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Public perception of bioenergy with carbon capture and storage in Denmark: Support or reluctant acceptance?

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ABSTRACT

Most climate change mitigation scenarios rely on negative emissions technologies like bioenergy with carbon capture and storage (BECCS). However, little is known about public support for BECCS. This paper gauges Danes' willingness to pay (WTP) for biomass with carbon capture and storage and examines factors influencing it. Denmark is a suitable case study given its reliance on biomass and negative emissions to achieve climate targets. Results from a questionnaire-based survey indicate a mean WTP of 3072 DKK (412 EUR) per household per year. This correspondents to a 12% increase in heat and electricity expenses. The need for negative emissions is the main stated reason for WTP. This may be interpreted as reflecting either support for, or reluctant acceptance of, BECCS. Results show that being younger, being concerned about climate change and believing that it is mainly caused by human activity, and believing in the mitigation potential of biomass and that sustainability is a precondition of its use have a significant effect on WTP. Public views on BECCS are complex but must be acknowledged if discussion of the role of BECCS in the decarbonisation agenda is to move forward.

1. Introduction

Numerous regions worldwide are increasingly being exposed to natural disasters whose frequency and intensity are also increasing (IPCC, 2018; Spence et al., 2011). Despite national and international institutions having stepped up their climate change mitigation efforts since the Rio Declaration on Environment and Development (UNFCCC, 1992), these efforts need to be redoubled to reduce the greenhouse gas (GHG) emissions being released into the atmosphere and to limit global temperature increases to a maximum of 2 °C, or better 1.5 °C, above the pre-industrial average, as stated in the Paris Agreement.

In this context, the EU has adopted net-zero GHG emissions targets. Over the past couple of decades, IPCC reports have highlighted that reducing GHG emissions released into the atmosphere is not enough to achieve net-zero targets and that active removal of atmospheric emissions is necessary (Abt et al., 2022; IPCC, 2022). A recent report by the European Scientific Advisory Board for Climate Change also argues that net-zero targets will necessitate CO_2 removal from the atmosphere (ESABCC, 2023). Amongst the current CO_2 removal options, carbon capture and storage (CCS) is the only technology that is close to large-scale usage. If biomass energy is coupled with this technology, and assuming that the former is CO_2 neutral, there is the potential to achieve negative emissions. This negative emissions technology (NET), known as bioenergy with carbon capture and storage (BECCS), is expected to contribute to net-zero targets because, in principle, it will lead to carbon-negative, rather than carbon-neutral, energy production (Drollette, 2022).

Our dependency on fossil fuels, which comprise around 81% of the global primary energy demand (IEA, 2019), has created an unprecedented need towards the development of low-carbon societies. Despite the theoretical climate potential of BECCS to help develop such societies, and even though many of the current scenarios for phasing out fossil fuel reliance hinge on its use (Drollette, 2022; Hilaire et al., 2019; Fuss and Johnsson, 2021), this technology has been widely criticised for the ethical and environmental risks it presents. At the core of the criticism is the reliance of BECCS on the assumption that the bioenergy feedstock is carbon-neutral and that employing BECCS is deferring the unprecedented mitigation efforts needed today (Fuss et al., 2014; Dyke et al., 2021).

The existing debates surrounding BECCS are dominated by the voices of a few stakeholders, including academics, industry representatives, and politicians. Public opinion, despite its central role in policy, is not

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represented in those debates. Several analyses investigating perceptions of CCS have emerged in the last couple of decades (de Best-Waldhober et al., 2012; Romanak et al., 2021; Upham et al., 2015; Wallquist et al., 2012; Wolske et al., 2019), but with some exceptions (see e.g., Bellamy et al., 2019; Klaus et al., 2020; Merk et al., 2019; Thomas et al., 2018) studies of perceptions of BECCS in broader society do not abound. However, the increased reliance on and the ongoing debates over BECCS, and the fact that any climate mitigation initiative carried out will inevitably be strongly affected by public support or opposition (Pour et al., 2018) make it especially urgent to disentangle public opinion about BECCS.

Most studies of BECCS focus on its techno-economic potential (e.g., Almena et al., 2022; Azar et al., 2010; Bui et al., 2021; Cabral et al., 2019; Daggash et al., 2019; Huang et al., 2020; Kraxner et al., 2014a, 2014b; Muratori et al., 2020; Patange et al., 2022; Weng et al., 2021) and its trade-offs or challenges (Babin et al., 2021; Cobo et al., 2022; Stoy et al., 2018; Waller et al., 2021; Yamagata et al., 2018). To our knowledge, no study has focused on public support for BECCS in monetary terms. Assessment in monetary terms can provide insight into the strength of support for or rejection of this technology and it can be useful as it is expected that large (economic) incentives will be required for BECCS to compete with other, more mature technologies (Black et al., 2021; Creutzig, 2016). An established method of assessing the monetary value of technologies addressing a public good problem – such as the problem of CO_2 in the atmosphere that BECCS is supposed to solve – is contingent valuation (CV) (Bateman et al., 2002). In this method, individuals' willingness to pay (WTP) for a particular good is elicited using a hypothetical market. Eliciting how much someone is willing to pay for the implementation of BECCS is a way of measuring how large the benefit of such implementation is to the individual. Thus, the underlying rationale is that maximizing people's utility in a broad sense is what society strives for, and hence eliciting their preferences expressed in WTP for a certain good is a way to assess its value relative to other goods and services.

Against this background, the present study gauged public support for BECCS using the CV method (see Section 3.2) and Denmark as a case study (see Section 2). In the given CV scenario, the question takes the form of a policy expenditure issue, which can help answer the question of whether BECCS can be economically feasible if delivered through an increased tax. This study also explored the reasons for the (un)willingness to pay, and investigated the influence of several potential explanatory variables that might determine WTP, namely: sociodemographic variables (age, gender, income, education) and a series of perception variables related to both climate change and the use of biomass. It can be argued that WTP is embedded in systems of belief and complexes of attitudes, and that we should therefore expect respondents answering the CV question to be reflecting these social-psychological variables when they report their preferences for an unfamiliar technology (Sauer and Fischer, 2010). Thus, a further objective of this study was to assess whether social-psychological variables are underlying factors determining heterogeneity in preferences. This is investigated both by direct interaction and through a latent class model. This study, the first to examine public acceptance of BECCS in monetary terms, provides insights into a small (but, we hope, growing) body of knowledge about the legitimacy of BECCS from a social perspective. This study is therefore of strategic relevance for climate mitigation and energy policies. Note that this study focuses on the potential carbon removal that BECCS is expected to provide. It is thus beyond the scope of this paper to focus on the geological storage or utilisation of the captured carbon.

The paper proceeds as follows. First, we describe and justify the country case study under consideration (Section 2). Descriptions of the development of the survey instrument, the CV method, the econometric models used to analyse the data, and the explanatory variables, are offered next (Section 3). The results of the study are presented in a subsequent section (Section 4), followed by a discussion of these and their implications (Section 5). Lastly, the study's main conclusions and policy implications are set out (Section 6).

2. BECCS in Denmark

Our analysis is focused on the support for woody biomass (i.e., biomass from forest sources) coupled with CCS of the population of Denmark. Denmark is a particularly interesting case, since to meet its climate goals, including that of achieving net zero by 2050 (see *The Danish Climate Act, Act. No 965 of 26 June 2020*, 2020), the Danish Government is relying upon both biomass and negative emissions (Danish Council on Climate Change, 2020; 2022). Fossil fuels accounted for 57% of the gross energy consumption in Denmark in 2021 (Danish Energy Agency, 2021). Woody biomass – in the form of wood pellets, wood chips, firewood, and wood waste – is currently seen as an important energy source to reduce the share of fossil fuels in Denmark's energy mix. Indeed, woody biomass is currently the major renewable energy source in Denmark, accounting for 48% of the renewable energy mix (Danish Energy Agency, 2020) and contributing substantially to district heating systems. However, the sustainability credentials of this energy source have been largely questioned. Because a large share of the woody biomass in Denmark is imported, it is challenging to trace and ensure its sustainability, including its carbon neutrality. This large import share has been criticised as a means merely of exporting the problem because carbon stock reductions are accounted for in the country where the biomass is produced while its burning is considered carbon-neutral. Further, the average usage of 10 GJ of woody biomass per capita per year is estimated to be what can be produced sustainably at the global level (Danish Council on Climate Change, 2018). This is considerably lower than the current Danish per capita consumption per year, which amounts to 35 GJ (Danish Energy Agency, 2020). Thus, a key challenge is the shortage of carbon from sustainable biomass (Danish Council on Climate Change, 2022). This challenge is amplified by the fact that demand for, and consumption of, biomass is expected to rise globally over the coming years (Danish Council on Climate Change, 2022), not only as a result of natural gas shortages and price increases, but given the current need to end dependency on Russian oil (Booth, 2022). These controversies, together with those about BECCS (e.g., Beier, 2021; Djursing, 2022; Jørgensen, 2021; Køhler, 2022), make the study of the Danes' opinion on BECCS particularly pressing to disentangle.

3. Materials and methods

3.1. Sampling strategy and survey design

Participants in the study were drawn from an online panel of Danes operated by a survey research agency (*Voxmeter*) in the Spring of 2021. The panel includes around 100,000 registered adults. Informed consent was obtained from all of the participants, and permission to conduct the study was granted by the ethics board at the Faculty of Science and the Faculty of Health and Medical Sciences at the University of Copenhagen. A total sample size of 1023 was obtained after excluding respondents who failed to provide meaningful responses. In all, 37 potential participants were discarded given their extremely short survey completion times (< 7 min) in comparison with the average time needed, and in response to straightlining behaviour (i.e., systematically providing identical responses to the items in a battery of questions).

We used quota sampling to recruit respondents. Acknowledging the often preferred probability sampling strategy and the inherent biases in quota sampling, we followed recommendations by Brown et al. (2017) to enhance the quality of the sample and guarantee the most robust results possible. The recruitment process involved sample quotas for gender, age, and geographical region, so that the sample reflected the Danish population across these criteria. Quota sampling was conducted on a *probability sample*, which allowed for reducing selection biases and ensured that the results obtained are an acceptable reflection of the actual perceptions of Danish people (Brown et al., 2017).

Table 1 shows the shares for the quotas, as well as education and income, in our sample, and compares these with the corresponding shares in the Danish population. We obtained a generally representative sample that aligned with the wider Danish public in terms of age, gender, and geographical region. However, individuals with higher education were overrepresented, and those with lower incomes were underrepresented. The respondents' ages ranged from 19 years to 83 years, with a mean of 49 years (*SD* = 15.86), and 59% of respondents had completed a higher education programme. The sample was near-equally split by gender, with 49% men and 51% women. Table 1 also shows the sociodemographic characteristics of the sample after respondents with a protester profile when answering the CV question had been removed (see Section 3.2 for more details). See Appendix A (Tables A.1 and A.2) for a detailed comparison of the sample with the Danish population. Overall, then, the characteristics of the sample in terms of age, gender, and geographical region closely approximate those of the Danish population.

Data for the study were elicited using a questionnaire, available in the supplementary file in Appendix B, designed to assess public attitudes to woody biomass energy and BECCS in Denmark. This survey consists of four main sections. The first includes questions about housing, knowledge about woody biomass, and other energy sources. The next presents a CV question to elucidate WTP for BECCS (see Section 3.2. and Appendix C). The third section focuses on perceptions of climate change. The final section gathers background information. Another paper has been published using the same data but focusing on attitudes to, and concerns associated with, woody biomass (see Ugarte Lucas et al., 2022). The current paper is novel in focusing explicitly on BECCS and investigating WTP. Before the final launch of the survey, the questionnaire was pre-tested and pilot-tested with 11 and 100 randomly selected Danish individuals, respectively. These two processes ensured that necessary changes to the survey instrument were made. During the pre-test, the CV question was carefully examined to select the bid levels (i.e., amounts of tax increase presented in the CV question) and study comprehension of the survey. The pilot test helped elucidate the adequacy of the bids.

Table 1
Comparison of sociodemographic characteristics of respondents with those of the Danish population.

	Sample (*n* = 1023) (%)	Sample without protest voters (*n* = 730) (%)	Danish population 2021[a] (%)
Gender			
Female	50.64	52.10	50.26
Male	48.88	47.31	49.74
Other	0.29	0.35	–
Do not wish to say	0.2	0.23	–
Age (years)			
18–34	20.43	20.33	27.38
35–49	30.89	31.07	22.92
50–64	24.44	24.53	24.52
65 or more	24.24	24.07	25.19
Education			
Primary, high school, vocational training	40.96	41.00	64.96
Higher education (1 to 5 years), and PhD	58.85	58.76	35.05
Do not know	0.2	0.23	–
Region			
Hovedstaden	28.93	29.67	31.76
Sjælland	14.47	13.55	14.37
Syddanmark	23.66	23.25	20.95
Midtjylland	22.78	22.78	22.82
Nordjylland	10.17	10.75	10.10
Income (DKK)[b]			
< 200,000	5.87	5.61	15.40
200,000 – 399,000	27.27	26.87	35
400,000 – 599,999	18.18	18.11	18.30
≥ 600,000	33.92	34.35	31.30
Do not know/Do not wish to say	14.76	15.07	–

Notes.
[a] Census information is available at Statistics Denmark (www.dst.dk).
[b] Income levels in EUR: < 26,848; 26,848 – 53,563; 53,697 – 80,545; ≥ 80,545.

3.2. Contingent valuation method

The outcome variable of our study, namely WTP for the implementation of BECCS, was elucidated using a single-bounded dichotomous-choice CV question, the theoretical foundation of which stems from random utility theory. This stated preference method can be used to estimate the economic value of non-marketed commodities that cannot be elucidated by revealed preference methods. It does so by allowing for a hypothetical scenario where respondents are asked to provide their WTP for a particular bid based on the information provided (Bateman et al., 2002). The dichotomous-choice format has been shown to have several advantages over the open-ended format in terms, for instance, of its simplicity for respondents (relatively lower cognitive burden) and reduction of incentive to provide strategic responses (Champ and Bishop, 2006; Ivanova, 2005). Moreover, the dichotomous-choice approach replicates a real-life voting decision (Champ and Bishop, 2006) that is adequate for the nature of our CV question.

Following recommendations in the CV literature, we designed the CV question in a manner including questionnaire pre-test, follow-up questions, clear description of the hypothesised scenario, and substitute reminder (see e.g., Bateman et al., 2002). We presented respondents with an explanatory text describing BECCS. We aimed to keep this text short, concise, and neutral in tone. It was the result of multiple iterations following up on reviews of the questionnaire as well as pre-testing interviews. Respondents were asked in a hypothetical scenario if they would be willing to pay for the implementation of BECCS. The question used a referendum-type format to elicit WTP for a specified amount as a single addition to tax – an option that could be realistic in the future considering current political debates. The payment vehicle was described as an increase in the respondent's household's energy tax, as that is an easily recognisable way of paying for electricity. Note that Danish consumers pay both a per-energy unit tax (differentiated, but it applies to all types of energy) and a CO_2 tax. The latter does not apply to biomass as it is considered carbon neutral.

A general best practice for CV questions is to be specific about the quantity of the proposed change (e.g., Johnston et al., 2017). In our case, the change is a reduction in emissions through BECCS. A first draft of the CV question presented an estimate of the mitigation potential of BECCS. The pre-test results showed that such a scenario was confusing for respondents. Further, obtaining a reliable estimate is not possible given the uncertainty associated with the CCS technology and the CO_2 neutrality of the bioenergy feedstock. Further, the choice of energy source is often not voluntary for the individual consumer. For example, this is the case for private households connected to district heating. In conclusion, we opted for the most realistic scenario description – despite causing the exact quantity of the good to be imprecise. This has to be kept in mind when interpreting the results.

The payment was described as an annual one given that capturing carbon is a continuous cost. The monetary values used ranged from 50 DKK (7 EUR) to 8000 DKK (1074 EUR) (Table 2). There were 1023 observations divided into 9 groups, with approximately the same number of individuals assigned to the first 8 bids and 50 individuals to the highest bid. Respondents were reminded to consider their budget constraints and alternative uses of their income. To analyse the reason(s) behind the answer to the CV question and identify protest responses, the CV question was accompanied by follow-up questions. The payment question and follow-up questions are shown in Appendix C.

Table 2
Bid distribution ($n = 1023$).

Bid (DKK)	Bid (EUR)	Frequency	Percent
50	7	123	12.02
250	34	122	11.93
500	67	124	12.12
750	101	120	11.73
1000	134	122	11.93
1500	201	120	11.73
2000	268	121	11.83
4000	537	121	11.83
8000	1074	50	4.89

In the formal analyses, we excluded strategic bidders and protest zero bidders because their answers do not reflect the trade-offs to be made when answering the CV question, and thus do not elicit their true WTP. Strategic bidders are those who try to influence the provision of the good, or policy, by signalling their support through overbidding. They were identified as those who answered *Yes* to the WTP question and then, when asked about their reason for that answer, chose the response option "*I am interested in the promotion of woody biomass for energy no matter the additional costs for my household*". Protest zero bidders are those who state a zero bid despite valuing the good or policy. They were identified as those who answered *No* to the WTP question and then selected "*I am in favour of the proposal but it should be financed by existing taxes*" as the reason for their answer. There were 123 protest zero bidders and 44 strategic bidders, and thus a total of 167 protesters.

3.3. Econometric models

3.3.1. Logistic regression model

In the dichotomous-choice CV format used in this study, respondents were asked to choose from two alternatives: the current situation (option z_0), i.e., no implementation of BECCS, and a situation of change (option z_1), i.e., implementation of BECCS. Drawing upon the econometric models of Soliño et al. (2009a) and Soliño et al. (2009b) to evaluate WTP for biomass energy, we define the indirect utility function in Eq. (1):

$$V\left(z_j, y_j, \varepsilon_j\right) = v\left(z_j, y_j\right) + \varepsilon_j,\ j = 0, 1 \tag{1}$$

where v is the deterministic part of the utility associated with z_j and income y_j, and ε_j is an error term. The valuation question offers respondents the possibility of an exchange in the form (in our survey) of an environmental improvement by means of potential achievement of negative emissions, at a price (A). If we assume an improvement of $z_1 > z_0$, we arrive at Eq. (2):

$$v\left(z_1, y_j - A\right) + \ \varepsilon_1 > v\left(z_0, y_j\right) + \ \varepsilon_0 \tag{2}$$

The probability of choosing one alternative over another then becomes (3):

$$\begin{aligned} Pr(yes|A) &= Pr\left\{V\left(z_1, y_j - A\right) > V\left(z_0, y_j\right)\right\} \\ &= Pr\left\{v\left(z_1, y_j - A\right) + \varepsilon_1 > v\left(z_0, y_j\right) + \varepsilon_0\right\} \\ &= Pr\left\{v\left(z_1, y_j - A\right) - v\left(z_0, y_j\right) > (\varepsilon_0 - \varepsilon_{1i})\right\} \\ &= Pr\{\Delta v > (\varepsilon_0 - \varepsilon_{1i})\} \end{aligned} \tag{3}$$

where $Pr(yes|A)$ represents the probability that the respondent accepts the exchange at the proposed price, and $Pr(no|A) = 1 - Pr(yes|A)$. Let $\eta = \varepsilon_0 - \varepsilon_1$ and F_η be its cumulative distribution function. If we assume a logistic distribution, this function will specify a logistic function. We then have the logit model in the form of Eq. (4):

$$Pr(yes|A) = \ F_\eta\ (\Delta v) = \frac{1}{1 + e^{-\Delta v}} \tag{4}$$

If we also assume the utility function to be linear, the utility differential can be expressed through Eq. (5):

$$\Delta v = \ \alpha + \gamma A + \beta' s,\ \alpha = \alpha_0 - \alpha \tag{5}$$

where s is a vector of independent variables, β is a utility coefficient vector and γ is a coefficient associated with A. Substituting in Eq. (4) we obtain Eq. (6):

$$Pr(yes|A) = \ F_\eta\ (\Delta v) = \frac{1}{1 + e^{-(\alpha + \gamma A + \beta s_i)}} \tag{6}$$

Eq. (7) is the resulting logistic regression equation (estimated by maximum likelihood):

$$\ln\left(\frac{Pr(yes|A)}{1 - Pr(yes|A)}\right) = \alpha + \gamma A + \beta' s \tag{7}$$

From this we can derive the mean WTP for a specific group of respondents with characteristics of s by solving Eq. (8):

$$\alpha + \gamma A_0 + (b_1 s_1 + b_2 s_2 + \ldots + b_n s_n) = 0 \tag{8}$$

Mean WTP is then given by Eq. (9):

$$Mean(WTP) = -\frac{(\alpha + \beta' s)}{\gamma} \tag{9}$$

The mean WTP derived from the logistic regression model was calculated using Krinsky and Robb's method (1986), and the associated 95% confidence interval for the WTP measure was computed using 30, 000 repetitions and holding the independent variables at their mean.

3.3.2. Latent class model

We run a latent class model to identify heterogeneity in respondents' preferences. Responses are grouped into m discrete classes with distinct preferences. Eq. (6) can be written as:

$$Pr(yes|A) = \ F_\eta\ (\Delta v) = \sum_{m=1}^{M} k_m \frac{1}{1 + e^{-(\alpha + \gamma A)}} \tag{10}$$

where k_m is the class probability membership function given by Eq. (11) below and δ_m is a class-specific vector of parameters with characteristics of s.

$$k_m = \frac{\exp(\delta_m s)}{\sum_{m=1}^{M} \delta_m s} \tag{11}$$

The mean WTP – as defined by Eq. (9) – and the associated 95% confidence intervals for the classes derived from the latent class model were calculated using the delta method. All the data analyses for this study were conducted using STATA version 17.

3.3.3. Explanatory variables

Table 3 describes the variables considered in the estimation of Eq. (7). Only the perception variables in Table 3 were used in the estimation of Eq. (11) (see further details in Section 4.3). The explanatory variables consist of both continuous and categorical responses (see overview below). The description of the measurements of the variables *Concern, Mitigation, Knowledge, Biodiversity* and *Sustainability* is also reported in a previous study using the same dataset (see Ugarte Lucas et al., 2022). The variables *Age* and *Income* were transformed into two dummy variables to allow for nonlinearity. Decisions about which sociodemographic variables to include were made on both theoretical and empirical grounds. Theoretically, *Income* should have an influence owing to the diminishing marginal utility of money. Empirically, the variables *Age, Gender* and *Education* have been shown to influence WTP for various environmental goods (Horowitz and McConnell, 2002; Ladenburg and Dubgaard, 2007; Torgler and García-Valiñas, 2007) and renewable energy technologies (Stigka et al., 2014). The perception variables related to the bioenergy feedstock were included in the logistic

Table 3
Explanatory variables.

Variables	Description	Frequency (%)
Bid	Amount specified as a single tax supplement presented in DKK (1 = 50; 2 = 250; 3 = 500; 4 = 750; 5 = 1000; 6 = 1500; 7 = 2000; 8 = 4000; 9 = 8000)	-
Sociodemographic variables		
Age - young	Young age group (1 = 18–34; 0 = other)[a]	28.15
Age - middle	Middle age group (1 = 40–64; 0 = other)[a]	54.72
Gender	Gender in a binary form (1 = male; 0 = female)	49.12
Income - low	Annual household income before taxes in DKK (1 = < 300,001; 0 = other)[b]	18.67
Income - high	Annual household income before taxes in DKK (1 = > 600,000; 0 = other)[b]	33.92
Education	Education level (1 = higher; 0 = primary)	58.96
Perception variables		
Concern	Concern about climate change (1 = concerned; 0 = not concerned)	77.96
Anthropogenicity	Belief in human activity as the main cause of climate change (1 = belief; 0 = other)	49.27
Mitigation	Belief in the mitigation potential of woody biomass (1 = belief; 0 = other)	33.82
Knowledge	Level of knowledge (1 = good; 0 = other)	17.50
Deforestation	Belief in deforestation associated with biomass (1 = belief; 0 = other)	48.58
Biodiversity	Biodiversity protection as a precondition of the use of biomass (1 = agree; 0 = other)	62.27
Sustainability	Sustainability as a precondition of the use of biomass (1 = agree; 0 = other)	70.58

Notes. [a] The reference against which the young and middle age groups are compared is the old age group (1 = 65 or more; 0 = other). [b] The reference against which the low and high income groups are compared is the middle income group (1 = 300,001 DKK (40,273 EUR) – 600,000 DKK (80,545 EUR); 0 = other).

regression model for exploratory purposes without any a priori hypotheses about their potential influence on WTP. Woody biomass is a contested energy source, and therefore the influence of determinants of other renewable energy sources might differ where it is concerned.

Categorical variables consisting of five-point Likert scales (in some cases with an off-scale *I don't know* response option) were transformed into dichotomous variables by coding the two upper levels of the Likert scale to "1" and all the other levels to "0". The main reason for this dichotomization is that we are interested in the two *alternative states* of the variables, that is, in their binary form. Respondents were asked about their belief about the cause(s) of climate change using an adapted version of a question set developed by Leiserowitz et al. (2019), as is also done by Peterson St-Laurent et al. (2018). A binary variable with two factors was created (*Anthropogenicity*), regrouping respondents into those who believe that the climate has changed "*primarily due to human activities*" and those who selected any of the other response categories ("*primarily due to natural processes*", "*equally by natural processes and human activities*", "*the climate has not changed*", and "*I don't know*"). Concern about climate change (*Concern*) was measured by asking respondents to indicate their level of concern on a five-point Likert scale (*extremely concerned* to *not at all concerned*), as is also done by Peterson St-Laurent et al. (2018). We also asked respondents to self-rate their general knowledge of woody biomass (*Knowledge*) on a five-point Likert scale (*very good* to *very poor*), as is also done by Zyadin et al. (2012).

Respondents' levels of agreement with a series of woody biomass perception variables were assessed on five-point Likert scales (*strongly agree* to *strongly disagree*, with an off-scale *I don't know*). The statements were associated with respondents' belief in the mitigation potential of biomass (*Mitigation*) ("*The use of woody biomass for energy leads to less GHG emissions than the use of fossil fuels*"), belief in the deforestation potential of woody biomass (*Deforestation*) ("*The use of woody biomass for energy leads to more deforestation than the use of fossil fuels*"), the importance of biodiversity as a precondition of the use of woody biomass (*Biodiversity*) ("*It is acceptable to use woody biomass for energy as long as it does not negatively affect forests and biodiversity*"), and the importance of sustainability as a precondition of the use of woody biomass (*Sustainability*) ("*Woody biomass should only be used for energy if it is possible to ensure its sustainability*").

4. Results

4.1. Descriptive statistics

4.1.1. Perception variables

Results of some of the perception questions (*Concern, Mitigation, Knowledge, Biodiversity* and *Sustainability*) are reported in full in Ugarte Lucas et al. (2022). Almost half of the respondents self-rated as having *poor* or *very poor* levels of knowledge, and most of them (78%) showed moderate (or higher) concern about climate change (Ugarte Lucas et al., 2022). As regards belief in the causes of climate change in recent decades, more than half of the respondents (51%) believed that the world's climate has changed mainly as a result of human activities, 34% as a result, equally, of human activities and natural processes, and 8% as a result primarily of natural processes. Only 1% of the respondents did not believe in climate change, and 6% chose the response option *I don't know*.

Table 4 shows the respondents' evaluations of the statements about biomass. Regarding respondents' belief in the mitigation potential of biomass (*Mitigation*), almost one-third chose the response option *I don't know* and one-fourth chose the response option *neither agree nor disagree*. Approximately one-third agreed with the statement that biomass has mitigation potential (28% agreed and 5% strongly agreed). Almost half of respondents agreed with the statement that biomass leads to deforestation (*Deforestation*) (31% agreed and 18% strongly agreed) and 28% chose the response option *I don't know*. More than half of respondents agreed with the importance of biodiversity as a precondition of the use of woody biomass (*Biodiversity*) (42% agreed and 19% strongly agreed) and more than two-thirds of respondents (71%) agreed with the importance of sustainability as a precondition of the use of woody biomass (*Sustainability*) (45% agreed and 26% strongly agreed).

4.1.2. (Un)willingness to pay – reasons behind

Table 5 shows the distribution of answers to the bid levels. As expected, there was an inverse relationship between WTP and the tax increase specified, i.e., as the bid level falls, WTP increases. From the table, it can be seen that the median WTP is between 1500 DKK (201 EUR) and 2000 DKK (268 EUR).

The respondents were asked for the reason(s) behind their answers (see Appendix C for details). Multiple answers were allowed. Of the respondents who were willing to pay ($n = 521$), 69% selected "*We need negative* CO_2 *emissions*" as a reason. This was the most popular reason chosen, followed by "*The use of woody biomass for energy already helps reduce GHG emissions, and combining it with* CO_2 *capture is even more beneficial for the environment*" (28%) and "*Woody biomass should be used for energy until other technologies become available*" (21%). 6% selected "*Woody biomass is a cheap energy source*" (see Fig. 1). 10% of respondents chose "*Other*" reasons, such as "*I am in favour of technology development*" and "*The captured* CO_2 *can be used for other purposes*".

Of the respondents who were *not* willing to pay ($n = 335$), around 41% chose "*I would rather pay for the promotion of other energy sources such as solar or wind*" as their reason. This was the most popular reason, followed by "*We should reduce our* CO_2 *emissions, not solve the problem with* CO_2 *capture*" (33%) and "*We cannot be sure that trees are replanted when the woody biomass is imported from abroad*" (31%) (see Fig. 2). Around 29% of those who were *not* willing to pay gave, as the reason, that they could not afford to pay for this technology. 22% did not believe in the mitigation potential of woody biomass, and another 21% stated

Table 4
Level of agreement (%) with statements assessing the perception of woody biomass ($n = 856^a$).

Variable	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	I don't know
Mitigation	2.57	6.89	25.35	27.80	4.79	32.59
Deforestation	0.70	2.45	19.86	31.07	18.11	27.80
Biodiversity	2.10	5.02	19.86	41.71	18.69	12.62
Sustainability	0.58	2.80	14.49	45.44	25.70	10.98

Note. [a] Sample size excluding protest voters. Therefore, the numbers differ slightly from Ugarte Lucas et al. (2022), who also report results for the *Mitigation, Biodiversity* and *Sustainability* variables using the same dataset.

Table 5
Distribution of *Yes* and *No* responses ($n = 856$).

Bid (DKK)	Bid (EUR)	*n*	Yes	No	No (%)
50	7	107	86	21	20
250	34	108	87	21	19
500	67	102	65	37	36
750	101	102	66	36	35
1000	134	100	66	34	34
1500	201	105	51	54	51
2000	268	98	50	48	49
4000	537	91	35	56	62
8000	1074	43	15	28	65

that using woody biomass negatively impacts forests and biodiversity. 19% thought that the technology is too risky. The least popular reason (10%) was that "*Woody biomass should be used in other sectors and for other products before it is used to produce energy*". *Other* reasons for not being willing to pay were: "*The assumptions about BECCS are too uncertain*" and "*I am in favour of nuclear power as a substitute for fossil fuels*".

4.2. Logistic regression results

Results from the logistic regression model are shown in Table 6. The fit of the model is suitable, with an adjusted McFadden's Pseudo R^2 of 19.30%. The model allows for an identification of the effects of the explanatory variables (see Table 3) on the probability that a respondent would vote *Yes* to the introduction of carbon capture. The variables that influence the WTP are *Bid, Age – young, Concern, Anthropogenicity, Mitigation* and *Sustainability*. The probability that a respondent is willing to pay the yearly household tax for BECCS decreases with the magnitude of the tax increase (*Bid*), as expected. Younger respondents (*Age - young*) (coefficient = 0.649, $p < .05$), respondents concerned about climate change (*Concern*) (coefficient = 1.012, $p < .001$) and those believing that human activity is the main cause of it (*Anthropogenicity*) (coefficient = 0.973, $p < .001$), and respondents believing in the mitigation potential of woody biomass (*Mitigation*) (coefficient = 0.836, $p < .001$) and those believing that sustainability should be a precondition of the use of woody biomass for energy (*Sustainability*) (coefficient = 0.569, $p < .01$), are all more likely to be willing to pay for BECCS. *Gender, Income, Education, Knowledge, Deforestation,* and *Biodiversity* did not have an influence. The sample mean WTP derived from the logistic regression model was 3072 DKK (412 EUR) per household per year (Table 6). As expected, it is higher than the median WTP from the non-parametric estimation (based on Table 5) due to the relatively large share of respondents accepting the highest bid.

4.3. Latent class regression results

We first run a model with all the explanatory variables (see Table 3) as predictors of class membership. However, none of the sociodemographic variables had a significant effect, so we run a model only with perception variables as predictors. Two latent classes were selected based on the Bayesian Information Criterion (BIC). The BIC was 1004 for a model with two classes and 1075 for a model with three classes. The solution with a lower BIC was chosen.

Table 7 shows the results from the latent class model with two classes. Class 2 is the largest group, with respondents having a probability of 66% of falling into this group. The WTP for Class 1 and Class 2 is 93 DKK (12 EUR) and 6690 DKK (898 EUR) per household per year, respectively. Compared to the respondents that are more likely to belong to Class 1, the respondents that are more likely to belong to Class 2 are more concerned about climate change (*Concern*) (coefficient = 1.788; $p < .001$), and are more likely to believe in human activity as the main cause of climate change (*Anthropogenicity*) (coefficient = 1.766; $p < .001$), in the mitigation potential of woody biomass (*Mitigation*) (coefficient = 1.649; $p < .01$) and in sustainability as a precondition for the

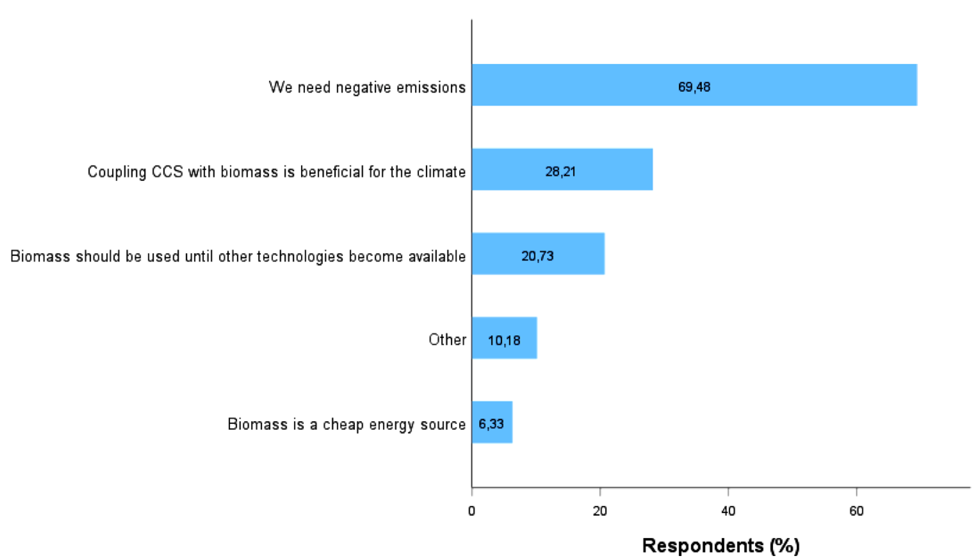

Fig. 1. Reasons for willingness to pay for bioenergy with carbon capture and storage (CCS).

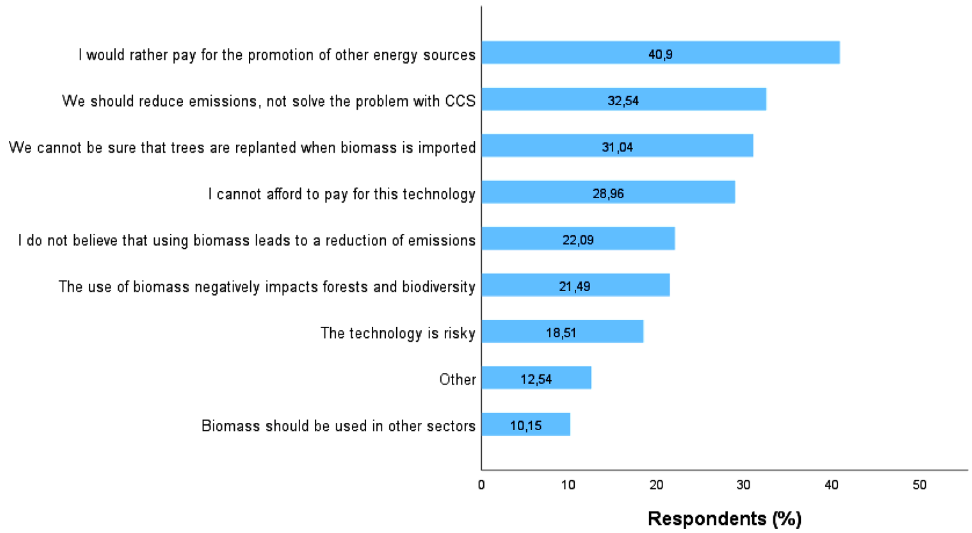

Fig. 2. Reasons for not being willing to pay for bioenergy with carbon capture and storage (CCS).

Table 6
Parameter estimates for the logistic regression model.

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0003591*** (0.0000512)	7.02
Sociodemographic variables		
Age - young	0.649* (0.281)	2.31
Age - middle	0.171 (0.210)	0.82
Gender	0.054 (0.184)	0.29
Income - low	−0.266 (0.236)	1.12
Income - high	0.0572 (0.211)	0.27
Education	0.133 (0.182)	0.73
Perception variables		
Concern	1.012*** (0.218)	4.65
Anthropogenicity	0.973*** (0.188)	5.17
Mitigation	0.836*** (0.210)	3.99
Knowledge	0.001 (0.248)	0.01
Deforestation	−0.265 (0.185)	1.43
Biodiversity	0.087 (0.201)	0.43
Sustainability	0.569** (0.209)	2.72
Constant	−1.041** (0.307)	3.39
WTP in DKK/household/year (95% CI)	3071.51 (2516.09; 3883.22)	
WTP in EUR/household/year (95% CI)	412.18 (337.64; 521.10)	
n	730	
Log-likelihood	−392.731	
McFadden's Pseudo R^2	0.193	
AIC	815.463	

Notes. Significance level: *$p < .05$, **$p < .01$, ***$p < .001$. AIC = Akaike's Information Criterion.

Table 7
Parameter estimates for the latent class model.

	Class 1		Class 2	
Average class probability (%)	33.84		66.16	
	Coefficient (SE)	*t*-ratio	Coefficient (SE)	*t*-ratio
Bid	−0.00251** (0.00116)	2.16	−0.000332*** (0.000063)	5.17
Constant	0.232 (0.415)	0.58	2.222***(0.407)	5.45
Class probability variables				
Concern	*Fixed*		1.788*** (0.439)	4.07
Anthropogenicity	*Fixed*		1.766*** (0.493)	3.58
Mitigation	*Fixed*		1.649** (0.519)	3.18
Knowledge	*Fixed*		−0.228 (0.421)	0.54
Deforestation	*Fixed*		−0.298 (0.314)	0.95
Biodiversity	*Fixed*		0.159 (0.335)	0.48
Sustainability	*Fixed*		1.016** (0.382)	2.66
Constant	*Fixed*		−2.512*** (0.620)	4.05
WTP in DKK/household/year (95%CI)	92.5 (−244; 429)		6690 (2197; 10,184)	
WTP in EUR/household/year (95%CI)	12.41 (32.74; 57.57)		897.76 (294.82; 1366.63)	
n	847[a]			
Log-likelihood	−461.790			
McFadden's Pseudo R^2	0.138			
AIC	947.581			
BIC	1004.481			

Notes. [a] The sample size for the latent class regression is larger than the sample size for the logistic regression because the former does not include sociodemographic variables, for which there were missing cases. Significance level: *$p < .05$, **$p < .01$, ***$p < .001$. AIC = Akaike's Information Criterion. BIC = Bayesian Information Criterion.

use of woody biomass (*Sustainability*) (coefficient = 1.016; $p < .01$). The variables *Knowledge, Deforestation*, and *Biodiversity* did not predict class membership. Although not directly comparable, McFadden's Pseudo R^2 in this model (Table 7) is lower than in the logit model (Table 6). However, the LCM still does explain some of the heterogeneity observed. It should be noted that some of the class probability is captured by heterogeneity not explained by the reported perception variables, as reflected by the significant constant (coefficient = −2.512; $p < .001$) under 'class probability variables'.

5. Discussion

5.1. Putting willingness to pay into perspective

In the current study, the average WTP for BECCS is 3072 DKK (412 EUR). For comparison, the average gross family income is 589,200 DKK (79,067 EUR) (Statistics Denmark, 2021) and the average heat and electricity expenses are 25,635 DKK (3440 EUR) (Statistics Denmark, 2021). Thus, the average WTP corresponds to a 12% increase in heat and electricity expenses. In an attempt to make a meaningful comparison of this amount with the expected cost of achieving CO_2 emissions reductions in Denmark, we converted the mean WTP to a price amount relative to tonnes of CO_2 emissions. With the proviso that emissions from the burning process are highly dependant on context (Taeroe et al., 2017; Zheng et al., 2022), we believe that 125 kg CO_2/GJ may be a reasonable number. We base this number on the average of the estimates provided by Taeroe et al. (2017) (71.4 kg CO_2/GJ after unit convergence) and Zheng et al. (2022) (175 kg CO_2/GJ). In 2018, the average citizen used 27 GJ of biomass (Danish Energy Agency, 2020). With an average Danish household size of 2.12 (*Danmarks Statistik*, 2022), this gives an average emission of 7.2 tonnes CO_2/household/year. The CV scenario explained to respondents that only up to 50% of the CO_2 emissions from the burning of biomass would be captured (Appendix C), resulting in a rough estimate of somewhat over 800 DKK (107 EUR) per tonne of CO_2 captured by BECCS. For comparison, the economic calculus of the marginal cost of a tonne of CO_2 saved by a CCS facility following a cost-effective approach at the Danish level ranges from 600 DKK (81 EUR) to 1450 DKK (195 EUR) per tonne of CO_2 (Svarer et al., 2022). This shows that, on average, people are willing to pay at least the more conservative estimate, which suggests that, in the case of Denmark, it may be economically feasible to implement BECCS with an increased energy tax. Considering that BECCS is not used yet in Denmark at a level above pilot, it is not possible to make a more precise comparison of the WTP results with the real cost of deploying this technology.

5.2. Support for or reluctant acceptance of BECCS?

The main reason given by the respondents who were willing to pay (69%), was that there is a *need* for negative emissions. This need could reflect a belief in the effectiveness of the technology for solving the climate crisis. Alternatively, it may reflect an *awareness of the need* to achieve negative emissions and not necessarily an approval of this technology, but rather a "reluctant acceptance" of it (Haikola et al., 2019; Merk et al., 2019). Possibly, and as explained by Haikola et al. (2021) in their evaluation of BECCS narratives, some people consider that the present political-economic system will not deliver decarbonisation successfully and therefore BECCS is a necessity. This might also be the case for CCS more broadly. In their review of CCS perception studies, L'Orange Seigo et al. (2014) report that this technology is seldom rejected wholesale, as the public sees the *need* for efforts to reduce emissions.

The second most popular reason given reflected trust (of the 28% of the respondents who were willing to pay) in the mitigation potential of biomass. 21% of the respondents who were willing to pay selected as a reason the statement that biomass should be used until other technologies become available. This reason for support reflects a well-known view of biomass as a "temporary solution" (e.g., see the view by the current Danish Minister of Climate, Energy and Utilities in Bahn, 2020). Finally, 9% of the respondents who were willing to pay chose, simultaneously, the reasons that biomass already helps reduce emissions and that it should nevertheless be used in a transition period.

Those who were unwilling to pay for BECCS most often gave, as their reason, that they would prefer to see renewable energy sources such as solar or wind promoted rather than biomass coupled with CCS (around 41% chose this reason). This is an argument strongly linked to the choice of renewable energy source. Some studies exploring perceptions of BECCS have also found that this technology is looked upon less favourably than alternative mitigation technologies (Fridahl, 2017; Fridahl and Lehtveer, 2018). In the same way, results presented by Oltra et al. (2010) more than a decade ago suggested that one of the reasons for respondents' rejection of CCS was their inclination to see renewable energy technologies as the priority. L'Orange Seigo et al. (2014) later found that one of the most prominent risks people associate with CCS is the disregard of other mitigation strategies, including the promotion of renewable energy technologies. Even in the context of the assumption that CCS technologies will play a significant role in Denmark, concerns over a delay in the development of technologies reducing emissions have been raised (e.g., Danish Council on Climate Change, 2021).

Arguments linked to choice of renewable energy source also appear to be implicated in the second most chosen reason for being unwilling to pay for BECCS – namely, that emissions reductions should be in place and the problem of climate change should not be solved with CO_2 capture. This reason was chosen by 33% of the respondents, and more than half (54%) of these also indicated a preference for solar and wind. This argument resonates with a study of geoengineering perceptions reporting that Swedish people perceive this way of addressing the climate crisis as focusing on symptoms rather than the causes of the issue, and that GHG reduction measures should be given priority (Wibeck et al., 2015). Similarly, Merk et al. (2019) report that German respondents prioritised GHG emissions reductions over reliance upon BECCS. Another popular reason for unwillingness to pay was scepticism about the sustainability of woody biomass (22% chose this reason). This issue is prominent – increasingly so – in the debate in Denmark (Andersen et al., 2022; Klimamonitor, 2022; Larsen, 2022; Müller, 2022). Uncertainties about the sustainability of bioenergy feedstock were also reflected in the fact that the third most chosen reason revolved around lack of certainty about regrowth for imported biomass (31% of respondents chose this reason) and the sixth most chosen reason indicated a lack of belief in the mitigation potential of biomass (22%). Surprisingly, in contrast with other studies where it was raised as an issue (e.g., Merk et al., 2019), negative impacts on biodiversity did not emerge as a significant reason affecting WTP in our study.

5.3. Explaining willingness to pay

By examining the explanatory variables of the logistic regression model we were able to characterise the respondents who were more likely to be willing to pay for the implementation of BECCS. This was supplemented by latent class analysis. Of the sociodemographic variables, only age explained WTP for BECCS. This is in keeping with other studies that found that being younger had a positive influence on WTP for renewable energy (Ivanova, 2005; Zarnikau, 2003). Somewhat surprisingly, income was not a significant factor. Latent class regression results didn't show either an effect of income or other sociodemographic characteristics. It should be noted that other studies find a lower WTP for renewable energy technologies, and climate mitigation more broadly, to respondents with lower incomes (Batley et al., 2001; Damigos et al., 2009; Stigka et al., 2014; von Borgstede et al., 2013; Zoellner et al., 2008). The lack of sensitivity to income in our study can question the validity of the CV study (see a note on the limitations of the CV design in Section 3.2 and Section 5.4). Yet, there may be reasons for the lack of effect of income in our study. First, people might look not only at what they are asked to pay, but what is a fair share, as emission reductions are a public good beyond household-specific emissions. The energy expenses of those in different income brackets typically differ, which may lead to differences as well. Second, there are several uncertainties associated with the policy. These are not made explicit, but if systematic differences of uncertainty preferences between income groups exist, this may explain the lack of influence from income.

Consistent with expectations, the two perception variables associated with climate change (*Concern* and *Anthropogenicity*) were found to influence WTP positively in both the logistic regression and the latent class models. Studies focusing on CCS have found similar results (Batley et al., 2001; Zoellner et al., 2008; Damigos et al., 2009; Oltra et al., 2010; Carley et al., 2012). Possibly, those believing in the human role in climate change have a feeling of responsibility to act faster – and here the potential of BECCS to generate negative emissions could be seen by many as a possible path to tackle the climate crisis.

Regarding perceptions of biomass, we found that people believing in its mitigation potential and in the importance of its sustainability as a precondition of its use were more likely to pay for BECCS. This was the case for both models. The fact that the sustainability of the bioenergy feedstock is a determinant of WTP for BECCS reflects a concern that is often raised about the difficulty of deploying a technology like BECCS if the adequacy of the feedstock itself is questioned (e.g., Abt et al., 2022). The biomass perception variables and the two perception variables associated with climate change help explain the notable difference between WTP estimates for Class 1 and Class 2 in the LCM. The respondents more likely to belong to Class 2 have an estimated WTP of 6690 DKK (897 EUR) per household per year, compared to 92.5 DKK (12 EUR) per household per year for respondents more likely to belong to

Class 1. The fact that class probability is (partly) explained by different concerns about climate change and biomass is in line with the logistic regression model results. However, we see a more pronounced effect in the LCM, reflecting that the heterogeneity is not captured by these concerns alone.

Surprisingly, the statements associated with deforestation and biodiversity loss did not turn out to be significant predictors in any of the models. It is possible that these are issues to which people do not attach importance when it comes to BECCS. Perhaps here the debate is more about whether it is right or wrong to use this technology rather than the specific issues associated with the bioenergy feedstock. Knowledge about biomass had no influence either, we found. This finding is at odds with the results of some studies focusing on WTP for renewable energy technologies (Batley et al., 2001; Damigos et al., 2009; Zoellner et al., 2008).

As previous research has pointed at differences in WTP between urban and rural respondents, we ran additional analyses to check whether statistically significant differences in our sample were based on this factor (see Tables D.1.1 and D.1.2 in Appendix D for detailed results). We found that for both groups, belief in human activity as the main cause of climate change and belief in the mitigation potential of biomass were determinants of WTP, and that for the rural group two extra factors were significant – namely, concern about climate change and concern about the sustainability of biomass. A likelihood ratio test of one subgroup against the joint sample revealed that there were no statistically significant differences based on place of residence. Similarly, we tested for differences between respondents with, and without, district heating. It emerged that respondents with district heating have a significantly larger WTP for BECCS (see Tables D.2.1 and D.2.2 in Appendix D). Despite our attempt to focus on the public good dimension of achieving negative emissions in the proposed hypothetical scenario, one may speculate that the scenario seemed closer to the individual carbon footprint dimension for district heating users, as biomass is largely used for district heating.

5.4. Limitations and future research directions

The present study has some limitations that should be borne in mind when interpreting the results. First, our data is cross-sectional and therefore causal inferences cannot be made. Second, although the sample obtained is fairly representative in terms of age, gender, and geographical region, it is not *totally* representative of the target population. Therefore, the external validity of the findings inevitably decreases (Bryman, 2012). Third, it is unclear whether the public would respond in the ways we have argued if they were to obtain relevant knowledge and were actually presented with the opportunity to choose. The established hypothetical market in our study meant that the respondents had to construct their preferences for, in this case, a rather unfamiliar and complex technology "on the spot", drawing upon the information presented in the survey and/or any pre-existing knowledge (Sauer and Fischer, 2010). The information provided to respondents was kept brief and related to emission reductions at an aggregate level. Although respondents were presented with the most realistic referendum scenario, the WTP estimate per tonnes of carbon emitted during bioenergy combustion relies on the respondents' prior knowledge about the quantities of bioenergy consumed, which is likely limited. In their study of German citizens, Merk et al. (2019) found low levels of familiarity with BECCS. This could well be true of Danish citizens as well, although future studies would be needed to confirm this. Fourth, dichotomous choice questions generally result in less uncertainty than open-ended ones and avoid issues of very high or very low bids, but they can lead to biased price estimates as a result of anchoring effects (Ivanova, 2005). In general, there is a tendency for hypothetical WTP to overestimate real WTP in CV studies. With this "hypothetical bias" critique in mind, we checked WTP for the sample *minus* respondents who were offered the highest bid (i.e., 8000 DKK or 1074 EUR) and then, separately, *minus* respondents saying *Yes* to the higher bid (see Tables D.3.1 and D.3.2 in Appendix D for detailed results). We found that WTP was lower in both cases: 2389 DKK (321 EUR) and 2259 DKK (303 EUR), respectively. Despite being lower than the main estimate, this is still a significant WTP, we would suggest.

Given that the BECCS debate is expected to evolve rapidly in the coming years, future longitudinal studies could evaluate the evolution of public attitudes as Denmark and other countries make progress in their energy transitions. Future studies could also benefit from studying the potential impact of social-psychological variables not included here. There are studies in the CV literature that have taken this approach (Luzar and Cossé, 1998), and these show that models explaining WTP can be improved with the use of an attitude-behaviour-based framework (Bernath and Roschewitz, 2008). Further, future research could also pay attention to how the public perceives the storage of CO_2 in geological reservoirs or its utilisation, and what factors (e.g., risk perception, benefit perception, trust, etc.) influence their views. Finally, further research into public attitudes to BECCS could benefit from the use of qualitative interviews. These would throw light on perceptions, including people's *knowledge* of BECCS, and their *perception of the role of it*, in a way that econometric models cannot.

6. Conclusions

Our population-based survey using the contingent valuation method suggests that Danes are willing to pay the cost of reducing emissions using BECCS. The main reason for this willingness – the perception that we need to achieve negative emissions – suggests that the respondents either embraced this technology or accepted it reluctantly. The main reason given by those unwilling to pay was a preference for the promotion of other renewable energy sources such as wind or solar power. Results from a logistic regression model show that the most important factors associated with willingness to pay are age, being concerned about climate change and believing that it is mainly caused by human activity, perception of the mitigation potential of biomass, and the importance of its sustainability as a precondition of its use. A latent class regression confirms these findings.

Given the lack of scholarship on public perceptions of BECCS, our research makes an important contribution. By eliciting public WTP for BECCS and the reasons behind it, and by examining and quantifying the influence of the factors that determine the WTP, this study helps to widen the discussion about BECCS and to inform policies aimed at inclusively facilitating energy transitions. Decision makers who aim to incorporate the public's voice in climate decisions should be cautious about ensuring the sustainability of biomass, as in our study this was a factor influencing the size of WTP. Also, even if the public is on average willing to pay for the implementation of BECCS, the additional fact that this is seen as a *need* suggests that this willingness should not necessarily be taken as full support for its implementation. It can indeed be seen as a pointer towards the perceived necessity of it, which is clearly not the same as a perception that it is necessary to prioritise negative emissions over emission reduction technologies or the perception that we should be reducing the energy consumption levels of wealthier countries. This study is a first step in what we hope will be an inclusive dialogue about the appropriateness of BECCS for tackling the climate crisis in the Danish context.

CRediT authorship contribution statement

Paula Ugarte-Lucas: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Jette Bredahl Jacobsen:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: During the writing of the paper, Jette Bredahl Jacobsen had a role as deputy chair of the Danish Council on Climate Change and vice chair of the European Scientific Advisory Board for Climate Change.

Data availability

Data will be made available on request.

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Appendix A. Sample and population comparison

Table A.1
Comparison of sociodemographics of the whole sample with those of the Danish population.

	Whole sample (n = 1023) (%)	Danish population 2021 (%)	Chi-square test
Gender			
Female	50.64	50.26	Non-significant (p = .69)
Male	48.88	49.74	
Other	0.29	–	
Do not wish to say	0.2	–	
Age (years)			
18–34	20.43	27.38	Significant (p < .05)
35–49	30.89	22.92	
50–64	24.44	24.52	
65 or more	24.24	25.19	
Education			
Primary, high school, vocational training	40.96	64.96	Significant (p < .05)
Higher education (1 to 5 years), and PhD	58.85	35.05	
Do not know	0.2	–	
Region			
Hovedstaden	28.93	31.76	Non-significant (p = .19)
Sjælland	14.47	14.37	
Syddanmark	23.66	20.95	
Midtjylland	22.78	22.82	
Nordjylland	10.17	10.10	
Income			
< 200,000	5.87	15.40	Significant (p < .05)
200,000 – 399,000	27.27	35	
400,000 – 599,999	18.18	18.30	
≥ 600,000	33.92	31.30	
Do not know/wish to say	14.76	–	

Table A.2
Comparison of sociodemographics of the sample without protesters with those of the Danish population.

	Sample without protesters (n = 856) (%)	Danish population 2021 (%)	Chi-square test
Gender			
Female	52.10	50.26	Non-significant (p = .21)
Male	47.31	49.74	
Other	0.35	–	
Do not wish to say	0.23	–	
Age (years)			
18–34	20.33	27.38	Significant (p < .05)
35–49	31.07	22.92	
50–64	24.53	24.52	
65 or more	24.97	25.19	
Education			
Primary, high school, vocational training	41.10	64.96	Significant (p < .05)
Higher education (1 to 5 years), and PhD	58.90	35.05	
Do not know	0.23	–	
Region			
Hovedstaden	29.67	31.76	Non-significant (p = .39)
Sjælland	13.55	14.37	
Syddanmark	23.25	20.95	
Midtjylland	22.78	22.82	

(*continued on next page*)

Table A.2 (*continued*)

	Sample without protesters ($n = 856$) (%)	Danish population 2021 (%)	Chi-square test
Nordjylland	10.75	10.10	
Income			
< 200,000	5.61	15.40	Significant ($p < .05$)
200,000 – 399,000	26.87	35	
400,000 – 599,999	18.11	18.30	
≥ 600,000	34.35	31.30	
Do not know/wish to say	15.07	–	

Appendix B. Questionnaire

The following is a link to the questionnaire-based survey: [doi:10.1016/j.ijggc.2024.104187].

Appendix C. Contingent valuation scenario

A new technology called CO_2 capture *has made it possible to capture and store the* CO_2 *released during the burning of woody biomass. The new technology is expected to have the potential to capture up to half of the total* CO_2 *emissions from burning woody biomass.*

Using this technology to capture CO_2 from the burning of woody biomass would increase the price of energy. Imagine that the government conducts a referendum on whether CO_2 capture should be introduced. If the technology is used, the additional cost will be paid by Danish households in the form of an energy tax or a tax increase.

a. If the initiative would cost your household 50 DKK extra per year, would you vote "Yes" or "No" to the introduction of CO_2 capture? (Please bear in mind that you would have less money available to use for other purposes if you were to vote "Yes")

☐ I would vote "Yes"
☐ I would vote "No"

<FILTER: If question a = "No" go to question c>

b. You have answered that you would vote "Yes" to the introduction of the CO_2 capture technology where Danish households would have to pay the additional cost. What is the reason for your answer? *(Please select all that apply)*

☐ We need negative CO_2 emissions.
☐ The use of woody biomass for energy already helps reduce greenhouse gas emissions, and combining it with CO_2 capture is even more beneficial for the environment.
☐ Woody biomass should be used for energy until other technologies become available.
☐ Woody biomass is a cheap energy source.
☐ I am interested in the promotion of woody biomass for energy no matter the additional costs for my household.
☐ Other. Please specify. *[open answer]*

c. You have answered that you would vote "No" to the introduction of the CO_2 capture technology where Danish households would have to pay the additional cost. What is the reason for your answer? *(Please select all that apply)*

☐ I think this technology is too risky. We don't know the implications.
☐ We should reduce our CO_2 emissions, not solve the problem with CO_2 capture.
☐ I do not believe that greenhouse gas emissions will be reduced by using woody biomass to produce energy – even if the emissions from the burning process are captured with this technology.
☐ We cannot be sure that trees are replanted when the woody biomass is imported from abroad.
☐ The use of woody biomass for energy negatively impacts forests and biodiversity.
☐ Woody biomass should be used in other sectors, and for other products, before it is used to produce energy.
☐ I cannot afford to pay for this technology.
☐ I am in favour of the proposal, but it should be financed by existing taxes.
☐ I would rather pay for the promotion of other energy sources such as solar or wind.
☐ Other reason. Please specify. *[open answer]*

Appendix D. Additional logistic regressions

D.1. Urban versus Rural

Table D.1.1
Parameter estimates for the logistic regression (urban respondents[a]).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0003122*** (0.0000841)	−3.71
Sociodemographic variables		
Male	0.243 (0.334)	0.73
Young	0.584 (0.434)	1.35
Middle-age	−0.132 (0.372)	−0.35
Low income	−0.648 (0.381)	−1.70
High income	0.1163733 (0.362)	0.32
Education	0.092931 (0.321)	0.29
Perception variables		
Concern	0.441 (0.393)	1.12
Anthropogenicity	1.048** (0.317)	3.31
Mitigation	0.949** (0.354)	2.68
Knowledge	−0.128 (0.444)	−0.29
Deforestation	0.042 (0.320)	0.13
Biodiversity	−0.381 (0.349)	−1.09
Sustainability	0.653 (0.358)	1.82
Constant	−0.424 (0.496)	−0.86
WTP in DKK/year/household (95% CI)	3421.87 (2288.81; 5974.62)	
WTP in EUR/year/household (95% CI)	459.19 (307.14; 801.76)	
n	261	
Log-likelihood	−140.21611	
McFadden's Pseudo R^2	0.178	
AIC	310.432	

Notes. [a] Respondents living in one of the four largest Danish cities, namely Aarhus, Odense, Aalborg or Copenhagen. Significance level: $*p < .05$, $**p < .01$, $***p < .001$. AIC = Akaike's Information Criterion.

Table D.1.2
Parameter estimates for the logistic regression (rural respondents).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.000395*** (0.000066)	−5.98
Sociodemographic variables		
Male	−0.044 (0.233)	−0.19
Young	0.761 (0.393)	1.93
Middle-age	0.310 (0.264)	1.17
Low income	−0.077 (0.313)	−0.25
High income	0.004 (0.269)	0.01
Education	0.188 (0.230)	0.82
Perception variables		
Concern	1.281*** (0.272)	4.71
Anthropogenicity	0.961*** (0.241)	3.99
Mitigation	0.791** (0.268)	2.95
Knowledge	0.013 (0.311)	0.04
Deforestation	−0.442 (0.237)	−1.86
Biodiversity	0.358 (0.254)	1.41
Sustainability	0.616* (0.268)	2.30
Constant	−1.376** (0.403)	−3.41
WTP in DKK/year/household (95% CI)	2902.63 (2232.49; 3893.79)	
WTP in EUR/year/household (95% CI)	389.51 (299.59; 522.52)	
n	551	
Log-likelihood	−246.551	
McFadden's Pseudo R^2	0.218	
AIC	523.102	

Notes. Significance level: * $p < .05$, ** $p < .01$, *** $p < .001$. AIC = Akaike's Information Criterion.

D.2. District heating versus no district heating

Table D.2.1
Parameter estimates for the logistic regression (district heating respondents).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0004024*** (0.0000722)	−5.57
Sociodemographic variables		
Male	−0.210 (0.248)	−0.85
Young	0.770* (0.392)	1.97
Middle-age	0.357 (0.281)	1.27
Low income	−0.500 (0.315)	−1.59
High income	0.096 (0.292)	0.33
Education	0.206 (0.248)	0.83
Perception variables		
Concern	1.034*** (0.289)	3.58
Anthropogenicity	1.140*** (0.264)	4.32
Mitigation	1.093*** (0.305)	3.58
Knowledge	−0.173 (0.346)	−0.50
Deforestation	−0.018 (0.253)	−0.07
Biodiversity	0.058 (0.282)	0.20
Sustainability	0.527 (0.290)	1.81
Constant	−0.933* (0.404)	−2.31
WTP in DKK/year/household (95% CI)	3578.87 (2779.98; 4957.36)	
WTP in EUR/year/household (95% CI)	480.26 (373.06; 665.25)	
n	437	
Log-likelihood	−215.016	
McFadden's Pseudo R^2	0.237	
AIC	460.032	

Notes. Significance level: * $p < .05$, ** $p < .01$, *** $p < .001$. AIC = Akaike's Information Criterion.

Table D.2.2
Parameter estimates for the logistic regression (no district heating respondents).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0003162*** (0.0000754)	−4.19
Sociodemographic variables		
Male	0.341 (0.290)	1.18
Young	0.508 (0.422)	1.20
Middle-age	−0.167 (0.333)	−0.50
Low income	0.087 (0.380)	0.23
High income	0.115 (0.327)	0.35
Education	0.015 (0.287)	0.05
Perception variables		
Concern	1.058** (0.351)	3.02
Anthropogenicity	0.818** (0.283)	2.89
Mitigation	0.619* (0.308)	2.01
Knowledge	0.346 (0.367)	0.94
Deforestation	−0.584* (0.289)	−2.02
Biodiversity	0.024 (0.308)	0.08
Sustainability	0.643* (0.324)	1.99
Constant	−1.170* (0.508)	−2.30
WTP in DKK/year/household (95% CI)	2199.59 (1239.97; 3499.36)	
WTP in EUR/year/household (95% CI)	295.17 (166.40; 469.59)	
n	293	
Log-likelihood	−167.200	
McFadden's Pseudo R^2	0.169	
AIC	364.4	

Notes. Significance level: * $p < .05$, ** $p < .01$, *** $p < .001$. AIC = Akaike's Information Criterion.

D.3. Hypothetical bias analyses

Table D.3.1
Parameter estimates for the logistic regression (sample without respondents offered the highest bid).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0005471*** (0.0000806)	−6.78
Sociodemographic variables		
Male	0.027 (0.192)	0.14
Young	0.635* (0.293)	2.17
Middle-age	0.074 (0.219)	0.34

(*continued on next page*)

Table D.3.1 (*continued*)

Explanatory variable	Coefficient (SE)	*t*-ratio
Low income	−0.203 (0.249)	−0.82
High income	0.052 (0.220)	0.23
Education	0.113 (0.191)	0.59
Perception variables		
Concern	0.980*** (0.224)	4.38
Anthropogenicity	1.027*** (0.197)	5.22
Mitigation	0.978*** (0.222)	4.40
Knowledge	0.025 (0.263)	0.10
Deforestation	−0.252 (0.193)	−1.31
Biodiversity	0.133 (0.207)	0.64
Sustainability	0.586** (0.215)	2.72
Constant	−0.861** (0.321)	−2.68
WTP in DKK/year/household (95% CI)	2388.53 (1960.52; 3024.72)	
WTP in EUR/year/household (95% CI)	320.53 (263.09; 405.90)	
n	693	
Log-likelihood	−364.155	
McFadden's Pseudo R^2	0.202	
AIC	758.311	

Notes. Significance level: * $p < .05$, ** $p < .01$, *** $p < .001$. AIC = Akaike's Information Criterion.

Table D.3.2
Parameter estimates for the logistic regression (sample without respondents saying *Yes* to the highest bid).

Explanatory variable	Coefficient (SE)	*t*-ratio
Bid	−0.0006024*** (0.0000718)	−8.39
Sociodemographic variables		
Male	0.024 (0.192)	0.12
Young	0.634* (0.291)	2.18
Middle-age	0.074 (0.219)	0.34
Low income	−0.211 (0.249)	−0.85
High income	0.051 (0.221)	0.23
Education	0.117 (0.191)	0.61
Perception variables		
Concern	0.981*** (0.225)	4.36
Anthropogenicity	1.028*** (0.197)	5.21
Mitigation	0.963*** (0.222)	4.35
Knowledge	0.030 (0.261)	0.11
Deforestation	−0.253 (0.192)	−1.31
Biodiversity	0.125 (0.207)	0.60
Sustainability	0.592** (0.216)	2.74
Constant	−0.799* (0.318)	−2.52
WTP in DKK/year/household (95% CI)	2258.68 (1895.97; 2727.33)	
WTP in EUR/year/household (95% CI)	303.10 (254.43; 365.99)	
n	718	
Log-likelihood	−365.789	
McFadden's Pseudo R^2	0.239	
AIC	761.577	

Notes. Significance level: *$p < .05$, **$p < .01$, ***$p < .001$. AIC = Akaike's Information Criterion.

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