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EPRG Working Paper 1810

Cambridge Working Paper in Economics 1826

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Keywords Public preferences; Low carbon; Energy technologies; CCS; Wind; Nuclear

JEL Classification C54, Q42, Q54

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Publication April 2018
Financial Support EPRG survey was funded through a grant from the UK Engineering and Physical Sciences Research Council (EP/K000446/1)

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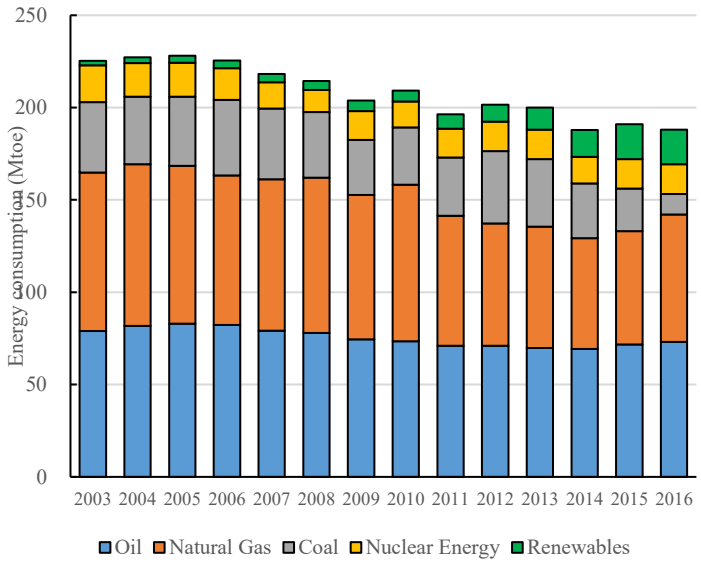
Acknowledgments: The EPRG survey was funded through a grant from the UK Engineering and Physical Sciences Research Council (EP/K000446/1)

1. Introduction

Innovative and emerging technologies are accompanied by significant uncertainties in risk management [1]. Public acceptance is a common risk facing new technologies because it affects the potential for their widespread deployment. Throughout history, many new technologies, including nuclear power, embryonic stem cells, genetic modification (GM), and nanotechnology, have experienced strong public opposition after their introduction [2].

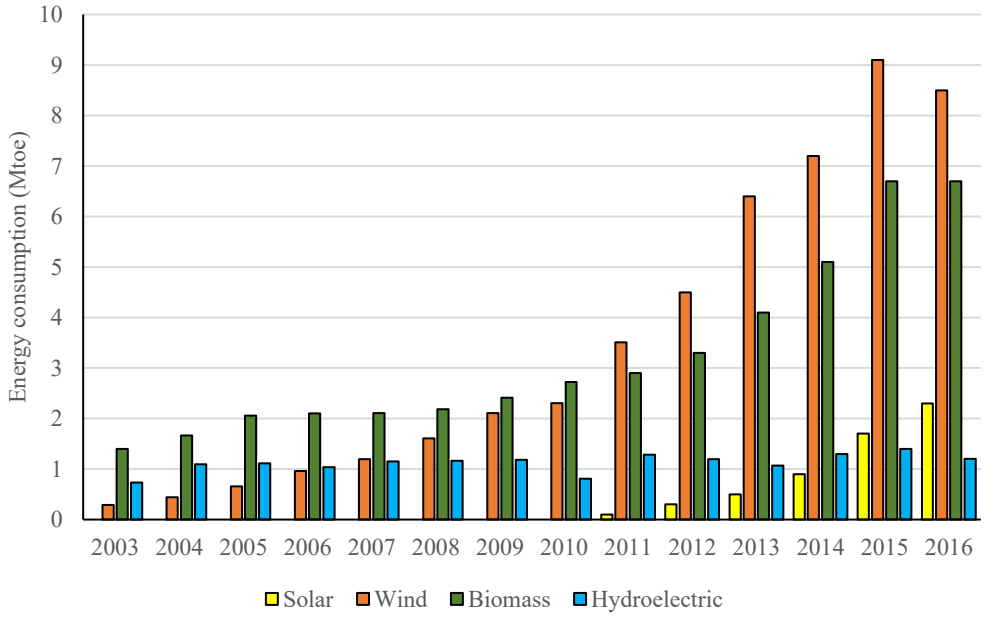
The progress of low-carbon energy technologies is intimately linked to growing concerns over climate change. Beginning with the United Nations Framework Convention on Climate Change and through the Kyoto Protocol and Paris Accord, the international community has committed to actions on climate change. The UK set an ambitious mitigation target, aiming to reduce its GHG emissions by at least 80% by 2050 (relative to a 1990 baseline), which it enshrined in its 2008 Climate Change Act [3]. However, the UK also faces an energy security problem as it increasingly relies on imported energy to meet it energy needs having been a net oil and gas exporter in the 1990s. Considering the necessity of mitigating climate change and securing energy supplies, the energy mix needs to shift dramatically by replacing conventional fossil energy with low-carbon options. Fig. 1 shows the evolution of the UK energy mix from 2003-2016. Over the period, conventional fossil energy consumption (oil, natural gas and coal) has fallen from approximately 90% of total consumption to 80% driven primarily by the dramatic increase in renewables from 1% to 10% and the role of coal has shrunk dramatically, particularly since 2014. Although there has been important progress, the adoption of low-carbon energies, such as wind, solar, nuclear, still has a long way to go if the UK is to meet its 80% target.



Source: BP (2017) [4]

Fig. 1. The primary energy mix in the UK from 2003-2016

Considering the current degree of dependence on fossil fuels in the UK energy mix, new technologies that can mitigate the carbon emissions from burning fossil fuels, such as carbon capture and storage (CCS), would be needed to satisfy emission reduction goals [5]. However, there have only been a handful of commercial-scale CCS projects globally and the UK cancelled its proposed £1 billion demonstration program in late 2015 [6]. Nuclear energy currently plays an important part in the UK energy mix – contributing more than 19% of UK electricity in 2013. However, all but one of the nuclear power plants is over 40 years old and the role of nuclear energy in the UK's future energy system is highly contested [7]. Fig. 1 shows that renewable energy still accounts for a small proportion of the UK energy mix although its share has been growing rapidly (from a small base). Among the different forms of renewable energy, wind and biomass account for the largest proportion of total consumption (Fig. 2). The UK has also set a goal of producing 30% of its electricity from renewable energy by 2020.



Source: BP (2017) [4]

Fig. 2. The structure of renewable energy consumption 2003-2016

Incentives to encourage investment in low-carbon energy is essential, but the role of public acceptance cannot be ignored. Public support is a crucial factor that has been put forward to be a considerable obstacle to the cost-effective development of new low-carbon energy technologies [8]. The IPCC Special Report on Renewable Energy and Climate Change Mitigation argued that large-scale renewable energy can only be implemented successfully with public support and understanding [9]. Therefore, it is necessary to investigate public attitudes towards different kinds of low-carbon technologies and determine which factors influence public support. Are the factors similar or different for different kinds of technologies? How do these factors influence public support?

We commissioned a public survey in the UK to study public attitudes towards different low-carbon energy technologies, using nuclear power, CCS and wind energy as examples. We systematically compared the determinants and influences of public support for three low-carbon energy technologies. Although our work focuses on CCS, wind power and nuclear energy, we would expect that given the diversity in these three technologies there would be wider lessons on public preferences for other low-carbon energy technologies.

2. Literature review

The three technologies we study fit into the wider literature on emerging technologies. It is important to study both the determinants of public attitudes towards emerging technologies and the attitudes themselves to understand what accounts for support. Many studies of novel technologies often start by exploring the role of scientific knowledge. Allum et al. conducted a meta-analysis and found that across 40 countries and almost 200 representative surveys, there was a small positive correlation between general attitudes towards science and general knowledge of scientific facts, controlling for a range of possible confounding variables. [10]. Siegrist et al. found that key influences on support for GM field experiments were attitudes towards "economy/health and environment", "trust and honesty of industry and scientists", and "competence" [11]. Chen et al. demonstrated that public attitudes towards nanotechnology applications are determined by the perceived benefits and risks of using nanotechnology, which are in turn dependent on public opinions towards technology in general, their knowledge of nanotechnology, and their trust in the institutions involved [2].

Researchers are increasingly interested in social attitudes towards low-carbon energy technologies. Numerous studies have been published on this subject [e.g., 8, 12, 13, 14], and we provide a brief literature review below.

2.1 What are public attitudes towards diverse low-carbon energy technologies?

Given the advantages and disadvantages of diverse low-carbon energy technologies and different national contexts, publics hold varying levels of acceptance and support for these technologies. We will focus here on general attitudes of the wider public, not on local (or regional) attitudes or views of specific projects.

The three technologies we consider differ enormously in terms of public familiarity and saliency and, of these, CCS is, by far, the least known. However, an increasing number of work from the social sciences focused on public acceptance and communication of CCS [15]. Daamen et al. first suggested that for CCS it was important to understand the role of pseudo-opinions, or opinions provided by those who claim to know nothing about a subject [16] and they found these views are unstable and easily changed. Support for CCS varies widely, and most studies have been conducted in North America and Europe with slightly stronger support in Europe, although there have been studies in Australia, Japan, India and China [17-23]. L'Orange et al. pointed that it is not easy to compare acceptance degrees across studies because the public is unfamiliar with CCS and opinions were greatly influenced by the information provided

[24]. Malone et al. went further and questioned the reliance on surveys on a subject such as CCS [25].

By contrast, there have been several decades of surveys on renewable energy and public opinion consistently ranges from moderately to overwhelmingly positive [26, 27]. Europeans show strong support overall [12, 28, 29]. A Eurobarometer survey conducted across the EU-28 discovered high support levels for deploying renewable energy sources (e.g., 80% in favour of solar energy, 71% wind, 65% hydroelectric energy and 55% biomass), with only small numbers opposed [12]. Most studies have focused on attitudes towards specific kinds of renewable energy, especially wind power, which is one of the best-applied renewable energy technologies. The longest history of studies of public opinion has been with regard to nuclear power [30, 31]. According to European Commission [32], nuclear energy leads to the most objection among the EU public. However, public opinions of nuclear power are complicated, divided and have changed gradually [32]. Nuclear energy has conditional support that has been called "reluctant acceptance" by some researchers [7, 33]; that is, the public will tend to support nuclear if it can make contributions to mitigate climate change or energy security [34]. A disproportionate number of past research of public viewpoint of nuclear energy have been performed in the UK [13]. Corner et al. found that historically, the public in the UK has shown significant opposition to nuclear power [7]. However, more recently, since nuclear power has been reconstructed as a low-carbon technology at the policy level, the public has begun to take nuclear power as an important aspect of the national future energy structure [35].

Considering that multiple low-carbon technologies will often compete for funding in the energy system, it is interesting to compare public attitudes towards different kinds of low-carbon technologies. Although many studies have focused on only one kind of energy technology, several studies have compared different kinds of low-carbon technologies [36-40]. For example, van Rijnsoever et al. investigated the role of labelling, time and heterogeneity in the formation of public support for energy technologies, including photovoltaic solar energy, offshore and onshore wind energy, biomass, and coal [38]. The results showed that respondents' acceptance levels for energy technologies change when labels are revealed or unseen. Cherry et al. investigated how perceptions of both CCS and wind energy are shaped by local economic benefits and individuals' cultural world outlook [36]. Fleishman et al. investigated public support for CCS and other low-carbon technologies and different low-carbon portfolios, but the determinants of these preferences were not examined [8].

2.2 What factors influence public attitudes and how?

In general, public acceptance of energy technologies depends on many factors and would be difficult to cover in a single study. These factors can be classified into three broad categories: economic factors, psychological factors and demographic factors [41].

Whether a given energy technology will be seen as offering greater economic benefits or risks is a direct and important indicator of public acceptance. There is a recognition that emerging low-carbon energy technologies may be costly, and people

are not generally pleased with the prospect of higher energy bills. Upham and Roberts used focus groups in six European countries and find that, except in Spain, cost is the most important contributor in deciding which electricity source that participants believed should be used [42]. Moreover, the participants were also concerned that the economic risks involved with CCS are higher than those of renewable energy. Similar concerns about cost was found by Ribeiro et al.: a perception that renewable energy technologies will lead to lower energy prices increases technology acceptance significantly [37]. According to a survey conducted in South Korea, the perceived price of renewable energy technologies was the elementary determiner of the purpose to apply the technologies before the Fukushima Daiichi nuclear accident [43].

Unlike economic factors, which affect public attitudes intuitively, psychological (behavioural) factors have more complicated influences. Huijts et al. presented a comprehensive framework considering the key psychological factors influencing public preferences on basis of a review of psychological laws and studies of empirical acceptances of energy technologies [41]. We use this framework to summarize the psychological factors and effects in our study. Perceived trust, fairness, knowledge and experience are recognized as the psychological factors that influence public acceptance. When the level of knowledge is not high, the trust in related stakeholders has been proved to be a trustworthy contributor of the support for a new energy technology [24]. Furthermore, trust not only affects opinion formation directly but also affects it indirectly by influencing perceived costs, risks and benefits [44]. Fairness, or how fairly people consider the way a technology is applied, is also a predictor of acceptance and categorized into two types, procedural fairness and distributive fairness, which interact with trust [41]. Knowledge about the technology itself, the effects of the technology and other relevant issues is a very important variable because it can directly impact people's perceptions of risks and benefits [45]. However, subjective and objective knowledge about an energy technology may have various effects, and these two types of knowledge should be distinguished. Experiences with one specific energy technology may make knowledge grow. Likewise, experiences may also affect perceived risks and benefits. Knowledge has also been shown to be an important factor contributing to the formation of attitudes about other emerging technologies, such as genetically modified (GM) foods [46].

Previous studies have found that demographic factors, including age, income, gender, education, and political affiliation, also affect public attitudes [7, 17]. For example, Kim et al. found that the males tend to strongly support nuclear energy than women, and a higher educational level leads to more reluctant acceptance [13]. Generally, income level has been found to positively affect acceptance of nuclear power, and older people are more likely to strongly support for nuclear power than younger people. Miller et al. found that people with a higher education are more knowledgeable about the debate over climate change and are more favorable towards CCS [47]. Karlstrøm and Ryghaug concluded that political affiliation has a greater impact on opinions of different energy technologies than previously thought [48].

Scholars have also studied a wide range of factors, including politics and ideology [48-50], cultural worldviews [36], and environmental values and concern about climate

change [9, 33]. Thus, many determinants can affect public attitudes. We focus on the key factors that scholars have found to be the most important. Multiple factors may interact and cannot be clearly separated. For example, individual traits may impact acceptance through psychological factors rather than through direct effects [41]. Likewise, the level of trust may have an influence on the perceived economic benefits and risks.

The factors mentioned above may have different influences on different energy technologies, but there is a lack of literature comparing these factors' influences on public attitudes towards different low-carbon energy technologies [36,48]. However, it is unreliable to compare the impact of the same factor on different technologies if the survey is not conducted in the same context.

Given that there are a large body of studies on public preferences for low-carbon energy technologies, the innovations provided by this work include the following:

a) An investigation of public attitudes in the UK towards different low-carbon energy technologies in the context of addressing climate change, and b) a comparison of the factors, both unique and overlapping, that affect the attitudes towards different kinds of technologies. Research has shown that people do not base their choices on one technology's observed characteristics alone [38]. Therefore, instead of focusing on the risks and benefits of a specific low-carbon energy technology, we pay more attention to the large-scale, common factors that may affect social support, including attitudes towards energy issues, climate change and environment, in an effort to draw out some broader conclusions.

3. Methodology and data

3.1 Survey and data collection

We developed a questionnaire to investigate the factors that impact public attitudes towards different kinds of low-carbon energy technologies. In our survey, the low-carbon energy technologies we focused on were CCS, wind and nuclear power. We included questions about the environment, climate change, energy, climate change mitigation technologies, and general social and economic issues. The questionnaire consisted of separate sections on: a) demographic information, including age, gender, social status, region, party, education level, and income; b) environmental attitudes, attitudes towards energy issues and climate change; c) knowledge on energy issues and climate change; and d) other social, economic, and political factors.

The survey was administered by the YouGov for the Energy Policy Research Group (EPRG) at the University of Cambridge in June 2014. YouGov is an online polling company and market research firm based in the United Kingdom. The UK YouGov panel has over 400,000 respondents, and restrictions are put in place to ensure that only people who meet certain requirements were allowed to participate. In the end, this survey received 2080 responses, including those who did not complete the full survey.

3.2 Regression model

To estimate how the factors affected people's choices, we developed a multiple regression model, which is shown in Equation (1):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_m X_m \quad (1)$$

where i is the ith observation and Y_i is the vector of the ith observation of the dependent variable. The levels of support for a given low-carbon energy technology were classified into 5 groups: 1-definitely use, 2-probably use, 3-neutral, 4-probably not use and 5-definitely not use. X_i is the ith observation of the explanatory variables, which include the demographic factors, environmental attitude, social, economic, and political factors, knowledge about energy and climate change issues, and attitudes towards energy issues and climate change; and β_i is the vector of coefficients to be estimated.

3.3 Data processing

The descriptive statistics of potential independent determinants are shown in Table A-III in the Appendix. In the survey, all "do not know" and "prefer not to say" responses are treated as missing values and not included in our analysis. Some of the socio-demographic variables in the table were adjusted to reduce the length of the scale to a binary variable. For example, for the demographic question about employment status, there were 8 options offered, including full time, part time (8-29 hours a week), part time (less than 8 hours) work, being a full-time student, unemployed or retired. To simplify, we reclassified the 8 options into a binary dummy variable where 1 represents full-time work and 0 represents the other 7 options. Similarly, the work organization and education level variables were also combined into two categories from the initial 7 and 18 options, respectively (separating those working in the private sector or self-employed from others and those with at least an undergraduate degree from the rest of the sample).

There were two groups of questions, a self-assessment and an objective assessment of respondents' knowledge about energy and climate change issues. For the question "*Have you heard of or read about any of the following in the past year?",* we offered 16 options: (a) more efficient appliances, (b) more efficient cars, (c) hydrogen cars, (d) nuclear energy, (e) bioenergy/biomass, (f) deforestation/reforestation, (g) solar energy, (h) CCS, (i) wind energy, (j) iron fertilization, (k) geoengineering, (l) ocean acidification, (m) shale gas, (n) enhanced oil recovery, (o) hydraulic fracturing (fracking) and (p) land reification (an imaginary technology as a test). We considered the (yes or no) answers to some specific options (CCS, nuclear and wind) as variables, and we calculated the total number of items that respondents had heard of or read about. This number is included in the model as an indicator of self-assessed knowledge. Similarly, we also calculated the number of correct answers to the other two knowledge questions. Detailed statistical results are shown in Appendix Fig. A-I. The region, party information and social grade are not ordered or binary variables, so the three variables are included in the model as categorical variables, with *London*, *Lab* (Labour Party supporter) and *AB* as the reference categories, respectively.

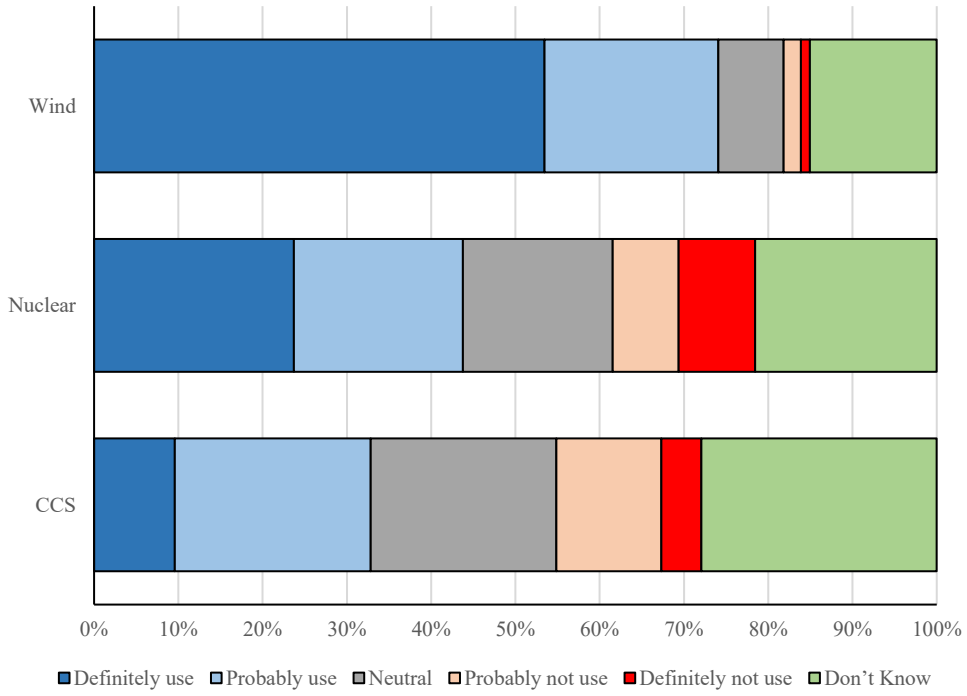
4. Results and discussion

4.1 Public preference for different low-carbon energy technologies

The main objective of our survey is to investigate public preference for different low-carbon energy technologies and the factors that influence different preferences. Here, we define "support" as respondents' willingness or readiness to accept the use of a given energy technology to address climate change. With this in mind, we asked the respondents the following question:

The following technologies have been proposed to address climate change. If you were responsible for designing a plan to address climate change, which, if any, of the following technologies would you use?

We offered different kinds of technologies for this question, and for each technology, the respondents can choose from 6 responses: definitely use, probably use, neutral, probably not use, definitely not use and do not know. Fig. 3 summarizes the responses.



Note: The full descriptions for each kind of technology are: CCS: Capturing carbon dioxide from natural gas-fired (or coal-fired) power plant exhaust and storing it in underground reservoirs; Nuclear energy: Producing energy from a nuclear reaction; Wind energy: Producing electricity from the wind, traditionally in a windmill.

Fig. 3. Summary statistics of public support for different types of low-carbon energy technologies (n=2080)

More than half of respondents (53.5%) would definitely use wind energy, compared to only 23.7% for nuclear power and 9.6% for CCS. Only a very small number of the respondents indicated that they would probably not use (2.1%) or definitely not use (1.1%) wind. By contrast, overall opposition (definitely not use and probably not use) for nuclear power and CCS was 16.9% and 17.2%, respectively. Thus, respondents clearly preferred wind energy to address climate change. This affirms the results of [52], who found that renewable energy is regarded most positively, followed by traditional fossil fuels and then nuclear energy. This may be because wind

energy is generally acknowledged to be a clean, safe, mature and sustainable energy choice compared with nuclear and CCS. Nuclear gains more support than CCS in part because of the greater uncertainty surrounding CCS and the large number who respond 'don't know' to questions regarding CCS, which may lead to many who profess unstable or 'pseudo' opinions [53].

A related explanation for these results could be respondents' knowledge or familiarity with different kinds of energy technologies. More than half of respondents (55%) had read about or heard of wind energy in the past year, which drops to 40.9% for nuclear power versus only 21.2% of respondents that had read or heard of CCS in the past year, reflected in the much larger number of respondents who responded 'don't know' to questions on CCS. Therefore, we infer that knowledge is one factor influencing people's choices, and we hypothesize that the more knowledgeable a respondent is about a given technology, the more supportive they will be of low-carbon energy technologies.

4.2 Factors influencing public preferences for low-carbon energy technologies

The regression model estimation results are shown in Table 1. The goodness of fit measure (R^2) for the CCS model is much worse than those for nuclear or wind, which is unsurprising because, as noted above, people have a much lower understanding of CCS and tend to answer "don't know" or say "they have never heard of it" or "know very little about it".

Table 1 Regression results for three low-carbon energy technologies

	CCS		**Nuclear**		**Wind**	
	B (S.E.)	Sig.	B (S.E.)	Sig.	B (S.E.)	Sig.
Demographic factors						
Age	-0.004 (0.002)	*	-0.005 (0.002)	**	0.003 (0.002)	
Gender	-0.223 (0.073)	***	-0.457 (0.075)	***	0.026 (0.065)	
Social grade						
AB (reference)						
C1	0.092 (0.083)		0.102 (0.085)		0.064 (0.074)	
C2	0.080 (0.103)		0.246 (0.107)	**	0.013 (0.093)	
DE	0.066 (0.100)		0.126 (0.104)		0.063 (0.090)	
Party						
Lab (reference)						
Con	-0.026 (0.093)		-0.043 (0.096)		0.181 (0.083)	**
Lib Dem	-0.066 (0.117)		-0.102 (0.122)		-0.177 (0.107)	*
SNP/Plaid Cymru	0.152 (0.291)		0.220 (0.309)		0.051 (0.272)	
Other	0.571 (0.198)		0.115 (0.202)		0.198 (0.175)	
None/DK	0.136 (0.091)		-0.166 (0.095)		-0.033 (0.082)	
Environmental attitudes						
Single most important issue facing the country						
Environment	0.189 (0.079)	**	-0.100 (0.082)		-0.100 (0.071)	
Social, economic, and political factors						
Increase international aid, stay the same, decrease international aid or remove entirely?	-0.039 (0.048)		-0.049 (0.050)		-0.001 (0.043)	
Are science and technology making our lives healthier, easier, and more comfortable?	0.115 (0.037)	***	0.138 (0.038)	***	0.004 (0.033)	

Knowledge about energy and climate change						
Self-assessment						
Heard of or read in the past year?	-0.006 (0.010)		-0.014 (0.010)		-0.017 (0.009)	**
Objective assessment						
Activities with significant impact on CO2 levels in atmosphere						
(No. of correct answers)	-0.026 (0.022)		-0.036 (0.022)		-0.035 (0.019)	*
Nuclear power plants	0.034 (0.085)		0.230 (0.088)	***	-0.039 (0.076)	
Windmills	-0.153 (0.184)		0.091 (0.189)		0.495 (0.163)	***
Can CCS reduce the following environmental concerns?						
(No. of correct answers)	-0.371 (0.074)	***				
Climate Change			-0.172 (0.076)		-0.125 (0.066)	
Attitudes towards energy issues						
Trust in energy-related information from:						
Regional/ local government	0.003 (0.028)		-0.041 (0.029)		-0.015 (0.025)	
Electricity, gas and other energy companies	-0.027 (0.028)		-0.044 (0.029)		0.028 (0.025)	
Environmental protection organizations	0.032 (0.025)		0.130 (0.026)	***	-0.067 (0.023)	***

Impact on future energy bills of:						
Building more onshore wind farms	-0.002 (0.033)		-0.185 (0.034)		0.280 (0.030)	***
Recent agreement to build nuclear power plant	-0.006 (0.030)		0.286 (0.031)	***	-0.037 (0.027)	
Building coal or gas plants with CCS	0.219 (0.031)	***	0.008 (0.033)		-0.030 (0.029)	
Attitude towards climate change						
Opinion about climate change (options 1-4: 1, serious problem and immediate action is necessary| 4, concern unwarranted)	0.032 (0.052)		0.022 (0.053)		0.164 (0.047)	***
Change needed to lifestyle and consumption habits to stop effects of climate change	-0.027 (0.087)		0.258 (0.090)	***	-0.235 (0.079)	***
Constant	2.163 (0.354)	***	2.151 (0.369)	***	1.338 (0.324)	***
R^2	0.159		0.287		0.297	
observations	979		1030		1054	

Note: * indicates significant at the 10% level; ** indicates significant at the 5% level; *** indicates significant at the 1% level.

Most demographic variables considered in our study, including region, education level, work organization and employment status, did not have significant impacts on support for the three energy technologies, which is in slight disagreement with the other research. It is interesting to note that older individuals were more likely to support nuclear, a finding that is in agreement with those from a previous study conducted by Corner et al. in Britain [7]. Kim et al. also concluded that younger people are less likely to support nuclear energy because they tend to obtain more information about the potential risks of nuclear [13]. In addition, we found older people were more supportive of CCS. As expected, males tended to support both CCS and nuclear, because compared with the relatively mature wind technology, CCS and nuclear are new, uncertain and "risky" and there is a longstanding concern over nuclear power in particular because of its association with radiation [30]. However, age and gender did not significantly affect public support for wind energy. Respondent's social grade did have an effect on their support for nuclear power. Using the classification system developed by the UK Office of National Statistics (ONS), respondents in the C2 social grade (skilled manual occupations) were less likely to support nuclear power than those in the AB social grade (managerial and professional occupations).

Environmental attitudes were anticipated to be an important factor, since it was expected that those more concerned about the environment would exhibit greater support for environmentally friendly and low-carbon energy technologies. However, our results do not support this hypothesis. Among the three questions about environmental attitudes, only one showed a weak significance level of 5% for CCS. People who believed that the environment is one of the most important issues facing the country were less willing to support CCS (Table A-I has full results for most important issues). This result supports the claim that general pro-environmental values do not lead to greater support for CCS technology [52].

We also tried to see if more general views on spending priorities and on science and technology had an impact on technology support – for example, we thought that support for international aid might reflect broader support for government programmes and that a more positive view of science and technology would be associated for 'techno-fix' options such as nuclear power and CCS. Views on international aid did not have any significant influence on the support for the three technologies, but a respondent's attitude towards science and technology did influence support for both CCS and nuclear. People who agree that science and technology are making our lives better are more willing to support CCS and nuclear, and both findings were significant at the 1% level. This may be because these technologies, especially CCS, are perceived as relatively new and advanced energy technologies.

We also tested whether knowledge about energy and climate change issues had an effect on attitudes. The results indicated that both the self-assessment and objective assessment of their level of knowledge influenced public support. The people who assessed themselves as more aware of (i.e., have heard of or read about) different kinds of low-carbon technologies was associated with support for wind energy. However, this

self-assessment did not significantly affect support for nuclear or CCS, which is consistent with the finding that there is only a weak relation between knowledge about CO_2 and CCS and attitudes towards CCS [55]. Compared with self-assessed knowledge, objective assessment knowledge has a clearer effect on public support since all the coefficients of the surveyed questions are statistically significant. The results also showed that respondents with more knowledge about energy and climate change are more supportive of the three low-carbon technologies.

A range of energy-related perceptions are expected to affect support for low-carbon energy technologies including cost and trust in key stakeholders in the energy sector. The level of trust in the information provided about energy-related issues did have an influence, but trust in different information sources, e.g., the UK government, regional/local government, and energy companies, which are all responsible for energy technologies, and environmental protection organizations, had very different impacts. Trust in regional and local governments did not significantly affect support for any of the three technologies. By contrast, trust in the information provided by environmental protection organizations and energy companies on energy-related issues was significant but had the opposite effect on public support for nuclear and wind energy. Respondents who trust environmental NGOs are more inclined to support wind energy and more inclined to oppose nuclear, and both results are significant at the 1% level. This is unsurprising insofar as environmental groups tend to be strongly supportive of wind power and strongly opposed to nuclear power and relatively cautious on CCS [54].

We also found that the cost of energy is a common factor that influences support for the three technologies. Unsurprisingly, when people believe that low-carbon energy technology will raise their energy bills, they are less likely to support them, and our findings are statistically significant at the 1% level for all three options. This finding is in line with previous work [37, 43]. Perceived cost is another kind of perceived risk. A large number of scholars have pointed that although there are numerous issues involved in assessing new technologies, cost is one of the leading contributors affecting perceptions [43]. We also surveyed public attitudes towards current energy prices and found that 88.2% of the respondents believe they are high (30.6% moderately high, 30.5% very high and 27.1% unreasonably high). However, public attitudes towards energy prices in general do not directly affect public support for low-carbon technologies since none of the coefficients are statistically significant. Our result indicates that people do not believe that low-carbon energy technologies will inevitably increase the price they pay for energy, which is in agreement with a finding from Portugal that few people believe that renewables will increase their electricity bills [37]. Therefore, before implementing new energy technologies in the UK, decision makers should carefully consider the impact (both real and perceived) that these technologies will have on energy bills.

Regarding attitudes towards climate change, respondents who agree that climate change is so serious that immediate action is needed are more supportive of wind energy, but this belief in a need for climate action does not affect public support for the

other two energy technologies, which is particularly striking for CCS, which can only be justified on climate change grounds. Previous studies have found that the public opposes the use of nuclear power, primarily for environmental and safety reasons [7, 52, 55, 56]. Spence et al. (2010) showed that concern about environment and climate change are negatively associated with nuclear energy but positively associated with renewable energy [52], which is also in line with historical environmental beliefs and discourses [52, 56]. In addition, a belief in the need to radically or dramatically alter our behaviour to stop the effects of climate change is negatively related with support for nuclear energy but is positively correlated with support for wind energy.

5. Conclusions and implications

Public attitudes towards emerging technologies are recognized as important factors in their successful implementation. Our study examines the determinants of support for nuclear, CCS and wind technologies and analyses public preferences for different low-carbon energy technologies on the background of climate change in the United Kingdom.

Each of these technologies has a different risk profile. Wind is viewed by the public as a relatively low-risk technology, whereas nuclear energy is thought of as a higher-risk technology. CCS is also viewed as having potential risks, but they are not as fully recognized as those of nuclear power since respondents express low awareness of CCS technologies.

Compared with nuclear energy and CCS, wind energy is, by far, the most preferred technology for mitigating climate change; wind energy, nuclear energy, and CCS receiving the support of 74.1%, 43.8% and 32.8% of respondents, respectively. It is unsurprising that people will prefer what they perceive as lower-risk technologies to achieve a climate change mitigation target. Public attitudes towards climate change is strongly correlated with support for wind power: those who believe that climate change is such a serious problem that immediate action is needed exhibit a strong preference for wind power. Our model also shows that respondents' political party affiliation affects public support for wind energy: for example, Liberal Democrat supporters were more likely to support wind than supporters of the Labour Party and Conservatives are less likely to support wind than Labour Party supporters, which broadly corresponds to the individual parties' positions on low-carbon energy development, with Conservatives most hostile to siting onshore wind in particular.

Demographic factors played a more important role in models of support for nuclear energy more than the two other energy technologies. Older respondents and those of a higher social grade were more supportive of nuclear. Pro-environment attitudes had negative effects on support for CCS, while support for action on climate change was negatively correlated with support for nuclear power.

To some extent, CCS and nuclear are perceived as "risky" techno-fixes. Our findings resonate with those of Lock et al. that lay attitudes towards CCS echo concerns over nuclear power [57]. In that context, it is not surprising that male respondents, who

have been shown more tolerant of risks and more supportive of novel technologies [13, 33], were more inclined to support both CCS and nuclear. Similarly, respondents who believed that science and technology are making our lives better also favoured using CCS and nuclear.

Although both nuclear power and wind are low-carbon technologies, the relationship between support for using these options and taking actions on climate change diverges – there is a clear positive relationship between opinions about climate action and support for wind, whereas there is an inverse relationship between support for nuclear power and aggressive climate action, i.e., stronger supporters of the need for significant behavioural change to address climate change tend to oppose the use of nuclear energy. Similarly, we found that trust in environmental protection organizations had this opposite effect – that is, people who trust environmental protection organizations are more likely to favour wind energy and more likely to oppose nuclear. Neither finding is particularly surprising since many environmentalists (and environmental organizations) are strong supporters of renewables but have an unfavourable view of nuclear energy [54].

Perceived cost and objective knowledge were found to influence support for all three technologies. The perceived effects of low-carbon technologies on energy bills significantly influenced public support: when people believed that low-carbon energy technologies would increase their energy bills, they preferred not to support them (significant at the 1% level). Objective knowledge was directly and positively related with public support for low-carbon energy technologies. However, some factors, including most of the demographic factors tested (e.g., region, education level, income, work organization and employment status) and trust in the UK government, did not affect support for any of the three technologies.

6. Limitations and future work

Inevitably, any study of public preferences for low-carbon energy technologies and the determinants thereof, will have limitations. We focused here on only CCS, nuclear and wind energy within the portfolio of low-carbon technologies, but there are many other options to evaluate, including solar energy (usually ranked as the most popular option) and biomass as well as other 'older' options such as hydroelectric power or geothermal energy all of which involve their own considerations with regard to acceptance by local publics as well as the general public.

We define public attitudes here as being whether people are willing to support using a given low-carbon technology as part of a portfolio to address climate change. This belief is different from what attitudes might be towards, say, siting a wind turbine or nuclear power plant near their home.

Our focus, like most other studies (and policies), has been on low-carbon electricity, but there is growing interest in low-carbon heat and transport, although to date there has been little empirical work on the subject. Furthermore, in light of calls in the Paris Accord to keep global temperature growth below 2°C, with an aim for

1.5°C, there is increasingly a need for studies of carbon-neutral fuels and negative emissions technologies such as bioenergy with carbon capture and storage (BECCS) [58].

On our narrower question of low-carbon electricity, there may be other important factors determining public attitudes which were not covered in our study, including more detailed features of knowledge, framings and perceived risk and benefits. Moreover, we were focused here only on the determinants of overall support for a technology, but implementation will ultimately depend not only on generalised support at a national level, which may affect permitting proceedings and political support, but on whether individual projects receive a social license to operate from local populations.

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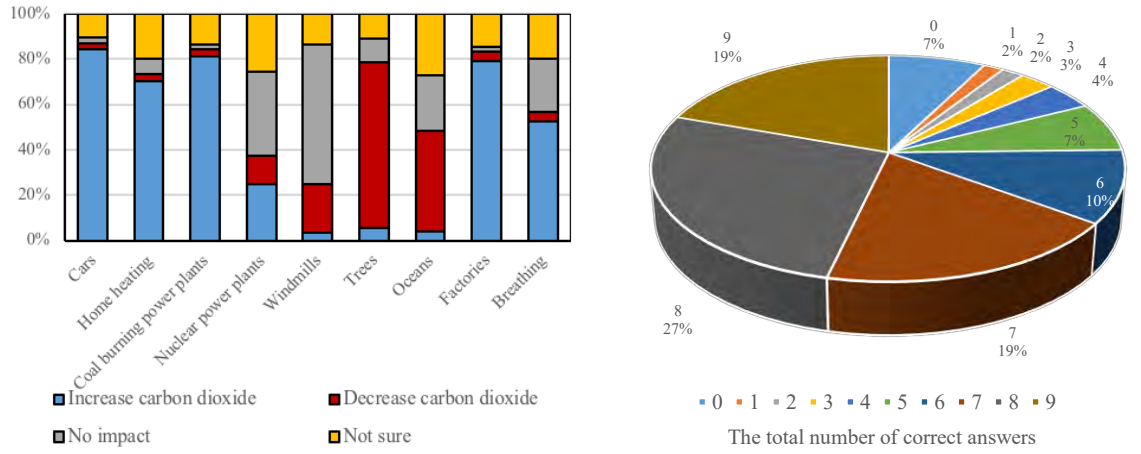
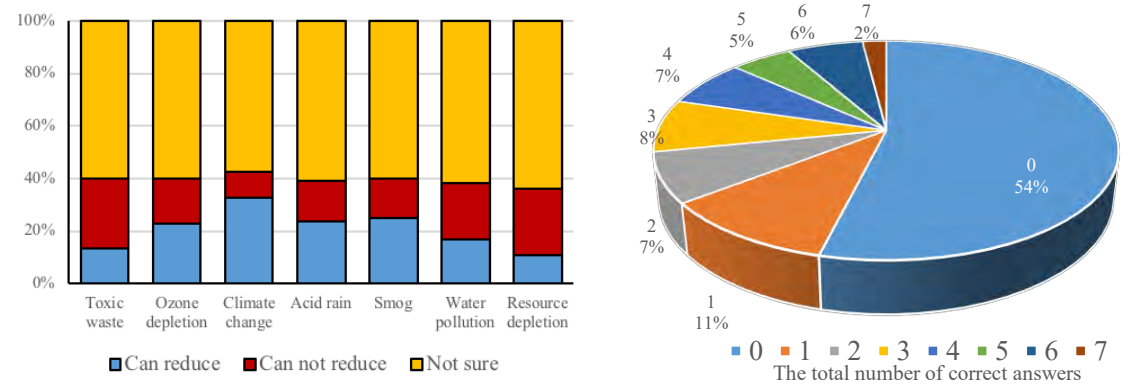
Appendix



(a) Response to the question *Which, if any, of the following activities have a significant impact on levels of carbon dioxide in the atmosphere?*



(b) Response to the question *Do you think "Carbon capture and storage" or CCS can or cannot reduce each of the following environmental concerns?*

Fig. A-I. Summary statistics of questions on knowledge about energy and climate

Table A-I Respondents' choice of the most important issues facing the country

Option	Percentage	Option	Percentage
Immigration & Asylum	52.3%	Pensions	13.7%
The economy	50.4%	The environment	13.2%
Energy prices	27.0%	Family life & childcare	10.4%
Health	26.0%	Tax	9.8%
Europe	21.2%	Crime	9.7%
Education	18.9%	Transport	2.9%
International conflicts	15.7%		

Note: Respondents are allowed to choose up to three options.

Table A-II Respondents' choice of the most important environmental problems

Option	Percentage	Option	Percentage
Overpopulation	57.0%	Toxic waste	14.9%
Climate Change	43.9%	Endangered species	10.7%
Resource depletion	33.7%	Ozone depletion	9.6%
Destruction of ecosystems	26.4%	Smog	4.5%
Green spaces	17.7%	Acid rain	1.7%

Note: Respondents were allowed to choose up to three options.

Table A-III Descriptive statistics of dependent variables and potential independent determinants

Variable	Obs	Min	Max	Mean	S.D.	Code
Support for CCS	1499	1	5	2.72	1.100	1-definitely use, 2-probably use, 3-neutral, 4- probably not use 5-definitely not use
Support for nuclear	1632	1	5	2.47	1.323	1-definitely use, 2-probably use, 3-neutral, 4- probably not use 5-definitely not use
Support for wind	1756	1	5	1.82	1.090	1-definitely use, 2-probably use, 3-neutral, 4- probably not use 5-definitely not use
Demographic factors						
Age	2078	18	100	47.09	17.160	Actual age
Gender	2080	0	1	0.5	0.500	0, female; 1, male
Social grade	2080	1	4	2.28	1.128	1, AB; 2, C1; 3, C2; 4, DE
Region	2080	1	5	2.90	1.166	1, London; 2, Rest of south; 3, Midlands/Wales; 4, North; 5, Scotland
Party	2080	1	6	3.00	2.066	1, Lab; 2, Con; 3, Lib Dem; 4, SNP/PC; 5, other; 6, None/DK
Education level	2003	0	1	0.48	0.500	0, Less than a university degree; 1, University degree and above
Income	2080	0	1	0.43	0.495	1, Deciles 1-8; 0, Deciles 9-10
Work Organization	1604	0	1	0.39	0.489	0, Self-employed or private sector; 1, Others
Employment status	2080	0	1	0.43	0.495	1, full time; 0, others *(a. part time ; b. full time student; c. retired; d. unemployed; e. not working; f. other)*
Environmental attitude						
Please select which you believe to be the most important issue facing the country?						
Environment	2080	0	1	0.13	0.339	1, yes; 0, no
Energy Price	2080	0	1	0.26	0.444	1, yes; 0, no
Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view?	1835	1	4	2.38	0.733	Scale 1-4: 1, The highest priority to environment|4, The highest priority should be given to the economy
How effective or ineffective do you think environmental regulations are in protecting the environment in your local community?	1687	1	5	3.20	0.991	Scale 1-5: 1, Very effective|5, Very ineffective

Social, economic, and political factors						
We currently assist other nations through international aid. Do you think we should increase international aid, let it stay the same, decrease international aid or remove it entirely?	1930	1	4	2.71	0.816	Scale 1-4: 1, increase|4, remove entirely
To what extent do you agree or disagree with the following statement: Science and technology are making our lives healthier, easier, and more comfortable	2002	1	5	2.24	0.919	Scale 1-5: 1, strongly agree|5, strongly disagree
Attitudes towards energy issues						
How would you describe energy prices today?	1984	1	7	5.76	1.015	Scale 1-7: 1, Unreasonably low|7, Unreasonably high
To what extent do you **trust** information about energy-related issues from each of the following sources?						Scale 1-7:
The UK government	1954	1	7	3.36	1.601	1, not at all|7, totally
Regional/ local government	1922	1	7	3.37	1.492	1, not at all|7, totally
Electricity, gas and other energy companies	1963	1	7	2.50	1.417	1, not at all|7, totally
Environmental protection organizations	1957	1	7	4.16	1.697	1, not at all|7, totally
What impact, if any, do you believe the following would have on your future energy bills?						Scale 1-7:
Building more onshore wind farms	1763	1	7	3.68	1.228	1, very large drop in energy bills|7, very large rise in energy bills
Recent agreement to build a new nuclear power plant	1621	1	7	3.66	1.301	1, very large drop in energy bills|7, very large rise in energy bills
Building coal or gas plants with carbon capture and storage	1469	1	7	4.03	1.227	1, very large drop in energy bills|7, very large rise in energy bills
Attitude towards climate change						
Of these, please select the environmental problem you believe to be the single most important problem.						
Climate change	2080	0	1	0.44	0.496	1, yes; 0, no
From what you know about climate change, which of the following statements comes closest to your opinion?	1948	1	4	2.01	0.901	Scale 1-4: 1, Climate change has been established as a serious problem and immediate action is necessary|4, Concern about climate change is unwarranted
How much change do you think is needed to our general lifestyle and consumption habits to stop the effects of climate change happening?	2079	0	1	0.58	0.493	1, We need to radically/dramatically alter our behaviour; 0, others (*a. We need to dramatically alter our behaviour to be more energy efficient, but solutions to climate change must come through the development of clean energy sources; b. Changing our behaviour on such a large scale is not feasible; therefore, we need to rely on technological development of cleaner energy sources; c. Neither behaviour change nor widespread use of cleaner energy technology will stop climate change happening; d. Climate change is not a problem at all.*)

Knowledge about energy and climate change issues						
Self-assessment						
Have you heard of or read about any of the following in the past year?	2080	0	16	5.05	3.968	The number of correct answers
Nuclear energy	2080	0	1	0.41	0.492	1, yes; 0, no
Carbon capture and storage	2080	0	1	0.21	0.408	1, yes; 0, no
Wind energy	2080	0	1	0.55	0.498	1, yes; 0, no
How familiar are you with carbon capture and storage (CCS) technologies?	2079	0	1	0.40	0.489	1, others; 0, never heard of this *("others" include: a. heard before, but not at all familiar; b. not very familiar; c. neither familiar nor unfamiliar; d. somewhat familiar; e. very familiar)*
Objective assessment						
Which, if any, of the following activities have a significant impact on levels of carbon dioxide in the atmosphere? (The activities include cars, home heating, coal burning power plants, nuclear power plants, windmills, trees, oceans, factories, breathing and the options include "Yes, increases carbon dioxide", "Yes, decreases carbon dioxide", "No impact", "Not sure".)	2079	0	9	6.47	2.584	The number of correct answers
Nuclear power plants	1889	0	1	0.32	0.468	1, increase; 0, decrease or no impact
Windmills	1901	0	1	0.04	0.201	1, increase; 0, decrease or no impact
Do you think "Carbon capture and storage" or CCS can or cannot reduce each of the following environmental concerns? (The offered environmental concerns include toxic waste, ozone depletion, climate change, acid rain, smog, water pollution and resource depletion)	2079	0	7	1.54	2.088	The number of correct answers
Climate change	2079	0	1	0.33	0.469	1, can reduce; 0, not sure or cannot reduce

Note: All the variables listed here are potential independent variables, so not all of them will be included in the final model depending on their significance