nature energy

REVIEW ARTICLE

https://doi.org/10.1038/s41560-019-0399-x

Public perceptions of and responses to new energy technologies

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Energy's central place in economic, political and social systems—and the broad impacts that energy choices have on the natural world and public health—mean that new technologies often spur public reactions. Understanding these public responses and their drivers is important, as public support can influence new technology adoption and deployment. Here I review the literature on public perceptions of and responses to a wide range of new energy technologies. Unlike previous reviews that tend to focus on particular technologies or types of technologies, this Review covers both large-scale energy infrastructure projects, such as utility-scale wind and solar, fossil fuel extraction and marine renewables, as well as small-scale, 'consumer-facing' technologies such as electric vehicles, rooftop solar and smart meters. This approach reveals broad trends that may facilitate communication between policymakers, technologists and the public, and support the transition to a more sustainable energy system.

Nations worldwide are struggling with how to expand and improve access to energy in ways that allow people to live productive lives while minimizing impacts on the local and global environment. The Intergovernmental Panel on Climate Change's recent special report concludes that avoiding the catastrophic effects of climate change will necessitate swift and sweeping modifications to all facets of society, many of which relate to how we produce and consume energy[1]. Particularly in democratic societies, restructuring a nation's energy infrastructure requires public engagement[2]. Yet, such engagement can result in opposition and rejection. For example, widespread public opposition to nuclear energy, combined with its high capital costs, stymied its future in the United States. Likewise, the wind industry was shocked by local resistance to its initial proposals, and local acceptance is now considered a major barrier to its deployment[3]. And even seemingly benign components of the new smart grid, such as smart metering, have faced opposition due to concerns about security, privacy and potential health impacts[4].

Studies of public perceptions of and responses to new energy technologies attempt to understand, describe and explain what the public knows and thinks about these technologies—and, equally important, how they have responded or might respond to their deployment. Understanding public perceptions of and responses to new energy technologies can help facilitate communication between policymakers, technologists and the public; provide critical information for anticipating potential public reactions to new technologies and associated events, such as accidents; and inform educational efforts[5]. Public perceptions and responses can also serve as a check on new technologies with potentially risky outcomes[6]. And, although knowledge about public perceptions and responses does not guarantee acceptance or adoption, its absence is likely to result in failure.

Researchers employ a range of techniques to gauge perceptions of and responses to new energy technologies, including surveys, interviews, focus groups, participant observation, document analysis and case studies. Surveys are a particularly useful and relatively straightforward method for gathering descriptive information about public perceptions of new energy technologies, particularly at the level of the individual. If appropriate sampling strategies are followed, they can be adapted to gather generalizable information from a relevant population. Embedded messaging experiments, in which public perceptions are probed after respondents receive different kinds of messages about a technology, can provide additional information that is particularly useful for policymakers by showing whether certain messages or terminology (for instance, using 'shale oil and gas development' versus 'fracking'[7]) garner greater support. Geocoding of respondents can allow public opinions to be linked to proximity to actual energy development, as well as relevant local social, economic and political factors.

Survey approaches—which require standardized question wording and response choices, capture public attitudes at a single point in time and rely on self-reports—are less well suited to explore why people perceive technologies in a certain way, how they came to hold these perceptions and what actions they have taken as a result. For these questions, researchers conduct interviews, focus groups and participant observation. Such techniques are often embedded in a single case study or in comparisons among multiple case studies of communities, states, regions or nations experiencing actual or proposed development. The value of these approaches stems not from their statistical generalizability to a pre-determined population that has been sampled (as in representative surveying) but from their analytical generalizability to a theory of the phenomenon under study—a theory that may have much broader applicability than the specific case studied. Instead of drawing inferences from data to an entire population, researchers using these methods compare their results to pre-existing theory and are often not focused on testing hypotheses but on refining theory and generating new hypotheses[8].

Qualitative and quantitative content analysis (for instance, of media coverage, hearing transcripts, regulatory proceedings or social media content) can provide more nuanced views of support and opposition to new energy technologies than an opinion poll. Given the depth of information about issue framing, narratives and discourses available from these data sources, such work can elucidate, for example, how opposition to a wind project is composed of local resisters, siting sheriffs, local pragmatists and siting compromisers[9]—as opposed to simply describing people as supportive, opposed or undecided. We are likely to see more of this type of analysis as the use of computer-assisted analysis of text (and images) becomes more widespread.

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Finally, researchers continue to experiment with different techniques to elicit public perceptions, attitudes and behaviour towards technologies not yet deployed—including simulations, virtual/augmented reality, scenario planning and deliberative workshops. For example, simulations have been applied to explore public acceptance of technologies such as vertical axis wind turbines[10] and smart fridges[11]. Deliberative workshops—which bring together small groups of members of the public to explore and discuss a particular issue to obtain a fuller understanding of the public's perspective—have tackled shale oil and gas development[12] and smart homes[13].

Unlike previous reviews that tend to focus on particular technologies or types of technologies, I review the literature on public perceptions and responses to a wide range of new energy technologies, including those that require large-scale energy infrastructure projects (for example, fossil fuel extraction, wind farms, utility-scale solar, marine renewables), as well as small-scale, 'consumer-facing' technologies that rely on consumer acceptance and/or adoption (for example, electric vehicles, rooftop solar, smart metering and appliances, and so on). I also explicitly include articles from the wide variety of methodological approaches used in the field without weighting more heavily either quantitative or qualitative approaches to fully capture both theoretical and practical understandings of public perceptions and responses to new energy technologies.

Often hidden, sometime contentious

One consistent finding in this literature is that the public is often unfamiliar with energy technologies[14–17]. This finding mirrors results from decades of public opinion research showing that the public is often not well informed on specific policy issues[18]. For example, in national surveys of public views on hydraulic fracturing ('fracking') in the United States, most respondents said they knew little about the technology[19,20]. Although survey results in the United Kingdom indicate higher levels of awareness of fracking (70–80%)[21], only 12% of respondents claimed to know a lot about the subject; 42% claimed to know a little; and 22% said they were aware but did not really know what it was[21]. Those living in areas proximate to development in the United States reported higher levels of familiarity, though still only hovering around half of respondents[15,20].

Measures of actual knowledge of energy technologies, as opposed to self-reported familiarity, also reveal gaps. For example, when asked about smart meters and smart grids, only about one-third of participants in a convenience panel of US online respondents had heard of either term[22]. Participant-written definitions indicated no understanding of smart meters among 64% of respondents and no understanding of the smart grid among 47% of respondents[22]. Representative surveys of residents in 21 US cities about plug-in electric vehicles also exposed widespread misperceptions about basic features, such as appearance, costs and driving range, as well as limited awareness of state and local incentives for purchasing[23]. Such findings often frustrate scientists, technologists and developers, who wish for a more engaged and informed public. Yet, given important advances in our understanding about how people process information and make decisions (see below), in some ways, it may be scientists, technologists and developers who are operating on outdated assumptions of human decision-making.

Low levels of public awareness and understanding do not necessarily indicate an inability to understand energy technologies but instead suggest a lack of salience. Except in times of crisis, energy is often invisible to the average consumer, particularly those living in developed countries. Such crises can be acute and affect entire populations, such as the energy crisis of the 1970s, or chronic and affect vulnerable groups, such as energy and fuel poverty. Methods of energy production and/or generation are often distant and unknown; modes of transport are often buried or purposively camouflaged; use is embedded in commonplace daily routines; cost is often relatively low; and environmental impacts are neither apparent nor direct[24,25]. Moreover, our centralized energy systems often remove the public from decision-making[26] and privilege expert technical knowledge over other types of knowledge (local, traditional and so on)[27]. In short, for the average consumer, energy consumption is a ubiquitous yet largely unobserved phenomenon, except when supplies are disrupted or prices spike. In this sense, people tend to focus their attention more on energy disruptions than on everyday energy matters, unless such everyday energy matters are a chronic source of financial stress.

Lack of familiarity, knowledge and salience often leave the public unwilling to take a stance on a specific energy technology, particularly early in its deployment. A study by Whitmarsh et al.[28] of UK attitudes towards a range of energy technologies found large segments of respondents (30–70%) to be ambivalent about particular technologies, particularly less well-known technologies such as carbon capture and storage and underground coal gasification. Research on British views of smart meters found similar ambivalence, with 53% reporting that they were undecided whether smart meters should be installed in every British home[29]. The exception seems to be renewable energy, which consistently receives high levels of support in opinion polling[2,30].

This lack of information and ambivalence towards new energy technologies, and indeed emerging technologies more generally, initially led scholars to posit the scientific literacy model—also referred to as the information deficit model or familiarity hypothesis of risk and science communication[31,32]. Proponents of this model contend that providing more information about emerging technologies will lead to their acceptance, or at least shift public support/opposition to better reflect 'reality'[33,34]. In contrast, more recent scholarship has argued that, due to limited time and resources, people instead often act as 'cognitive misers', using mental shortcuts to filter information and develop opinions[32]. These mental shortcuts can be based on things like ideological predispositions, environmental and altruistic values[35], cultural worldviews[36], media portrayals[37] and elite cues[7]. According to the related concept of motivated reasoning, for new, contentious issues, people tend to seek out and believe information that is consistent with and confirms their prior attitudes[38]. The science literacy model and cognitive miser model may work to describe certain types of people or opinion formation at a certain time in a technology's lifecycle. For instance, the cognitive miser model may work well to describe the vast majority of the public but not those highly interested in scientific topics[39], whereas the scientific literacy model may work well to describe shifts in attitudes about new energy technologies for initially undecided populations after the provision of additional information[28]. Additional research is needed to evaluate shortcuts in contexts beyond the western, educated, industrial, rich and democratic countries, where these analytical concepts were developed and tested[40].

Once energy technologies become familiar, they often quickly become divisive, particularly those involving conventional fossil fuels[3]. When an energy technology becomes salient—which could be driven by extensive deployment, media coverage or proximity to proposed development—views often split, especially along partisan lines[31]. In short, recent social science research suggests that knowledge is not a panacea for improving public understanding and encouraging informed discussions of energy technologies. Instead, studies increasingly show that preconceived attitudes often determine how new information is processed.

Common factors shaping public perceptions and responses

Social scientists from a range of disciplines have assembled a vast amount of literature on the factors that shape public perceptions of and responses to new energy technologies. Instead of focusing on specific theories or models (summarized in Box 1), which are often

Box 1 | Common theoretical frameworks and models

Researchers studying public perceptions of and responses to new energy technologies draw on a wide array of theoretical frameworks and models, leading some scholars to lament the fragmented nature of insights in the field[26]. Even more troubling, many articles do not explicitly draw on a theory base, remaining largely descriptive, making advancements in the field difficult[9,47]. Here, I briefly review some commonly used theoretical frameworks and models.

The theory of planned behaviour. The theory of planned behaviour (TPB) postulates that one's intention to act is the result of a rational decision-making process that considers attitudes towards the behaviour, perceived social pressure to perform the behaviour and an evaluation of one's capability to perform it[47,121]. Thus, TPB largely views decisions to act in terms of one's own self-interest.

Value–belief–norm theory. Value–belief–norm theory (VBN) contends that an individual's motivations for pro-environmental behaviours are rooted in one's values, specifically concern for others and the environment[122]. These general values and others (self-interest, traditionalism, openness to change) shape one's general beliefs about the relationship between humans and the environment, which, in turn, shape one's beliefs about the effects of environmental issues on those things one holds dear and one's sense of responsibility to attend to those effects. These beliefs then affect one's sense of moral obligation to act[47].

Diffusion of innovation theory. Scholars have largely used TPB and VBN to explain consumer adoption of new energy technologies at the individual level. Diffusion of innovation (DOI) theory seeks to explain how an innovation spreads through a social system as a group-based phenomenon. Consequently, DOI focuses on how information about an innovation is communicated through the media and interpersonal channels[44]. The rate at which an innovation diffuses depends on characteristics of the innovation and its adopters.

Social practice theory. TPB, VBN and DOI focus on the different aspects of people and technology that shape perceptions and ultimately behaviour towards new consumer-facing energy innovations, typically using surveys[32,55]. Rather than putting individuals or technologies at the centre of analysis, social practice theory (SPT) focuses on the practices of everyday life—eating, cleaning, cooling and so on. These practices—composed of materials (things, technologies), competences (skills, know-how) and meanings (symbols, ideas, desires)[123]—often require energy[124]. SPT scholars explore how everyday practices change over time to become normal routines, often through historical case studies that show how such practices evolve in unexpected ways[125]. Openly critical of attitude–behaviour–choice models such as TPB and VBN that focus on understanding and encouraging individual pro-environmental behaviour[126], SPT has become increasingly influential in studies of how the public perceives and responds to smart meters, smart homes and demand response programmes[127].

A 'standard model' of public perceptions of risky technologies. To understand perceptions, opinions and responses to larger-scale energy development, sociological and psychological theories have again been important, as have contributions from geography (given important spatial elements) and risk communication (given concerns about public health and environmental risk). In the survey-based literature on these technologies, which is often focused on understanding public opinion as opposed to intent to adopt, a 'standard model' has developed that incorporates elements similar to those found in TPB, VBN and DOI: sociodemographic factors, issue familiarity, risk–benefit perceptions and views about important actors[31]. Place-based and process-based factors have started to be included in these models[83,99].

Social representations theory. Some scholars have encouraged more widespread engagement with social representations theory (SRT)[73]. They argue that a focus on the individual fails to incorporate the macro-level processes of social change associated with energy transitions and the role of social representations, identities and communication. Just as SPT challenges attitude–behaviour–choice models of consumer adoption and changes the lens of analysis from individuals to practices, SRT challenges long-held assumptions about the link between cognitive beliefs and attitudes and widens the lens of analysis beyond the individual[33]. SRT scholars argue that, instead of being shaped by cognitive beliefs, attitudes are influenced by social representations that include affect, attitudes, beliefs and practices[73]. These social representations make unfamiliar new energy technologies familiar by anchoring them in existing worldviews and by making them concrete using images or metaphors. Concepts from the study of social movements have also been applied to understand community response to proposals for energy facilities and echo similar factors, including threats (or perceived risks), framing, political opportunity and resources[76,84].

By approaching the transition to renewable energy sources and distributed generation as requiring the transformation of an entire sociotechnical system, scholars in these traditions emphasize the need to move beyond aggregating individual opinions about a particular technology (public acceptance) to consideration of social acceptance—a multilevel, polycentric, institutional process requiring sociopolitical, market and community acceptance of relevant technologies, polices and projects[92]. Scholars using these approaches often rely on case studies and/or content analysis. They also emphasize the importance of incorporating the views of multiple actors and how these groups interact, including considerations of the role of power and institutions in facilitating or impeding change[92,128].

discipline and/or technology specific, I categorize the dominant factors that researchers have identified as shaping public perceptions of new energy technologies into technology, people, place and process (Fig. 1). While I present these categories as distinct, there is considerable overlap and interaction between them. Writing about studies of energy facility siting, Oltra et al.[41] point out that one of the literature's main contributions was its rejection of one-dimensional explanations, arguing that it is now widely accepted that local opposition is not only the result of a technology's risk or its proximity to population centres but instead contingent on contextual factors. The same is true of the literature on public perceptions of and responses to new energy technologies—its contribution is in providing a more nuanced and more complicated explanation.

Technology. While 'objective' risks and benefits of particular technologies and projects may be quantified by natural scientists, engineers and risk management professionals, it is the perceptions of social, economic and environmental risks and benefits that have been linked to attitudes, policy preferences and behaviour[42,43]. In their seminal work on risk perceptions of technology, Slovic and co-authors[42] identified several key technological factors associated with increased risk perceptions and increased desire for stricter regulation. Specifically, they highlighted a technology's dread risk (for instance, perceived lack of control, catastrophic potential, fatal consequences, inequitable distribution of costs and benefits, involuntariness, high risk to future generations) and its unknown risk (for instance, unobservable, new, delayed, unknown to science).

Notably, nuclear power tends to score high on public perceptions of both of these risk types.

For energy technologies that require consumer purchasing, such as solar panels, electric vehicles or smart appliances, the aspects of an innovation that facilitate its diffusion are its relative advantage, compatibility, simplicity, trialability and observability[44]. Indeed, technical factors—such as performance, speed, style, recharging time, reliability, safety and driving range in the case of electric vehicles—and the perceived advantages and disadvantages these new technologies offer consumers compared with standard technologies are often found to be a major factor shaping consumer readiness or intent to adopt[45]. In the tradition of reasoned action models of behaviour (Box 1), higher upfront costs[23] and long payback periods[46] have long been identified as barriers, with financial incentives seen as preferred strategies for overcoming them[45].

For larger-scale energy projects (fossil fuel extraction, wind farms, utility-scale solar), questions about risks (safety, aesthetic, environmental, community character) and benefits (employment, tax revenue, services) also arise. Visual and auditory characteristics such as turbine colour, size and acoustics are important for public perceptions of wind energy[3,26]. Such physical characteristics echo similar considerations (style, speed, performance) for electric vehicle adoption. For offshore renewable energy, a project's proximity to the coast and associated visual impacts shape the public's view of development[16].

Table 1 summarizes the commonly cited benefits and risks for a range of new energy technologies. Perhaps unsurprisingly, consumer-facing technologies such as electric vehicles and residential solar share common risk–benefit profiles, with risks residing largely in short-term economic and ease-of-use categories and benefits in environment, social and long-term economic categories[45,47]. In terms of larger-scale development, wind, utility-scale solar and fracking share similar risk–benefit profiles (carbon emissions excepted) in that commonly cited risks to host communities largely fall into the environmental and social categories and benefits in the economic category[3,12,30]. Interestingly, studies of marine renewable energies show that simply moving energy development away from population centres does not necessarily facilitate acceptance[48]. Many of the same concerns remain in terms of their impacts to coastal and ocean habitats and industries. In contrast, few environmental or economic risks have been associated with smart meters, with perceived risks mostly falling in the social category. Carbon capture and storage is another interesting hybrid in that it shares many of the same perceived benefits of utility-scale renewables but raises concerns about public safety and slowing a transition to renewables, like fracking[49]. One common concern across all new energy technologies is whether they will exacerbate existing inequalities (rich/poor; developed/developing; rural/urban)[50].

Recommended policy actions to facilitate adoption and acceptance have thus often centred on correcting unequal distributions of costs and benefits to consumers and host communities. Indeed, in their comprehensive assessment of US public attitudes towards energy choices, Ansolabehere and Konisky[2] concluded that people want sources that are 'cheap and clean', positing a consumer model (in contrast to a political or values model) of public attitudes. Yet, financial incentives or compensation alone have often been found insufficient to explain acceptance[51] or adoption[52]. Moreover, social scientists studying sustainable behaviour and low-carbon transitions have consistently called for incorporating social, political and practice-based considerations into a field that has traditionally been dominated by techno-economic models and explanations[53]. We turn to some of these considerations now.

People. Sociodemographic factors, such as gender, age, ethnicity, income and education, have been repeatedly tested in terms of how they shape risk perceptions of and attitudes towards energy technologies. In general, women and young people are more likely to oppose fossil fuel technologies and are more concerned about its risks[15]. For renewable energy, the same divide has not been detected, but there are indications of an age gap in the other direction for public acceptance of demand response programmes, with younger people more accepting than older people[54]. Higher levels of income and education are often associated with early adoption of high-cost innovations, such as electric vehicles and rooftop solar[55]; but income and education have been less consistently linked to views on larger-scale energy development[15]. Openness to innovation and/or change has also been identified as an important trait among early adopters[46,47].

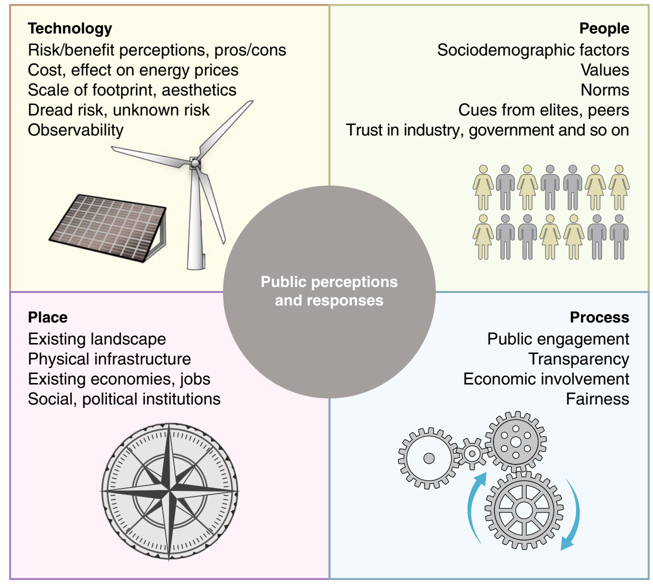

Fig. 1 | Factors affecting public perceptions of and responses to new energy technologies.

In the literature on risk perceptions, a so-called white-male effect—a tendency among US white males to rate all sorts of risks as low compared with women and minorities[56]—has been attributed not so much to gender and ethnicity but to identity, power and control. Those best served by the current system (that is, white males) consistently rank the risks associated with all manner of technologies, and indeed environmental risks more generally, as low. Those least served (that is, women, minorities) judge new technologies as riskier because they see themselves as vulnerable to exploitation[56,57]. Along similar lines, a recent survey of public perceptions of demand-side management in the United Kingdom found respondents concerned about affordability to be both more willing to reduce energy use and less willing to share energy data[17].

In the United States, the white-male effect has been further dubbed the 'conservative white-male effect', highlighting the role of political ideology in shaping views on environmental and energy issues[57]. The role partisanship plays in shaping views on energy has intensified in the United States, particularly when it comes to fossil fuel technologies, as industry donors have become increasingly associated with the Republican Party[58,59]. Indeed, political ideology has been one of the most consistent and strongest predictors of attitudes towards fracking in the United States, with conservatives more supportive and liberals less so[19,60–62]. The United States is not alone; political affiliations have also been shown to be important predictors of attitudes towards shale gas in the United Kingdom[28] and Canada[63]. Researchers have also found partisan divides in terms of support for and adoption of renewable energy technologies[30,55].

Table 1 | Commonly cited risk–benefit perceptions of various new energy technologies

	Benefits/advantages	Risks/disadvantages
Rooftop solar[47]	Reduced air pollution Carbon savings Eventual elimination of electricity bill Tax advantages	Initial expense Toxicity/flammability of materials
Electric vehicles[45]	Reduced air pollution Carbon savings Cheaper fuel Maintenance less frequent, less expensive Quiet Tax advantages High-occupancy vehicle lanes	Initial expense Recharging time Limited driving range Getting stuck without ability to recharge
Smart meters/grid[81]	Consumer savings through feedback, better management of energy usage Carbon savings Automated demand-side response A solution to renewable energy's intermittency and grid management Peak demand management Enhanced resilience	Individual privacy, hacking Cyber-terrorism Trust in automation, algorithms Health from wireless networks
Utility-scale wind[3]	Economic development Tax revenue Landowner and/or community compensation Reduced air pollution Carbon savings	Ecosystem impacts Visual impacts Impacts to property values, electricity rates, tourism and so on Sound annoyance and health effects Intermittency
Utility-scale solar[30]	Economic development Tax revenue Landowner and/or community compensation Reduced air pollution Carbon savings	Ecosystem impacts Visual impacts Impacts to property values, electricity rates, tourism and so on Toxicity/flammability of materials Intermittency
Fracking[15]	Economic development Tax revenue Landowner and/or community compensation Energy security	Ecosystem impacts Impacts to property values, tourism and so on Water pollution, use Air pollution Methane leaks Seismicity Health effects Social disruption Reduced investment in renewables
Marine renewables[16]	Economic development Tax revenue Community compensation Energy security Reduced air pollution Carbon savings Reliability (tidal, wave)	Ecosystem impacts Visual impacts Impacts to other marine industries, activities Intermittency (wind, solar)
Carbon capture and storage[49]	Carbon mitigation Economic development Tax revenue Community compensation	Ecosystem impacts Impacts to property values, tourism and so on Increased electricity price Leakage Public safety Seismicity Reduced investment in renewables

As described above, political ideology may serve as a mental shortcut to establish views on energy issues, especially for those with limited experience with a particular technology such that its risks and benefits are largely experienced in the abstract[20,64,65].

Interestingly, while we might assume that those expressing environmental attitudes would support renewable energy unconditionally, results have been mixed due to conflicting conservation priorities, pitting local harms to wildlife, landscape and so on against global benefits from reduced carbon emissions[3]. Moreover, results from studies on rooftop solar and electric vehicle adoption have cautioned against framing these technologies solely as 'green' choices (thus appealing to environmental values) because this may alienate more conservative adopters and may not align with perceptions of the technology's actual environmental impacts[45,46].

Public perceptions and responses are not formed in a vacuum. The views of others (or the perceived views of others) matter. The media, elites, peers and trusted messengers (for example, government, industry, academics or social movement activists)—and the strategies they select (for example, protest, educational efforts or social media campaigns)—shape public perceptions of and responses to energy technologies[31,37,66–71]. Researchers have highlighted the role of 'social representations'—or socially constructed summary views[72]—of a new energy technology in shaping individual attitudes and community responses[73,74] (Box 1). Such representations allow people to assign meaning to unfamiliar objects, such as new energy technologies, through social processes, such as interactions with others or examining mass media coverage. Often, such representations connect these new technologies to pre-existing mental constructs. For example, people have been shown to perceive and respond to emergent natural resource extraction activities such as fracking through the lens of shared views about the legacy of past resource extraction activities in their community[75].

Place. Not only are aspects of the proposed technology and the people involved important in shaping public perceptions of a new energy technology so too are the characteristics of the place(s) within which it is proposed or deployed, such as historical experiences with similar technologies and industries[75–77] or residence in a 'green' neighbourhood[45]. Indeed, while risks and benefits may be determined in isolation, acceptability and adoption are always context dependent[5]. For larger-scale developments, depending on a particular technology's perceived risks, its proximity to population centres or protected areas can be an important driver of perceptions[76,78]. Moreover, energy development—while sometimes greeted more favourably in rural areas[60]—can become problematic if it is seen as only serving urban interests without adequate compensation for the rural residents most affected or is incompatible with the existing landscape, tourism and recreational opportunities[79]. Moreover, place-based factors, such as a community's economic need for development, have been shown to shape perceptions of newly proposed development[75–77].

Urban–rural divides have been less prominent in the literature on consumer-facing technologies, with rooftop solar even offering an alternative for rural residents who are not well served (or who do not wish to be served) by the grid[46]. A recent analysis of solar panel adoption in the United States found a nonlinear relationship between population density and adoption, with peak adoption occurring at 1,000 people per square mile[80]. For electric vehicles and smart meters, however, infrastructure access in rural areas can be an issue[23,81]. Indeed discussions about rural–urban divides for these technologies have been largely focused on lack of rural access[81].

Whether a new energy technology's development 'fits' with a particular place is important in shaping peoples' perceptions and ultimately their behaviour[76,82–84]. In this sense, 'what was' often plays a critical role in perceptions of 'what will be'[85]. Scholars define 'place' to include both its physical aspects and the meanings and emotions individuals and groups associate with a particular location[83]. Positive emotional connections to a particular location create 'place attachment' and can be incorporated into one's sense of self or identity[83]. When energy development disrupts place-based attachments or threatens place-based identities, people are likely to perceive such development negatively and take place-protective action, such as launching petitions, filing lawsuits and protesting[82,83,86,87]. In one of the first studies to apply these place-based concepts to energy, Vorkinn and Riese[88] surveyed residents in a small Norwegian town slated for hydropower development and showed that place attachment explained more of the variance in attitudes towards the development than all other sociodemographic variables combined. Place-based constructs have since been used to explain attitudes towards offshore wind[89], wave energy[90], tidal energy[82] and hydraulic fracturing[91].

The place in which a new energy technology is proposed also matters because different locations have varying levels of technical potential and different regulatory and political contexts that shape risk and benefit structures. Regulatory and political contexts also establish the rules of the game in terms of, for instance, decision-making procedures as to whether a proposed development will move forward and financial incentives for consumer adoption. They also shape the cues that members of the public receive from political elites. Scholars are increasingly considering the entire sociotechnical system, particularly the role of social and political institutions, in both facilitating and constraining social acceptance of new energy technologies[73,92,93]. In contrast to public acceptance (the aggregated degree of acceptance by individuals), social acceptance is characterized as a multilayered process, incorporating sociopolitical acceptance of policies and technologies by the public, policymakers and key stakeholders; market acceptance by consumers, investors and firms; and community acceptance of individual projects[92,93] (Box 1).

Process. Particularly for large-scale energy development, characteristics of the decision-making process such as transparency, consultation and collaboration[94–96] shape public perceptions of new energy technologies. Public involvement is discussed in both political terms (having a say in decisions, access to important decision-makers and so on) and economic terms (community ownership, favourable leasing terms, appropriate compensation)[26]. Indeed, one reason we see higher levels of support for shale gas development in the United States than in other countries is likely due to the United State's unique mineral rights ownership structures that allow individual landowners to lease and earn income from such development[33]. Public participation can also accomplish important social goals, such as building trust in institutions and educating the public[97], which if done well, can in turn shape public perceptions of future energy technologies and development.

These process-based factors may be more important in shaping views and ultimately acceptance of new energy development than the actual distribution of costs and benefits[72,98,99]. Moreover, people appear to be more willing to accept decisions with which they do not agree if they feel those decisions were arrived at fairly[100]. Scholarship in this area highlights the need for both recognition justice (individuals must be fairly represented and have the right to participate in decision-making processes free from harm) and procedural justice (individuals must have equitable access to decision-making processes), in addition to the more commonly discussed distributional justice (costs and benefits should be equally shared)[50]. In contrast to the traditional 'decide–announce–defend' strategy of energy development, such work encourages increased consultation, engagement and collaboration[78,101].

Despite both the normative and substantive reasons for public participation in energy development, many large-scale energy projects continue to be sited using more traditional, less collaborative methods. Recent smart meter rollouts in the United Kingdom and Quebec have been criticized for their lack of public engagement in the process[81,102]. One reason for such hesitancy is that forums for public participation provide important opportunities for opponents to voice concerns and connect with one another to form opposition groups[27,76,103–106]. Moreover, more collaborative forms of engagement require industry and/or government leaders to devolve authority, control and power over decision-making to members of the public, which they are often loath to do[107].

One need only examine the literature highlighting the virtues of China's 'authoritarian environmentalism', in terms of its capacity to generate rapid national response to pressing environmental dangers, to see why some advocate for more streamlined decision-making processes—often involving less public participation—to facilitate energy transitions[108,109]. One oft-cited example is the role of municipal bans on gasoline-powered motorcycles in China in facilitating the explosive growth in the use of electric bikes[109]. Interestingly, studies of Chinese public opinion of hydraulic fracturing—a technology for which Chinese authorities have made a

Table 2 | Dominant study types in the study of public perceptions and response to new energy technologies

	Individual adoption/public opinion	Community response/social acceptance
Typical research questions	Who adopts (or not)? Who supports (or opposes)?	Under what conditions do communities, regions, nations and so on oppose (or support or accept)? What facilitates (or impedes) widespread adoption/social acceptance?
Theoretical approach	Psychology/social psychology (reasoned action, rational choice, theory of planned behaviour, value–belief–norm)	Sociology (diffusion of innovations, social representations, sociotechnical systems, social movements)
Primary methodology of choice	Surveys	Case studies of actual deployment, opposition, adoption; media/discourse analysis; institutional analysis
Preferred unit of analysis	Individual	Neighbourhood, community, region, country
Main factors emphasized	Technology People	Place Process

big push—indicate high levels of (reluctant) support, particularly among rural residents nearest to development. Such support is linked to both perceived economic benefits and political pressure from the central government[110–112]. Similarly, in Poland, where the central government has made a big push for shale gas development, public opinion has remained quite supportive, despite pockets of resistance[113,114], indicating the importance of both elite cues via policy signals and processes in shaping public opinions. While the climate crisis may justify swift, centralized decision-making to transition to cleaner energy technologies, one has to wonder about the long-term implications of selectively circumventing public engagement for particular technologies, given what we know about this engagement's potential social benefits.

Putting it all together

I have highlighted four categories of factors researchers have identified as shaping public perceptions of and responses to new energy technologies—technology, people, place and process (Fig. 1). Yet, scholars often privilege certain categories, depending on methodological and theoretical choices. In fact, two types of studies have dominated the field (Table 2): surveys aimed at explaining what types of individuals do (or do not) adopt/support, and case studies that seek to explain what factors facilitate (or impede) adoption/support.

Survey-based studies necessarily focus on the individual as the unit of analysis and overwhelming rely on rational models of attitude formation and/or behaviour, focusing on aspects of technology (particularly its risks/benefits or its advantages/disadvantages) and people (sociodemographics, knowledge, values). Place- and process-based factors have been incorporated into these models but are not yet part of the 'standard' model for these types of studies (Box 1). Case-based studies, in contrast, use a larger unit of analysis (community, nation) and often rely on sociological theories that emphasize contextual and institutional factors. While one could view these two approaches as at odds with one another, I think we would do better to view them as complementary and look for opportunities to incorporate insights from each into more comprehensive models.

To more closely match the reality of public perceptions and response requires examining how technology, people, place and process interact. In their article examining the impact of shale gas development in the US West, Haggerty et al.[115] argue that interactions between economic cycles, geology, technology and local context create particular social impacts in particular spaces and places. They go on to identify different types of impact geographies (boomtowns, industrialized countrysides, borderlands, petro-suburbs). Applying this approach would create typologies of public perceptions and responses to new energy technologies based on combinations of relevant factors. It is likely that specific combinations of technology, people, place and process come together to produce particular 'perception geographies'[116] or 'adoption hotspots'[67]. Once identified, scholars could then see whether such geographies or hotspots could be generalized to similar types of places and peoples confronting similar types of technologies and decision-making processes. Given advances in sensing technology deployment[80], metering real-time energy usage, and linking social data to geographic locations over larger time and spatial scales[20], the field seems uniquely poised for research in this vein. Such a focus would allow scholars and practitioners to discover links between individual attitudes, larger institutional structures and the physical environment. Such an approach would not only enrich the scholarly literature but also probably prove to be useful to developers and policymakers.

One particularly thorny issue that plagues the field as a whole is a tendency to focus on the atypical—the new 'hot' technology, the most contentious cases, the early adopters or the opponents[78,99]. In general, we need more studies that explore the entire range of technologies and outcomes[76]. Other areas ripe for research include how perceptions and responses evolve over time[117]; how they compare across multiple technologies and associated infrastructures, not only in the abstract but also in specific places experiencing development[2,64,118]; how perceptions relate to actual behaviour[45]; and what things look like beyond North America and Europe[114].

For practitioners wishing to engage the public and potentially change perceptions, technological design and decision-making processes appear to be the most mutable in the short term. Perhaps this is why we see so much interest in these aspects in practice. Yet, many scholars argue against a focus on technological fixes alone to overcome public opposition, as the reasons for opposition often go beyond the technology[92]. Of course, changing people and place is more difficult and requires long-term investments. We do, however, have examples of such investments in efforts to build support for nuclear energy in post-war Japan[119] and wind energy globally[70], as well as to maintain support for coal mining in West Virginia[69]. Given recent trends in populism and partisanship[120], it is likely that people and place factors will play outsized roles in shaping public perceptions of new energy technologies in the future. Thus, understanding and adapting technologies and decision-making processes to a particular place and people will become increasingly important for the successful deployment of new energy technologies.

Research on public perceptions of and responses to new energy technologies has and will continue to shed valuable light on the complex interface between energy technologies and the broader society they serve. The ultimate goal is to provide more useful—and, even more importantly, more broadly used—energy technologies that will provide generations to come with access to the energy they need to live productive lives with minimal impact on our surrounding environment.

Received: 5 June 2018; Accepted: 24 April 2019;
Published online: 27 May 2019

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Acknowledgements
I thank J. Flora and D. Schaffer for their thoughtful insights.

Competing interests
The author declares no competing interests.

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