (52%), noise (55%), odor (54%), air quality (52%), water quality (54%), impact on health (53%), climate concerns (52%), the economy (52%), and local employment (52%). There are no regional deviations in this trend, and implications of this are described

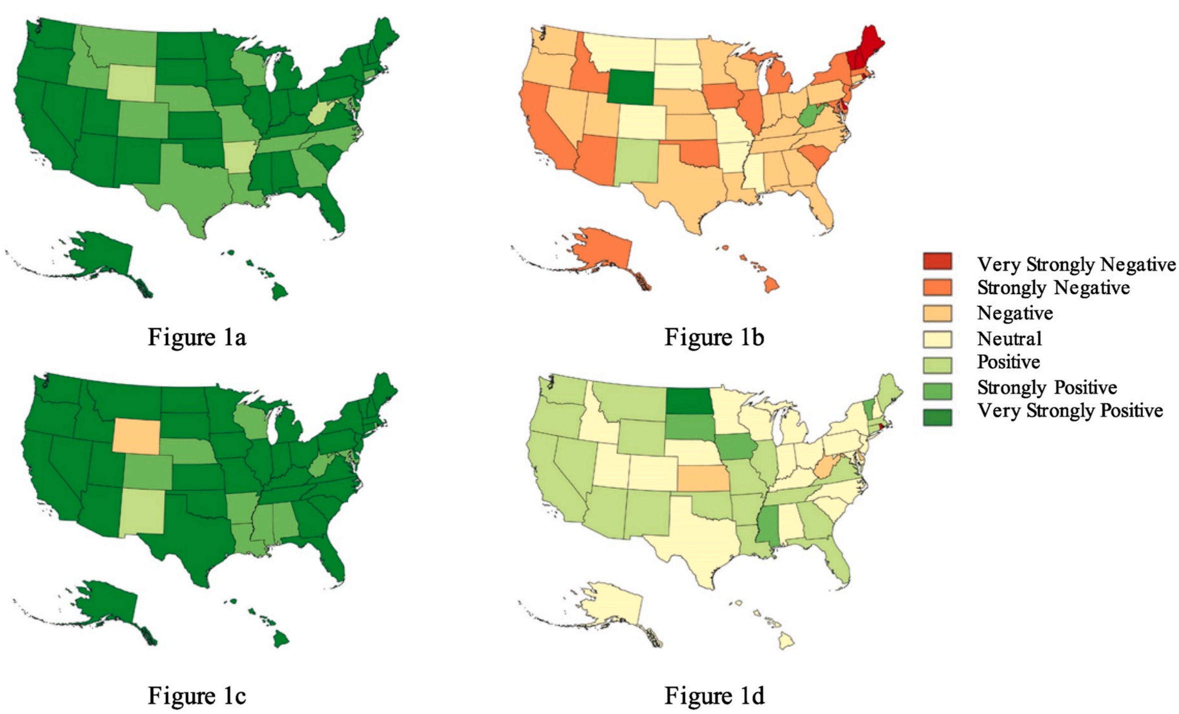

Fig. 1. a–d: National acceptance by state of wind turbines (1a), coal plants (1b), Solar Power PV (1c), biomass plants (1d), and color scale. Dark green = very strongly positive, green = strongly positive, light green = positive, yellow = neutral, orange = negative. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

in Section 4.

4.5. Above ground electrical transmission line expansion

Most survey participants respond with a neutral to positive assessment about above ground electrical transmission line expansion (54%) (Fig. 2(a)). Regarding negative influences, participants respond that there is a negative influence on change of landscape (58%), safety around the cables (50%), and impact on the environment (35%). A positive influence is given regarding local employment (53%) and the economy (46%). A cluster of slightly negative opinions exists in the North/East regions, where population and infrastructure density are likely a driver of the negative assessment.

4.6. Underground electrical transmission line expansion

Nationally, there overall positive assessment of underground electrical transmission line expansion technology (87%) (Fig. 2(b)), which is characterized by a perceived positive influence on change of landscape (50%), noise (40%), impact on environment (40%), safety around cables (53%), the economy (57%), and local employment (60%). It should be noted that the better assessment of underground power transmission lines compared to aboveground lines is driven by concerns about change to the landscape. As discussed earlier in the literature review, other studies have shown that this is due to a lack of understanding on the overall impact on the local environment.

4.7. Natural gas power plant

Overall, participants have positive assessments of natural gas power plant technology (75%). Participants answer that there is a positive influence on the economy (64%) and local employment (65%) and to a lesser extent water quality (33%) and climate concerns (32%).

The North/East regions deviated from this trend, as a plurality of participants responded that natural gas power plants have neither a positive nor negative influence on air quality (31.7%). This is nearly identical to the number of people that responded as natural gas power plants having a positive influence on air quality (31.5%). About 30% felt that there is a positive or no influence of natural gas power plants on climate concerns. Alaska is the only state with a strong negative assessment of natural gas plants (Fig. 3(a). This may be driven by local economics as natural gas is a competitor to oil in terms of energy supplies.

4.8. Use of battery storage devices in private households

There is a positive national assessment of battery storage technology (75%) (Fig. 3(b), particularly regarding technical safety (35%) and comfort (47%). The plurality response found neither positive nor negative impact on health (38%) though this technology has a negative impact for space needed (38%). There were no regional deviations from national trends.

4.9. Use of fully automated demand response devices in private households

The national assessment of this technology is positive (77%), where the positive drivers are technical safety (46%) and comfort (42%). This is perceived to be neither a positive nor a negative influence on health (49%) or space needed (47%). There were no regional deviations from the national trend. Wyoming and Alaska's negative assessments (Fig. 3 (c)) have no obvious causes, though these could be tied to the phrasing of the survey item.

4.10. Statistical analysis and results

This section provides a detailed statistical analysis of survey results, beginning by analyzing participants' preferences of future energy sources. Relationships between the various parameters studied were not analyzed as we focused on the technologies themselves, and these cross-correlation effects are difficult to determine cause and effect.

Participants were asked what type of energy mix they would prefer to get their power from in the near future (year 2030) on a national level using a 5-point scale. These questions helped evaluate public support of a policy direction toward increasing RES use and the corresponding required expansion of the electrical grid. Energy Mix 1 represented roughly the energy mix at the time of the survey, in essence no change from current. Energy mixes 2 and 3 represent various stages of the market evolution, with mix 2 roughly representing the status of RES adoption in an early adopter country like Germany at the time of the survey and mix 3 representing the RES adoption expected 5–10 years in the future for such as country. Details of the energy mixes are illustrated in Fig. 4.

As seen in Fig. 5, the strength of acceptance increased as the percentage of RES in the power generation mix increased. Energy Mix 3 also has the largest degree of a strict preference responses, with strict preference defined as stating that they were either "willing" or "not willing" to accept the mix. This is a positive indication supported by the survey data which suggests that majority of survey participants give an overall positive assessment for RES technology and that over 60% of the respondents would be either somewhat willing or willing to accept that RES at a national level. This energy mix also requires the largest amount of grid expansion. We can infer on a national level that grid expansion and RES technology would be broadly accepted.

National and local infrastructure generally have different issues, technical challenges and bottlenecks. In order to assess location-based drivers, participants were asked how close they would be willing to have this technology to their homes for various RES as well as above- and belowground HVPLs (Fig. 6 a-b). Respectively, 46% and 51% of participants responded that they would not accept a coal or nuclear power plant regardless of distance and of those who accepted, and 35–38% would require 5 or more miles (8 km) between the plants and their houses. A majority of participants (+50%) indicated that belowground transmission lines and solar PV expansion would be acceptable within a mile (1.6 km) of their homes.

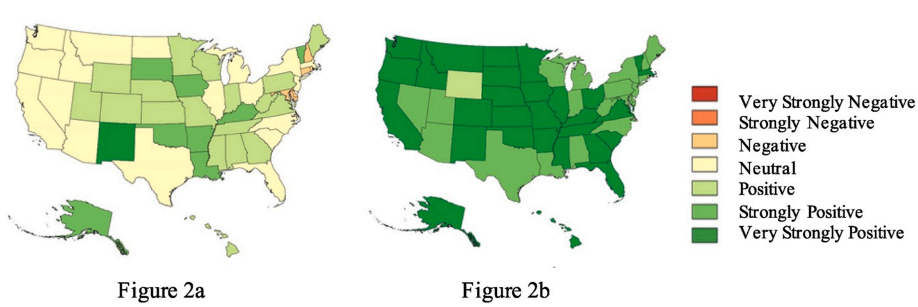

Fig. 2. a–b: National acceptance by state of above ground (2a) and underground (2b) power transmission lines.

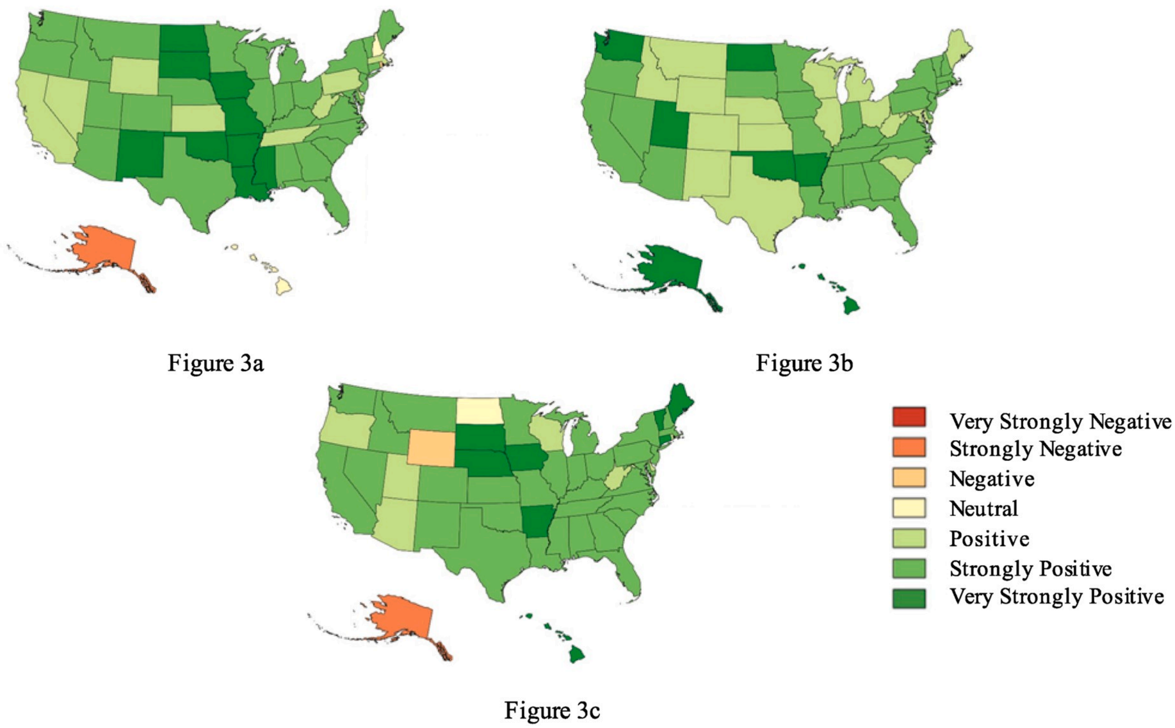

Fig. 3. a–c: National acceptance by state of natural gas (3a), battery storage devices (3b), and fully automated devices (3c).

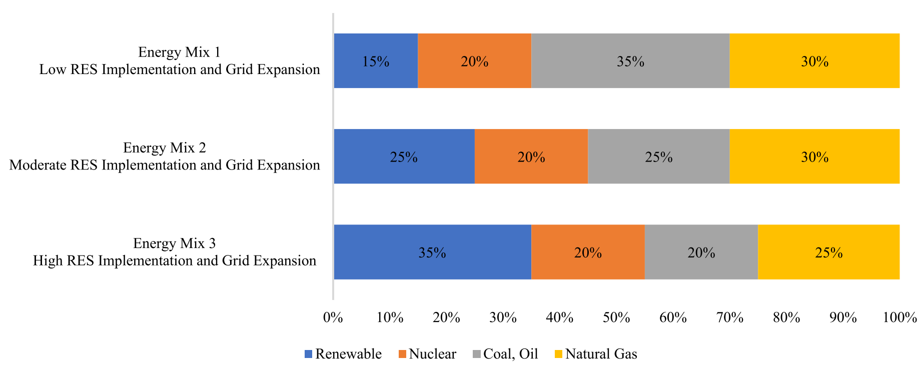

Fig. 4. Possible power generation mixes in 2030 for survey responses.

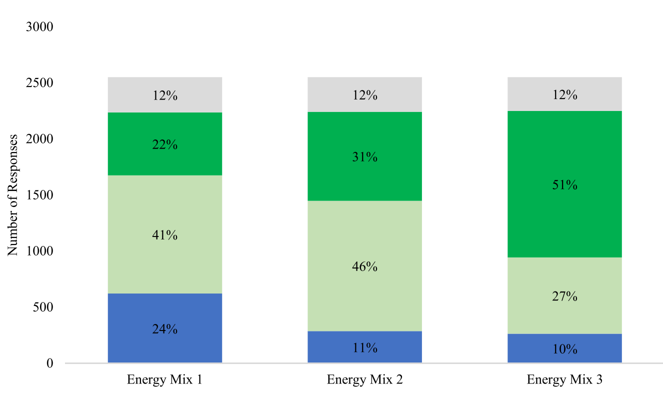

Fig. 5. Survey responses to three energy mixes. The original survey question was on a 5-point scale. The weaker preference responses of slightly willing and somewhat willing were grouped together, as were the responses for stronger preferences of willing and very willing.

Approximately 50% of participants would accept above ground grid expansion at a minimum distance of 5-miles (roughly 8 km) from their homes. At a 5-mile (8 km) minimum distance, the acceptance of wind and solar increases to 75% and 80%, respectively. Based on minimum distance, biomass power plants are the least popular RES technology, with distances similar to that of coal fired and nuclear power plants. While this may be realistic in some areas in the American West, in densely populated urban areas like the California coast or the Pacific Northwest cities, utility scale solar PV expansion will likely require extensive tradeoffs.

Comparing the distance preferences with the acceptance preferences for the electricity generation mix demonstrates that public acceptance of RES technology greatly increases when the minimum distance increases. All RES and grid expansion technologies would be accepted by at least 40% of the population if a minimum distance of 5 miles (8 km) could be guaranteed. Although the survey responses indicate a preference for Energy Mix 3, this may decrease if a minimum distance of 5 miles (8 km) cannot be guaranteed. At this minimum distance, at least 50% of the population accepts grid expansion. For shorter distances, there are disparities between the national acceptance and local acceptance, as indicated by the wide range of acceptances at 1 mile (1.6 km) in Fig. 6 a-b.

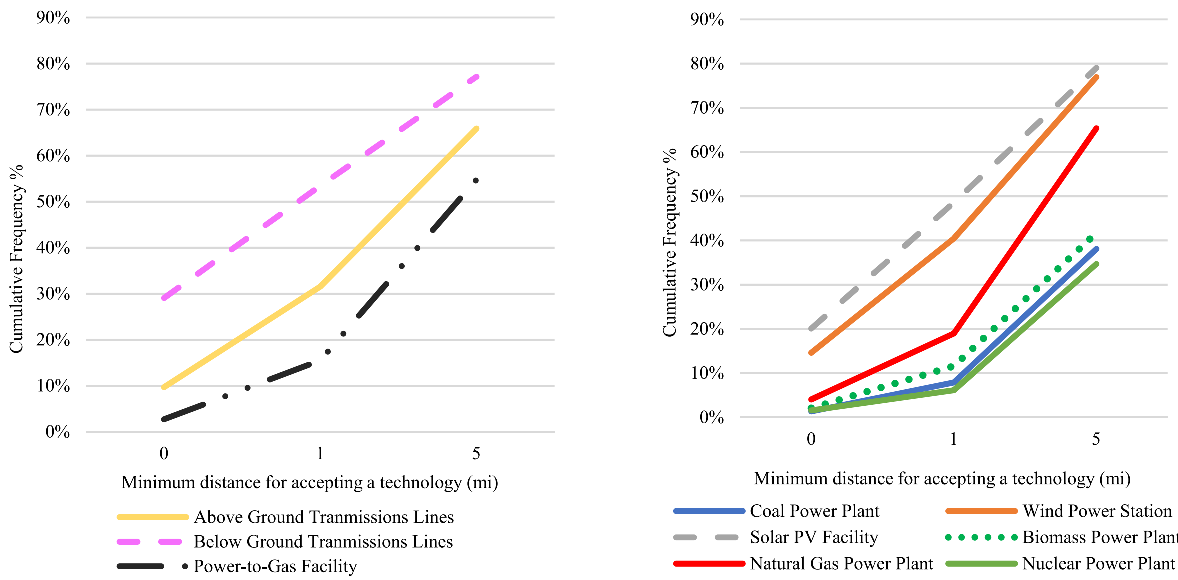

Figure 6a

Figure 6b

Fig. 6. a–b: Minimum distances required for accepting different electricity generation (6a) and infrastructure (6b) technologies. These figures do not include those that answered opposing a technology or those that answered limited knowledge regarding a technology.

The energy mix question did not frame the question in terms of relative distance from their homes. The percent that accepts RES technology would most likely be higher as well if participants were provided information about biomass power plants, as the majority response regarding biomass power plants was no experience or limited knowledge (41.6%).

4.10.1. Explicability of rejections of technologies

This portion of the analysis focuses on comparing subjective impact assessments of these technologies with the stated acceptance of respective technologies. For the purpose of this study, a participant 'accepting' a technology is defined as that participant accepting a minimum distance for a given technology. A participant 'rejecting' a technology is that participant responding that he or she would oppose the technology regardless of distance. The purpose of comparing these responses is to separate explicable rejections from non-explicable rejections. Explicable rejections are defined as technologies that were rejected regardless of distance and are valued negatively with respect to one or more drivers. Thus, if a respondent rejects a technology at any distance and has stated negative opinions, the rejection is logically consistent. Those who reject technologies at any distance and stated positive opinions about a technology are displaying logical inconsistencies in their preferences and are thus inexplicable rejections. As noted in Bertsch et al., 2016 such rejections may occur, for instance, in case of intangible preferences [3]. Thus, we analyzed results regarding Fig. 6 a-b for those who would not accept one or more technologies at all, regardless of the distance from their home, that were also associated with a negative impact of these technologies with respect to the different drivers. Explicable rejections have an absolute sample size of 2250. The sample size of inexplicable rejections varies by technology type as this depends on the number of participants who reject a technology regardless of distance. A summary of this analysis is given in Fig. 7.

The non-explicable rejection of solar PV modules (n = 164, 40%) and underground grid expansion (n = 150, 45%) are based on small sample sizes, as these were the least rejected technologies. Thus, the non-explicable rejections could be outliers. Ignoring these two technologies, coal has the smallest amount of non-explicable rejections (n = 1191, 5%) while natural gas power plants are the peak in non-explicable

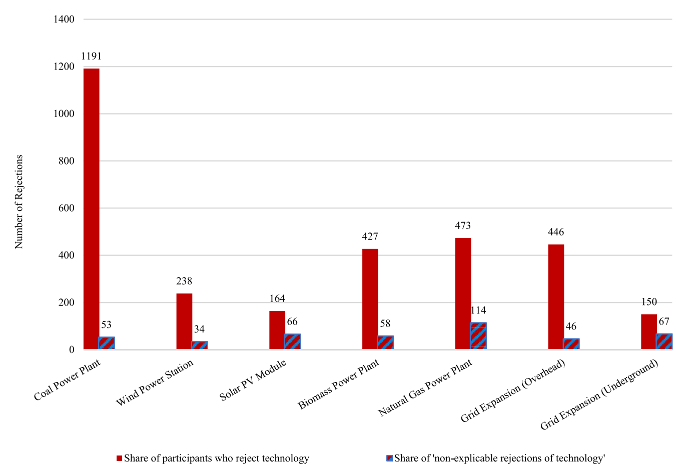

Fig. 7. Shares of technology rejection and 'non-explicable' preferences.

rejections (n = 473, 24%).

4.10.2. Relative importance of policy objectives

Participants were asked to make pairwise comparisons to assess their subjective preferences between economic viability, environmental responsibility, reliability of supply, and social acceptance of RES technology. An AHP analysis assigned weights to the responses as shown in Fig. 8. The weights of social acceptance were found to be much lower than the other areas of economic viability, environmental sustainability, and reliability of supply. Economic viability, environmental sustainability, and reliability of supply have higher value to respondents than social acceptance which indicates that respondents prefer traditional policy objectives over energy mix transitions that they may personally not accept. Particularly in the fight against NIMBY-ism, emphasizing benefits to (local) economics, the environment, and stability of supply may override local objections.

All of the weights are significantly positively correlated. There are strong positive correlations between economic viability and environmental sustainability (ρ = 0.992, p-value = 0.000) and between

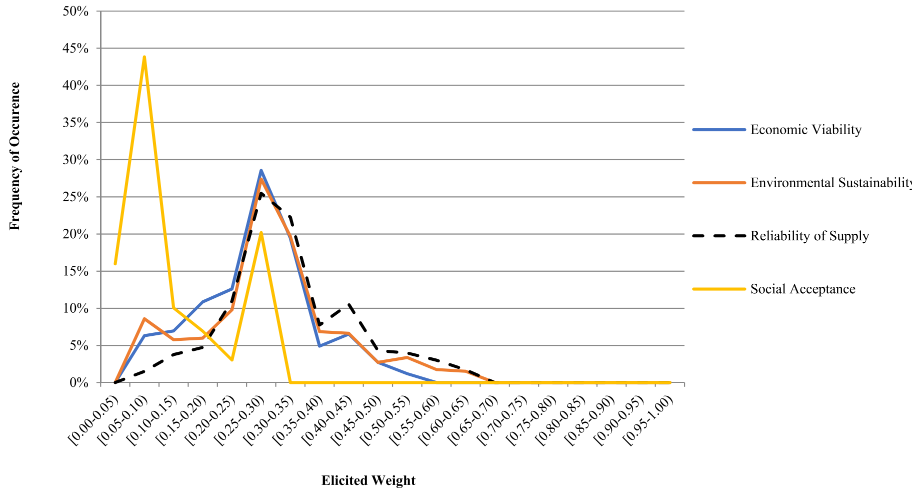

Fig. 8. Empirical weight distributions resulting from the pairwise comparisons (n = 638). Inconsistent preference statements are removed from this analysis (n = 1612). Leftward skews indicate strength of preferences.

environmental sustainability and reliability of supply ($\rho = 0.982$, p-value = 0.000). This is in opposition to Bertsch et al., 2017, as strongly negative correlations suggested that German respondents have strong preferences or beliefs about the importance of individual policy objectives [41]. Our results suggest that the objectives are seen as complements in the United States.

4.10.3. Willingness to change, pay, and relationships with policy

National trends indicate that participants are willing to change their lifestyle in order to reduce their environmental footprint (72%) but are not willing to pay more for energy in order to support the expansion of RES technologies in the energy sector (58%). These is largely driven by political affiliation as found in the results of a MANCOVA analysis (R^2 0.36) (Table 3). The effect is largely driven by moderates. Conservatives largely disagreed with whereas moderates were more willing to accept lifestyle changes (*r = -0.149, p = 0.000*) and paying more to support energy-sector innovations (*r = -0.121, p = 0.000*).

Age is positively related to accepting change and paying more for innovation in the technology sector. Lower income and achieved degree are correlated with a lower willingness to pay for technological innovation. While lower achieved degree is also related to willingness to accept lifestyle changes, there is no relationship with willingness to pay.

Of the participants who responded that he or she would be willing to pay more for energy to support the expansion of innovative technology in the energy sector (n = 1075), 41% make $50,000 to $100,000 per year. 48% of participants who were not willing to pay more made less than $50,000 per year. Consumers in income brackets between $50,000–100,000 can be considered as a target market for supporting innovation in RES. Participants also agreed that local government has a strong influence on the planning of local energy supply systems (59%) but did not agree that the local government considers their opinion in the planning of the state and regional power supply system (79%). They also did not agree that the government considers their opinion in consideration of overall national electrical power supply systems (79%). Age is a driver of this aspect, where increased age is related to likelihood to disagree with the below statements, as seen in Table 4. There are no other significant relationships to report.

4.10.4. Willingness to accept supply fluctuations from RES

A plurality of respondents was not willing to accept temporary scheduled blackouts (44%). In addition, contact with poorly informed customer service staff at the energy supplier (71%), long response times from the energy supplier's customer service (58%), or customer service staff that cannot understand needs (72%) are poorly rated. Reliability of supply (85%), provider responsiveness (72%), and confidence in customer service (64%%) are all very important. The results of a two-step cluster analysis show that older, more conservative participants {30.6% (n = 780)} may be willing to accept temporary, scheduled blackouts when presented with responsive, caring, and knowledgeable service providers and clear, correct scheduling.

75% of participants gave battery storage devices a positive assessment and 76% of participants gave automated devices a positive assessment regarding handling natural fluctuations in energy due to RES technology. Approximately 63% of survey participants gave both a positive assessment. Of those who responded with a positive assessment for both, only 27% would accept all RES technology regardless of distance from their home. Although participants may have positive views toward fluctuation control technology, only a minority would accept RES technology regardless of distance. However, combined with a sustained education and outreach campaign, demand-side management technologies could be broadly introduced. Given the similarity in outcomes of temporary scheduled blackouts and demand-side management techniques, it is reasonable to assume that this pattern could hold if consumers had access to full information and proper (energy provision) educational support.

4.10.5. The role of empathy in service provision

Subjective perceptions of quality of service are generally understood to drive use [42]. This mechanism surveyed responsiveness, reliability, confidence and empathy and sociodemographic variables in order to

Table 3
MANCOVA results comparing political beliefs and willingness to change.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Regarding political view point, I consider myself to be {conservative/moderate/liberal}.	I am willing to change my lifestyle in order to reduce my environmental footprint.	9.060	1	9.060	46.130	0.000
	I am willing to pay more for energy in order to support the expansion of innovative technologies in the energy sector.	7.012	1	7.012	31.041	0.000

Table 4
Correlation matrix of relationship with policy-making and age.

		My local government has strong influence on the planning of the local energy supply system.	The government considers my opinion in the planning of the state and regional power supply system.	The government considers my opinion in consideration of the overall national electrical power supply system.
How old are you?	Pearson Correlation	.067*	.103**	.112**
	Sig. (2-tailed)	0.001	0.000	0.000
	N	2550	2550	2550

assess if latent subjective drivers were in place which superseded the individual technology. Results of a MANCOVA and Bonferroni post-hoc analyses show that while some latent drivers exist between responsiveness, reliability, and confidence, the displayed empathy of front-line service personnel has significant implications on service acceptance. Empathy as a differentiator as compared to other aspects of service quality is discussed below.

Age and those who find that responsiveness and reliability of services are either important or very important concerning electricity supply and the utilities are significantly related. Older (age 55+) respondents were more likely to assess both as very important than the rest of the population. This may also reflect risk aversion from an aging population (Table 5).

Both age and highest achieved degree drive consumer perceptions of service quality in the energy sector. Older respondents are more likely to rate confidence in service provision as highly important. This is also true for those who report attaining post-graduate degrees or higher (Table 6).

Empathy is tightly coupled with multiple socio-demographic aspects (Table 7). Age, highest attained degree, home ownership, and household income have significantly different views of the role of empathy in energy provision service quality. Those who rent, have an income under $50,000/year, are younger, and have achieved a bachelor's degree or lower are less likely to rate empathy as necessary as a function of service quality. This group can be understood as being more transitional and therefore more transactional than their more established peers. On the other hand, empathy is likely to be considered very important in the groups that are older, with higher incomes, or have a higher level of education. This population breakdown should be considered and thoughtfully deployed in any major shifts towards RES. Empathetic outreach by policymakers and other stakeholders could reasonably be the differentiator in acceptance of established constituents. When coupled with reliable, responsive, and confidence of supply for transitional and ageing constituents, acceptance of innovations in the service domain are more likely.

5. Discussion

Majority of Americans are willing or somewhat willing to support decarbonizing the energy sector, even though this requires grid expansion (RQ1). This is similar to the studies conducted in Germany and Ireland [41]. A large number of participants had "no experience or limited knowledge" regarding biomass power plants. The majority of national and regional responses were as such regarding all impact categories for this technology, suggesting that participants have little exposure to this type of technology, although majority view it positively. Policymakers interested in furthering this type of energy provision should consider an awareness campaign which focuses on the traditional policy tradeoffs. All other technologies only had a small number of participants (roughly 20%) respond to answers as no experience or limited knowledge.

Although there were not substantial deviations between national versus regional trends (RQ2), two states in particular had strong differing opinions regarding national trends and within the regions in which those states were located. Wyoming responded strongly positively regarding coal fired power plants, whereas national results indicate negative feelings toward coal fired power plants. This is not shocking, as this is a state whose local economy is highly reliant on coal, explaining why respondents are more accepting of coal plants. Wyoming and Alaska also had negative assessments of automated demand response technology. The phrasing of the question in regard automated demand response technology may have led some participants to feel as though this would be a government- or utility-mandated technology. Exact phrasing of the question may be seen in the supplemental material. Research shows that often, a top-down approach to technology developments is negatively correlated with acceptance of new technology [25,27]. This most likely explains these two states negatively response to automated demand response.

The majority of participants view underground HVPLs much more positively than aboveground, suggesting that visibility of power lines may a driver of acceptance of RES technologies, given that deployment of such technologies will require decentralization of the grid (RQ3). As mentioned in the literature review, this is attributed to participant's misconception about the effects of belowground HVPLs on change of landscape [25]. At the same time, we note the impracticality of aboveground HVPL expansion at more than 5 miles (8 km) from constituents' residences. Were this technology to be expanded it would necessarily expand nearer to residential areas.

Furthermore, for the most common RES installations, at a separation of roughly 5 miles (8 km), more than 70% of participants would accept either a solar PV facility or wind power stations. This indicates that local

Table 5
Results of a Bonferroni post-hoc analysis considering Age and importance of Responsiveness and Reliability of a Service.

Responsiveness						95% Confidence Interval	
Bonferroni Multiple Comparisons Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
How old are you?	Important	Very Important	-.29*	0.066	0.000	−0.46	−0.11
Reliability							
Bonferroni Multiple Comparisons Dependent Variable	Variable: Reliability		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
How old are you?	Important	Very Important	-.47*	0.089	0.000	−0.71	−0.24

Based on observed means. The error term is Mean Square (Error) = 0.748.
*The mean difference is significant at the .05 level.

Table 6
Results of a Bonferroni post-hoc analysis considering Age, Highest Attained Degree and importance of Confidence in a Service.

Confidence							
Bonferroni Multiple Comparisons							
Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
How old are you?	Important	Very Important	-.26*	0.061	0.000	−0.42	−0.10
What is your highest achieved educational degree in school?	Very Important	Not important	-.48*	0.146	0.007	−0.86	−0.09
		Important	-.18*	0.043	0.000	−0.29	−0.07

Based on observed means. = 0.748.The error term is Mean Square(Error).
* The mean difference is significant at the .05 level.

Table 7
Results of a Bonferroni post-hoc analysis considering socio-demographic aspects and importance of Empathy in Service Quality.

Empathy							
Bonferroni Multiple Comparisons							
Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
How old are you?	Very Important	Not important	-.35*	0.091	0.001	−0.59	−0.11
What is your highest achieved educational degree in school?	Not important	Important	.26*	0.063	0.000	0.10	0.43
		Very Important	.45*	0.064	0.000	0.28	0.62
	Important	Very Important	.19*	0.044	0.000	0.07	0.31
Do you rent or own your current residence?	Very Important	Not important	.11*	0.036	0.014	0.01	0.20
What is your annual household income?	Not important	Important	.18*	0.056	0.005	0.04	0.33
		Very Important	.25*	0.056	0.000	0.10	0.40
	Important	Not important	-.18*	0.056	0.005	−0.33	−0.04

Based on observed means.The error term is Mean Square(Error) = 0.748.
* The mean difference is significant at the .05 level.

acceptance of RES greatly increases as distance from the home increases, a trend shown in Figures (6a) and (6b) (RQ3). If a minimum of 5 miles (8 km) is guaranteed, at least 40% of the United States would accept all RES technology. Biomass power plants are the least popular RES technology with regard to distance. This may be due to the majority of respondents having no experience or limited knowledge with this technology. If biomass is not included, leaving only solar PV and wind, acceptance increases to over 75% if a distance of 5 miles (8 km) from the home is guaranteed. This is not surprising, as majority of respondents preferred Energy Mix 3 which contained the largest percentage of RES technology and smallest percentage of fossil fuels. NIMBYism is not significant reasoning to explain why participants reject RES technology at distances less than 5 miles (8 km). NIMBYism may be a driver of the lack of acceptance of aboveground HVPLs (RQ3).

Environmental sustainability, economic viability, and reliability of supply were all of equal importance to each other regarding policy objectives (RQ4). This may be due to the newness of national discussions in the U.S. as compared to Germany or Ireland where similar studies were conducted [3,41]. Whereas both European countries have active renewable energy transition plans in place, the U.S. national level policy is very much in flux, much less set towards RES technologies. The policies directing to RES have been primarily set by various individual states. This may also support the difference in local level acceptance or opposition – in the United States most RES-positive policy is made at local or regional levels. In Ireland, where RES policies are already in place, opposition is much more likely to occur at the local level (see Refs. [41]).

A final key trend to note is the importance of socio-demographic characteristics regarding acceptance of RES technology (RQ5). These characteristics provide insight to generic trends and drivers on how different groups of people feel toward certain technologies or topics. By policy makers determining this information early on in planning stages, they may find methods to present and implement the RES technology to better suit the population affected by this technology and increase local acceptance. Doing this beforehand could also provide valuable insight as to which locations are better suited for RES technology by pre-determining where populations in the U.S. already have socio-demographic characteristics suited for RES implementation. This should be weighted with the technical feasibility for a given technology for those locations.

6. Conclusion

A majority of the U.S. supports decarbonization via RES, despite an increase in grid expansion. Given a choice, Americans prefer future energy mixes which contain higher levels of RES in the energy supply mix which requires the highest level of grid expansion. Environmental sustainability was given similar importance as economic viability and reliability of supply, further supporting decarbonization of the energy sector. The acceptance of wind and solar PV by 75% of the population if guaranteed distances of 5 miles (8 km) from their homes also supports this finding. Also, a plurality of participants agreed they would be willing to change their lifestyle to reduce their environmental footprint. Over 50% of participants would not be willing to pay more for energy in order to support the expansion of innovative technologies in the energy sector, which may be a 'deal-breaker.' This is largely a political divide rather than an income-driven concern. More research needs to be done to confirm if increase in energy prices would lead to a large number of participants rejecting RES technology.

6.1. *Implications for public policy*

On a federal level, the only energy source that received strong negative acceptance was coal fired power plants, which runs counter to the current administration's push supporting the coal industry. Federal and state policy should realize that economic viability, environmental sustainability, and reliability of energy supply are all important factors, with the importance levels being roughly the same for each. More emphasis should be put on economic viability and environmental sustainability, as many respondents are in favor of new energy technology development. However, the majority of respondents are not willing to pay more for such developments. State and local policy makers should also recognize the importance people assign to the location of energy facilities. This applies to the power plants as well as electrical transmission lines. There is also the importance of including the public in policy development and location decisions, especially early on, as this can help increase the overall acceptance of the final installations as well as offer valuable information for developers.

6.2. Limitations and future work

The perceptions and acceptance of nuclear power plants was not specifically included in the survey due to the understanding that there is a significant and organized opposition to this energy source. We did address issues associated with nuclear power in terms of minimum distances for acceptance from respondents' place of residence and in the various energy mixes that were presented. We also recognize that while an effort was made to balance the survey responses in proportion to regional population breakdown, there are some differences between the survey and U.S. regional population breakdown, although minimal. Some states had low response rates, which may exaggerate some preferences especially when trying to separate out results at the state level. The findings of this survey indicate answers to questions (stated preferences), not observed actions (revealed preferences). Stated preferences and observed behaviors can diverge. Also, on average 20% of responses were "not specified or I don't know" for majority of the questions asked where this was an answer choice. This suggests that for lesser-known technologies, careful consideration should be given to determine if stated preferences align with likely outcomes. In particular, the low acceptance for biomass plants regardless of distance from home and overwhelming positive acceptance of underground HVPLs may be explained by this.

Future work should aim to identify to what extent the American public will allow continued expansion and implementation of RES projects, specifically to determine potential 'deal-breakers' associated with RES, especially regarding local acceptance. In particular, a focus on the increase of energy prices from RES should be explored to determine allowable increases in energy prices, if any at all. A future study should also address concern regarding distributed energy generation technologies, such as rooftop solar, as this study focused on utility scale technologies. This study did not provide any explanations of the mentioned technologies, and further research should be done to identify if providing information about the technology helps participants make better informed decisions about opinions or preferences. The role sociodemographics play regarding trends of acceptance for RES technology should also be further investigated, as this would provide valuable insight for determining locations for RES projects. The role of NIMBYism in public opposition is still a sensitive topic, and future research should also focus on understanding individual attitudes and motivations for opposition, and whether these motivations in practice the same social attitudes or environmental attitudes in behavior.

CRediT authorship contribution statement

Tara Sharpton: Conceptualization, Data curation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization, Validation, Project administration. **Thomas Lawrence:** Conceptualization, Resources, Methodology, Formal analysis, Writing - original draft, Supervision, Funding acquisition, Validation. **Margeret Hall:** Conceptualization, Resources, Methodology, Data curation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Validation.

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Appendix A. Supplementary data

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