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Sustainability concerns are key to understanding public attitudes toward woody biomass for energy: A survey of Danish citizens

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ABSTRACT

Woody biomass energy makes up a large share of renewable energy consumption in the EU, and the largest share in countries like Denmark. However, little is known about how the public perceive it. This paper presents the results of a questionnaire-based survey of the public in Denmark focusing on attitudes toward woody biomass for energy. The main findings are that, while more people favor than oppose it, a large proportion are undecided about the use of woody biomass. The survey also revealed a lack of knowledge about this energy source. A Best-Worst Scaling methodology revealed that Danes prioritize environmental sustainability concerns – namely biodiversity loss, the hindering of the development of other renewable energy sources and the climate change mitigation potential of woody biomass – over societal and/or economic ones when it comes to the promotion of woody biomass. Finally, it was found that concern about climate change, belief in the mitigation potential of woody biomass, and being younger explained the formation of positive attitudes toward woody biomass. Policy makers aiming to take public concerns into account in discussions about Denmark's energy future should focus more on minimizing the negative environmental impacts associated with woody biomass rather than on its economic benefits.

1. Introduction

A key feature of the EU's political decision to reduce non-renewable energy use is the target, set by the European Green Deal, to reduce greenhouse gas (GHG) emissions by at least 55% by 2030 relative to 1990 levels and to achieve climate neutrality by 2050 [1,2]. In this context, new forms of bioenergy have recently attracted attention as alternatives to fossil fuels [3]. Of all the types of biomass used for bioenergy production in the EU, 70% comes in the form of woody biomass [4–7], making the EU the major consumer and producer of wood for energy purposes globally [8]. Within the EU, Denmark stands out. Woody biomass is the largest source of renewable energy in the country, making up nearly half (48%) of total renewable energy consumption [9]. Its use is promoted through a favorable tax and subsidy system, together with specific regulations that govern the district heating sector [10]. Denmark is at the same time the largest woody biomass importer in the EU [9], which is not surprising considering that only 14% of the country is forested. Of the woody biomass consumed in Denmark, more than half (57%) is imported, mainly in the form of wood pellets, and 40% of this is sourced from non-EU countries [9].

Over the past twenty years, the use of imported wood pellets has increased significantly; wood chip use has also increased, but at a slower pace [9]. The demand for woody biomass is expected to decline over the coming years, as demand for wind energy, solar energy and heat pumps increases [9]. Woody biomass will nonetheless continue to be an integral part of the renewable energy mix in the country, playing an important role in Denmark's transition towards reducing emissions by 70% by 2030 relative to 1990 levels and becoming carbon neutral by 2050 [11].

Rising consumption and imports of woody biomass in Denmark have led to fierce scientific and public debate about the sustainability and desirability of woody biomass (see e.g., Refs. [12–14]). The controversy, which has featured increasingly in both national magazines and newspapers (e.g., Refs. [15–18]), and more specialized magazines (e.g., Refs. [19–21]), reveals the political and technological challenges that Denmark faces in its efforts to effectively decarbonize its energy supply.

The contested role of woody biomass in the decarbonization of the energy sector has prompted researchers to examine

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perceptions of this energy option among a broad range of stakeholders along the value chain in various countries. Thus, studies have investigated the perceptions of forest landowners (e.g., Refs. [5,7,22–32]), policy makers (e.g., Refs. [5,33–35]), bioenergy industry representatives (e.g., Refs. [5,33–35]), biomass producers (e.g., Ref. [34]), academics (e.g., Refs. [33,5]), people engaged in forest projects (e.g., Ref. [36]), and civil society organizations (e.g., Refs. [5,33–35]).

The general view is that bioenergy policies should be formulated and implemented with the advice of bioenergy experts [37]. But surprisingly, despite the environmental and economic impacts that the use of woody biomass for energy has on the wider society, and even though public acceptance has been identified as a barrier to the use of woody biomass for energy [31], only a few studies exist on public perceptions of this energy source (see overview below). To our knowledge, moreover, no study exists that has explored these perceptions in the Danish context. Whether those who make up the wider Danish society, beyond bioenergy professionals, academics and policy makers, are positive about woody biomass use is essential to the development of appropriate policies. Understanding public perceptions is a first step towards eliciting public support of this energy source, especially in countries like Denmark where its use for energy is expected to continue in the years to come. At the same time, an understanding of public perceptions can help to elucidate opportunities to inform climate and energy policies based on the complex socioeconomic and ecological tradeoffs associated with the production of renewable energy using woody biomass.

The few studies that have examined public perceptions of woody biomass energy have focused on a number of considerations. These include concerns over its climate change mitigation potential (sometimes referred to in this paper simply as "mitigation potential"), feedstock and impacts on biodiversity, economic consequences (e.g., costs associated with the conversion of woody biomass and employment opportunities) and socio-cultural outcomes (e.g., relating to the value of forests and recreational opportunities), together with the possibility of addressing rising energy demands with other renewable energies (e.g., Refs. [38–41]). Further, some studies focus on the contingent valuation of woody biomass for electricity production. For example Ref. [43], examined public willingness to pay (WTP) for electricity from woody biomass, and Ref. [44] analyzed social preferences for the substitution of conventional energy sources by forest biomass-based energy in Spain. The stated preference methods of choice modeling and contingent valuation have also been designed to elicit public WTP for woody biomass energy in the USA (e.g., Refs. [45–47]) and Portugal (e.g., Ref. [48]), among other countries. Other authors have used discrete choice experiments to assess consumers' WTP for biomass electricity and have included sociodemographic variables as predictors as well as potential environmental impacts associated with electricity produced from biomass resources (e.g., Ref. [49]). However, these studies do not provide a comprehensive account of the types of concern that exist (e.g., societal, environmental and economic) and an assessment of which of these are considered most important by the public. Apart from a few exceptions in the literature (e.g., Ref. [43]), it is largely unclear to what extent the public is even familiar with, and knowledgeable about, woody biomass as an energy source. Moreover, we do not know what factors influence the formation of public attitudes. Factors such as views on climate change, the possession of relevant knowledge and sociodemographic status are clearly worthy of investigation. More broadly focused research on renewable energy sources has suggested that both knowledge relating to an energy source and views about climate change influence the formation of attitudes to those sources (e.g., Refs. [50,51]).

Against this background, the present study examined, first, public familiarity with and knowledge about woody biomass for energy. Second, it explored perceptions of climate change, and the mitigation potential of, and attitudes toward, use of woody biomass for electricity and heat production as an alternative to fossil fuels. Third, it investigated concerns associated with woody biomass. It sought to identify which of these the public believes should be prioritized, and how the concerns more generally relate to knowledge regarding woody biomass. Finally, the study asked whether positive attitudes toward the use of woody biomass are associated with factors such as the individual's sociodemographic status, views on climate change and relevant background knowledge.

2. Materials and methods

2.1. Questionnaire design

The study is part of a larger research project focusing on public attitudes toward woody biomass in Denmark in which a cross-sectional questionnaire-based survey provides the required data. A first consolidated draft of the questionnaire was developed after reviewing relevant literature on the topic and consulting climate and bioenergy experts. The questionnaire consisted of both open- and close-ended items divided into four main sections. These focused on (i) perceptions of climate change, (ii) familiarity with and knowledge about energy sources (including woody biomass), (iii) attitudes toward woody biomass and concerns and priorities regarding its use as a source of energy, and (iv) sociodemographic information (age, gender, level of education, region and income).

In this study the measures included were as follows. Familiarity with energy sources was measured by asking respondents whether they had heard about a series of energy sources using a multiple response question. Familiarity with woody biomass was measured by asking respondents whether they had heard about the use of this particular energy source to produce energy in combined heat and power (CHP) plants (response categories were *Yes*, *No*, and *I don't know*). We asked respondents to self-rate their general and specific knowledge about a number of considerations about woody biomass on a five-point Likert scale ranging from *very good* to *very poor* (as done by Ref. [52]) and *I know it very well* to *I don't know anything about it*, respectively. Concern about climate change was measured using a five-point Likert scale ranging from *extremely concerned* to *not at all concerned*, as done by Ref. [53]. Belief in the mitigation potential of woody biomass was assessed by asking respondents to state their level of agreement with the statement "*The use of woody biomass for energy leads to less GHG emissions than the use of fossil fuels*" on a five-point Likert scale (*strongly agree* to *strongly disagree*, with an off-scale *I don't know* response option). Attitudes toward the use of woody biomass were measured by presenting respondents with the question "*What do you think about replacing fossil fuels with woody biomass in Danish CHP plants to produce energy?*" and asking them whether they were *very positive*, *positive*, *neither positive nor negative*, *negative* or *very negative* about it. For regression analysis purposes, this variable was recoded into a dichotomous variable where 1 = positive attitude (*very positive* or *positive* response option) and 0 = non-positive attitude (*neither positive nor negative*, *negative*, or *very negative* response option).

Based on the existing literature (described in Section 1) on concerns associated with the use of woody biomass, and adjacent literature focusing on what determines public acceptance of bioenergy (e.g., Ref. [51]), we aimed to identify three types of concern: societal, environmental and economic. We first identified the extent to which respondents agreed with twelve statements that express these concerns and are often used in arguments that appear in the woody biomass for energy debate using a five-point Likert scale (*strongly agree* to *strongly disagree*, with an off-scale *I don't know* response option). This type of rating question, however,

does not allow respondents to point out what concerns are least and most important to them. We therefore introduced another technique: Best-Worst Scaling (BWS). BWS improves on rating questions in that it forces respondents to discriminate between preferences (or attributes) [54] and can be used to assess relative importance, and thus in essence elicit prioritization. Specifically, we used the so-called BWS object case [55]. This is a stated preference valuation method [56] in which respondents are presented with a set of attributes and asked to choose the *best* and *worst* among them, where *best* and *worst* can be transformed into any appropriate terms that constitute the extremes of a latent continuum [55]. This technique is rooted in the Random Utility Theory of human decision-making [57], which assumes that the choices made by individuals among a set of attributes can reveal how much they value the attributes under investigation. In this way, the frequency with which attribute A is chosen over attribute B reveals how much the former is preferred to the latter [55]. In other words, respondents' preferences for an attribute are proportional to the number of times this attribute is chosen in relation to other attributes [54]. Flynn et al. [54] argue that the cognitive process underlying an individual's choice is statistically equivalent to (1) an identification of all the possible pairs of attributes available, (2) a calculation of the difference in utility (i.e., assigned value) between the two attributes, and (3) a selection of the pair of attributes that maximizes the difference in utility between them.

In this survey, we formulated seven attributes linked with concerns related to either societal, environmental or economic aspects. Four of these were presented to respondents at a time, and the respondent was given a total of seven choice sets [58,59]. For each choice set respondents were asked to choose the *most important* and *least important* attribute [59] that the Danish Government should emphasize in their decision to continue using woody biomass for energy (see Table 1 for an overview of the selected attributes and Table 2 for an example of a choice set). We used a symmetrical Balanced Incomplete Block Design (BIBD) (see Appendix A). This has the advantage of ensuring a balanced appearance and co-appearance of the attributes across all the choice sets [59]. It also secures positional balance, and thus it is unnecessary to randomize the order in which attributes appear in each of the choice sets [59]. The BIBD design controls for context effects, since each attribute appears with every other attribute an equal number of times [60].

The final survey, available in the supplementary file in Appendix B, and the undertaking of this research project more broadly, were approved by the Research Ethics Committee for the Faculty of Science and the Faculty of Health and Medical Sciences at University of Copenhagen (case number: 514–0191/21-5000).

2.2. Pre-testing and pilot-testing

A first consolidated draft of the survey instrument was pre-tested on a group of eleven Danish informants during winter 2020 using a cognitive interview technique [61,62] and later pilot-tested on 100 randomly recruited Danish informants during spring 2021 to evaluate the instruments' comprehensibility, duration, logic, flow and wording of questions. Feedback from the pre-test and pilot-test helped refine the content validity and understandability of the survey instrument before the final questionnaire was launched, helping in particular to improve the clarity of the survey's formulation, explanatory texts, questions and response options.

2.3. Data collection and analysis

Respondents were recruited from an online panel of 100,000 Danes (>18 years old) by the survey bureau *Voxmeter*. To avoid the underrepresentation of certain segments of the Danish population sampling quotas for gender, age and geographical region based on the Danish population census of the first quarter of 2021 were imposed on the sample. The data were collected in the spring of 2021. Informed consent from the survey respondents was obtained. A total of 1023 completed questionnaires were collected, corresponding to a response rate of 20%. Of the 1023 respondents, 51% were female and 49% male. The ages of the respondents ranged from 19 to 83 ($M = 49.42$, $SD = 15.86$) and 59% of respondents had attended higher education (Table 3).

Descriptive statistical analyses were used, and the shares reported were weighted using a weight variable that adjusted age, gender and geographical region to the population census when reporting concern about climate change, familiarity and knowledge, attitudes, and agreement with concerns raised in the debate. To analyze the prioritization of concerns associated with woody biomass, a simple count analysis of the BWS question was applied, following the procedure presented by Ref. [63]; whereby best-worst (BW) scores are obtained by subtracting the number of times an attribute is chosen as *least important* from the number of times it is chosen as *most important*. These were then transformed into standardized scores to create a ranking of the attributes as also done elsewhere (e.g., Refs. [59,64]), using the equation: std. score = $(\text{Count}_{\text{Best}} - \text{Count}_{\text{Worst}})/(\text{r x n})$, where r is the frequency of the appearance of each attribute in the choice sets and n is the sample size. A Spearman's rank-order correlation was conducted to explore the potential association between general self-rated knowledge and prioritization of concerns, where the latter was assessed using individual-level standardized BW scores.

Finally, a binary logistic regression model was employed to predict the likelihood of reporting a positive attitude to the use of woody biomass for energy. In logistic regression, the dependent variable is a logit, i.e., the natural log of the probabilities of an event occurring, as shown in Equation (1):

$$logit(Y) = \ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_n x_{ni} + \varepsilon_i \quad (1)$$

where Y is the dependent variable, β_i are the estimated regression coefficients for the independent variables, and $\frac{\pi}{1-\pi}$ is the odds ratio (OR) of the probability that Y will occur (π) to the probability that Y will not occur ($1 - \pi$). OR measures the effect of independent

Table 1
Attributes used in the Best-Worst Scaling (BWS) question.

	BWS Attributes
Economic	*1*. That it leads to economic growth and employment opportunities in the wood industry sector.
	2. That prices of electricity and heat do not increase.
Societal	*3*. That it does not interfere with the possibility of using forests for recreational purposes (e.g., go for a walk in the forest).
	4. That it comes from Denmark, so we can ensure that no loss of forest occurs in other countries.
Environmental	*5*. That it does not interfere with the development of other renewable energy sources such as wind or solar.
	6. That it contributes to climate change mitigation.
	7. That no loss of animals, insects or plants occurs in forests.

Table 2
Example of a Best-Worst Scaling choice set.

Most important	Out of the following issues that the Government can emphasize in the decision to continue using woody biomass please choose one that is most important and one that is least important:	Least important
☐	That it comes from Denmark, so we can ensure that no loss of forest occurs in other countries	☐
☐	That no loss of animals, insects or plants occurs in forests	☐
☐	That prices of electricity and heat do not increase	☐
☐	That it contributes to climate change mitigation	☐

Table 3
Sociodemographic characteristics of the sample (unweighted) and comparison with the Danish population in 2021.

	Sample (n = 1023) (%)	Danish population 2021[a] (%)	Chi-square test
Gender			
Female	50.64	50.26	
Male	48.88	49.74	
Other	0.29	–	Non-significant ($p = .69$)
Do not wish to say	0.2	–	
Age (years)			
18–34	20.43	27.38	
35–49	30.89	22.92	
50–64	24.44	24.52	Significant ($p < .05$)
65 or more	24.24	25.19	
Education			
Primary, high school, vocational training	40.96	64.96	
Higher education (1–5 years), and PhD	58.85	35.05	Significant ($p < .05$)
Do not know	0.2	–	
Region			
Hovedstaden	28.93	31.76	
Sjælland	14.47	14.37	
Syddanmark	23.66	20.95	Non-significant ($p = .19$)
Midtjylland	22.78	22.82	
Nordjylland	10.17	10.10	

[a] Census information for the second quarter of 2021 is obtained from Statistics Denmark (www.dst.dk).

variables on the likelihood of reporting a positive attitude and represents the change in odds resulting from a unit change in the predictor. When OR = 1, the independent variable does not influence the odds of the outcome. When OR > 1, and when OR < 1, the independent variable is associated with higher and lower odds of the outcome, respectively.

The specific model we employed was designed to ascertain the effects of concern about climate change, belief in the mitigation potential of woody biomass, knowledge, age, gender, education, political orientation and income on the likelihood that respondents report a positive attitude to the use of woody biomass for energy as a substitute for fossil fuels, as shown in Equation (2):

$$\begin{aligned} Y_i = {} & \beta_0 + \beta_1 concern\ about\ climate\ change_i \\ & + \beta_2 belief\ mitigation\ potential_i + \beta_3 knowledge_i + \beta_4 age_i \\ & + \beta_5 gender_i + \beta_6 education_i + \beta_7 political\ orientation1_i \\ & + \beta_8 political\ orientation2_i + \beta_9 income1_i + \beta_{10} income2_i \\ & + \beta_{11} income3_i + \varepsilon_i \end{aligned} \quad (2)$$

where Y_i is the dependent variable modelled as $Y = 1$ if a respondent reports a positive attitude towards woody biomass and 0 otherwise, β_0 is a constant term, β_1 to β_{11} are the coefficients to be estimated and ε_i is the error term. The independent variables in our model consisted of continuous and categorical variables. In our analysis, general knowledge was treated as a continuous variable, since we aimed to model the underlying knowledge continuum reflected in the ordered scale. The coding of the independent variables, the baseline against which the categorical variables are compared and the empirical results from the estimation of Equation (2) are presented in Section 3.5.

All analyses were carried out using IBM SPSS Statistics version 27.0. We considered p-values below .05 statistically significant.

3. Results

3.1. Familiarity and knowledge about woody biomass

The energy sources Danes were most familiar with were solar, followed by natural gas, petroleum and wind. Biomass, waste, geothermal and hydropower were the least recognized energy sources (Fig. 1). When asked specifically about familiarity with woody biomass, 47% of respondents reported that they had heard about it prior to the survey, 45% that they had not, and 9% chose the response option *I don't know*. Just over a third of respondents (37%) characterized their own level of knowledge about woody biomass as *neither poor nor good*, and around 46% stated that their knowledge was *poor* or *very poor*. When asked about more specific considerations regarding woody biomass for energy, large shares of respondents reported knowing nothing at all about these: at the lower end 45% could not distinguish between wood pellets, wood chips and wood waste, and at the upper end 64% did not know what types of wood are used to produce woody biomass (Fig. 2). Only a small fraction of respondents (from 1% to 11%) reported that they had good or very good knowledge regarding the different considerations.

3.2. Concern about climate change and attitudes toward woody biomass

Around 41% of the respondents were *moderately concerned* about climate change, 24% were *very concerned* and 13% were *extremely concerned*. On the other hand, 16% and 5% were *slightly concerned* and

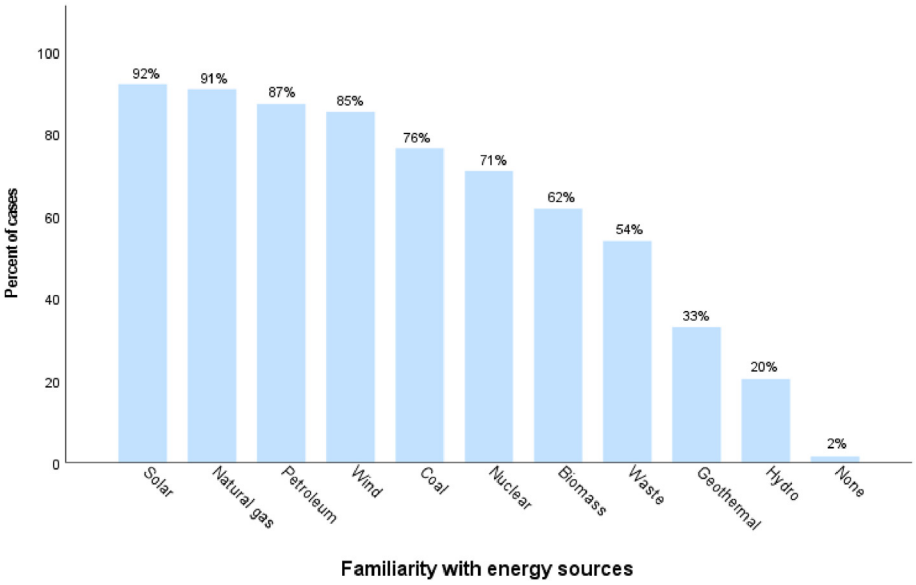

Fig. 1. Familiarity with energy sources from which heat and/or electricity can be produced (unweighted n = 1023).

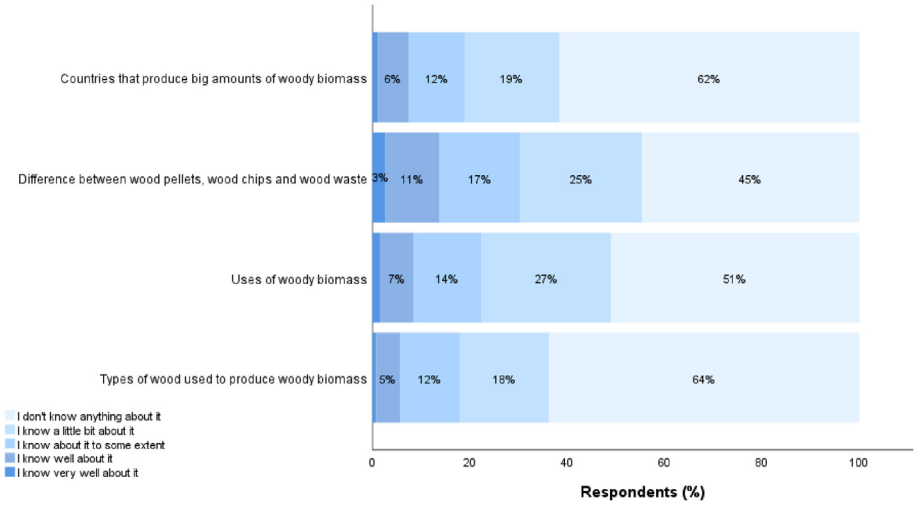

Fig. 2. Level of self-rated knowledge regarding different considerations associated with woody biomass (unweighted n = 1023).

not at all concerned, respectively. When asked about their perception of the mitigation potential of woody biomass compared with that of fossil fuels, almost two-thirds of respondents were undecided and responded either *I don't know* (32%) or *neither agree nor disagree* (26%). Around one in three agreed with the statement (29% agree, 5% strongly agree). Only approximately 6% and 2% of the respondents disagreed and strongly disagreed, respectively.

When the study participants were asked about their attitudes toward woody biomass for energy as an alternative to fossil fuels, the highest proportion (45%) were *neither positive nor negative*, while 30% and 9% were *positive* and *very positive* about it, respectively. Only 12% and 4% were *negative* and *very negative* about it, respectively. We presented a follow-up question to respondents who were *neither positive nor negative* asking them to report their reason(s) for their answer (they chose from multiple reason options). Almost two thirds (68%) reported that they needed to know more before forming an opinion. The second and third most chosen reasons were that it depends on where the woody biomass comes from and on whether it will hamper the development of renewable energy sources such as sun or wind (Fig. 3).

3.3. Concerns about woody biomass for energy

The question about respondents' level of agreement with a series of statements, covering different concerns, that appear in the woody biomass for energy debate revealed that a considerable proportion of the study participants were undecided, choosing the response options *neither agree nor disagree* (ranging from 12% to 33%) or *I don't know* (ranging from 11% to 32%) (Table 4). This undecidedness was higher for environmental and economic issues associated with felling residues left in forests, the prioritization of wood products instead of wood for energy and the cost-effectiveness of woody biomass resources (Items 4, 8 and 12, respectively). Respondents reported higher levels of agreement with the statements relating to future generations, the sustainability of woody biomass, use of other renewable energy alternatives, use of biomass in a transition period until other energy alternatives develop on a larger scale, and the avoidance of negative impacts on forests and biodiversity (Items 10, 3, 1, 2 and 7, respectively).

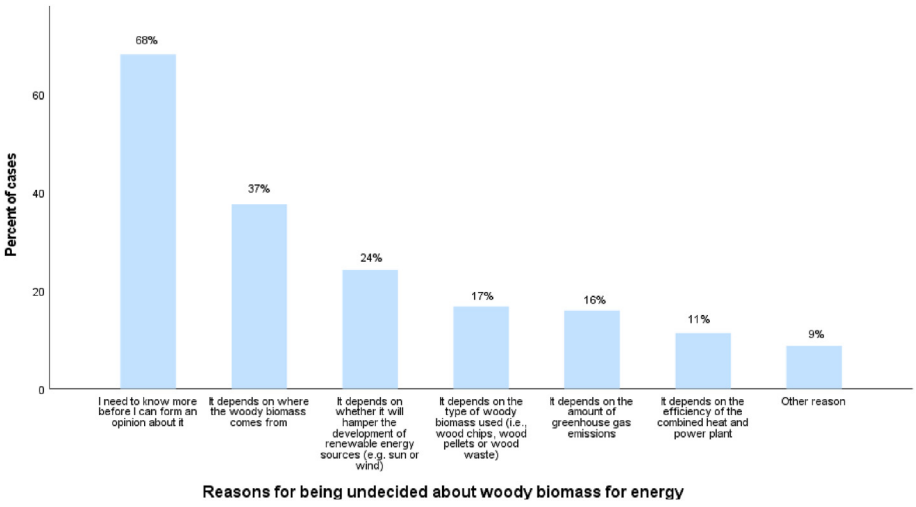

Fig. 3. Reasons for being undecided when asked about attitudes toward woody biomass for energy.

Table 4
Levels of agreement with arguments that appear in the woody biomass for energy debate (unweighted n = 1023).

	Items	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)	Disagree (%)	Strongly disagree (%)	Don't know (%)
Environmental	*Alternative energy sources*:						
	1. The Government should only promote the use of woody biomass if it does not hamper the development of renewable energy sources such as sun or wind.	26	41	16	3	2	12
	2. Woody biomass should only be used until renewable energy alternatives such as sun or wind come on a larger scale.	24	40	19	3	1	14
	Sustainability:						
	3. Woody biomass should only be used for energy if it is possible to ensure its sustainability.	25	46	15	3	1	11
	Resources:						
	4. Felling residues should not be used for energy, but should instead be left in the forests.	9	20	33	15	3	21
	5. Woody biomass should only be used for energy if it comes from wood waste.	17	38	24	5	1	16
	6. Woody biomass should only be used for energy if it comes from quickly rotting wood that would anyway emit carbon into the atmosphere.	11	30	30	8	2	19
	Biodiversity:						
	7. It is acceptable to use woody biomass for energy as long as it does not negatively affect forests and biodiversity.	19	44	19	5	2	12
	Alternative end-use:						
	8. The use of woody biomass for manufacturing of furniture should be prioritized because carbon can be stored in wood products for decades.	9	26	31	2	1	32
Societal	*9*. Woody biomass should only be used if it comes from Denmark so we become less dependent on imports of energy from other countries.	13	34	29	9	3	13
	10. Woody biomass should only be used for energy if it doesn't hamper the ability of future generations to decide how forests, land and resources should be used.	34	41	12	2	1	12
Economic	*11*. Woody biomass should only be used if it creates the cheapest possible green energy transition.	9	34	31	9	3	14
	12. Felling residues and wood industry residues should be used to produce woody biomass as long as there are no other places where they can be sold at a higher price.	8	28	32	9	2	21

Note: All percentages have been rounded off.

3.4. Priorities associated with woody biomass for energy

Table 5 shows the results from the simple count analysis conducted for the BWS question. The attributes associated with environmental concerns (i.e., biodiversity loss, hampering renewable energy sources, and climate change mitigation) were clearly chosen more often as *most important* (and less often as *least important*). Fig. 4 shows the public's prioritization based on the standardized BW scores.

Results from the Spearman's rank-order correlation showed that there was no statistically significant association at the 95% significance level between general self-rated knowledge and the standardized BW scores for the seven different attributes. Table 6 shows the means of the standardized BW scores for each level of general self-rated knowledge. Regardless of the level of knowledge reported by respondents, the three most important concerns were biodiversity loss, hampering of renewable energy sources and climate change mitigation, although not necessarily in that order.

3.5. Explaining attitudes toward the use of woody biomass for energy

Results from the binary logistic regression model (model fit information: $\chi^2(11) = 226.996$, $p < .001$; -2LL = 1114.513; Cox & Snell $R^2 = 0.202$; Nagelkerke $R^2 = 0.274$; adjusted McFadden's Pseudo $R^2 = 0.151$) predicting positive attitudes toward woody

Table 5
Results from simple count analysis conducted for the Best-Worst Scaling question (weighted n = 1020; unweighted n = 1023).

	Attributes	Most important	Least important	BW score	(BW)/*n*	Standard deviation	Standardized BW score	Rank
Environmental	Biodiversity loss	1609	343	1266	1.24	1.87	0.31	1
Environmental	Renewable energy sources	1606	417	1189	1.17	1.78	0.29	2
Environmental	Climate change mitigation	1524	545	979	0.96	2.00	0.24	3
Societal	Recreational use of forests	586	1093	−507	−0.50	1.73	−0.12	4
Economic	Increased energy prices	894	1526	−632	−0.62	2.47	−0.15	5
Societal	Locally sourced	630	1279	−649	−0.64	1.97	−0.16	6
Economic	Economic growth and employment	312	1958	−1646	−1.61	1.79	−0.40	7

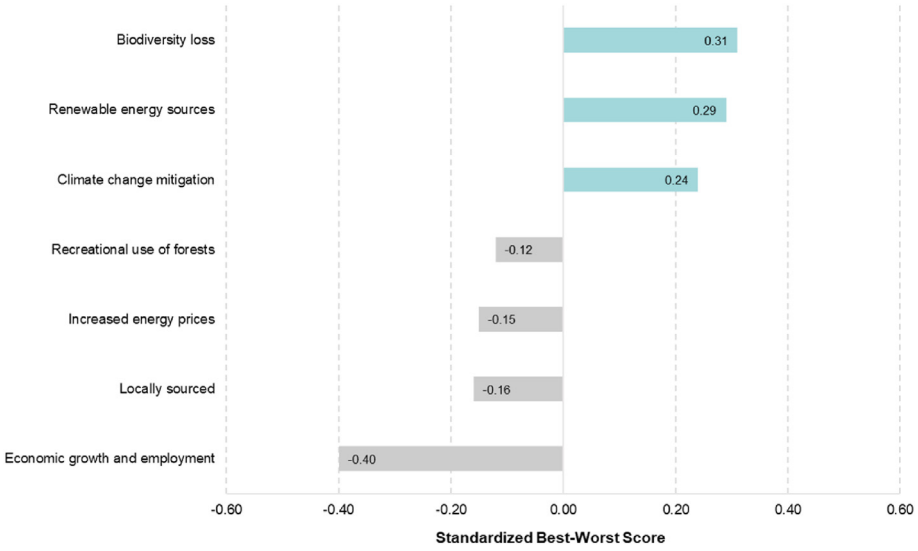

Fig. 4. Prioritization of woody biomass related considerations based on standardized BW scores (unweighted n = 1023). Standardized BW scores range from −1 to +1. Negative scores denote lower relative importance and positive scores denote higher relative importance.

Table 6
Mean standardized best-worst (BW) scores for each of the five levels of self-rated general knowledge.

	Knowledge						
Mean standardized BW score	*Very poor*	*Poor*	*Neither*	*Good*	*Very good*	*Rho*	*Sig. (2- tailed)*
Biodiversity loss	0.26	0.29	0.33	0.32	0.38	.052	.098
Renewable energy sources	0.22	0.30	0.31	0.35	0.12	.045	.148
Climate change mitigation	0.22	0.28	0.22	0.23	0.21	-.027	.389
Recreational use of forests	−0.12	−0.13	−0.11	−0.14	−0.15	-.003	.922
Increased energy prices	−0.12	−0.15	−0.16	−0.21	−0.04	-.032	.312
Locally sourced	−0.13	−0.15	−0.17	−0.19	−0.16	-.032	.304
Economic growth and employment	−0.34	−0.43	−0.42	−0.36	−0.36	.002	.945

biomass for energy are shown in Table 7. Positive estimates of coefficients indicate that an increase of one unit in the independent variable contributes more to the result = 1 of the outcome variable, whereas the opposite is true for negative estimates. As explained in Section 2.3, ORs indicate the effect of variations in the independent variables on the probability of reporting a positive attitude. When applying these criteria on the model results we find that people concerned about climate change ($p < .01$) and people who believe in the mitigation potential of woody biomass ($p < .001$) are more likely to report a positive attitude to the use of woody biomass for energy. In addition, being older ($p < .01$) decreases the likelihood of reporting this positive attitude. As reported in Section 3.2, a minority (39%) of the respondents indicated a positive attitude (*positive* or *very positive*). This is also reflected when we run a regression model without predictors, where we find that the constant has a negative coefficient (−0.468) and an OR below 1 (0.626). This shows that the probability of reporting a positive attitude (i.e., $Y = 1$) for the entire sample is < 0.50.

4. Discussion

The present study indicates that, although more people seem to favor than oppose the use of woody biomass as a renewable energy source, the public is largely undecided about whether or not this way of producing energy is desirable. Indeed, a significant share of participants in the study (45%) were *neither positive nor negative* about this use of woody biomass. This contrasts studies that report clear public support for (as opposed to undecidedness about) woody biomass in the form of WTP both in Europe and in the USA (e.g., Refs. [47,48,65]). The main reason for the reported undecidedness was a need to know more about the topic before forming an opinion, and half of respondents reported having a lack of general knowledge about this energy source, which corresponds with results by previous studies (e.g., Refs. [66,67]). In line with this, Soliño et al. [43] found that only 77% of people from the Spanish region of Galicia consider biomass a renewable energy source, despite it having being labelled that way for decades. This lack of knowledge is further

Table 7
Binary logistic regression model focusing on potential predictors of general attitudes toward the use of woody biomass to produce energy as an alternative to fossil fuels (1 = positive attitude; 0 = non-positive attitude). Significance level: *$p < .01$, **$p < .001$.

Total sample = 1005[a]		Binary logistic regression
Variables[b]	β	**Odds ratio (95% CI)**
Concern about climate change	0.611	**1.842(1.266–2.680)***
Belief in mitigation potential	2.057	**7.824(5.741–10.663)****
Knowledge	−0.012	0.988(0.847–1.153)
Sociodemographic variables		
Age	−0.014	**0.986(0.977–0.996)***
Gender	−0.045	0.956(0.707–1.293)
Education	−0.260	0.771(0.569–1.045)
Political orientation1	0.224	1.251(0.911–1.719)
Political orientation2	0.046	1.047(0.637–1.722)
Income1	0.128	1.136(0.744–1.736)
Income2	0.217	1.243(0.810–1.907)
Income3	0.154	1.166(0.691–1.967)
Constant	−1.056	0.348*

[a] The sample size was 1005 because there were 18 missing observations on two of the independent variables (5 missing values for gender, 11 missing values for concern about climate change and 2 missing values for education).

[b] Coding: (1) Concern about climate change (1 = concerned – *moderately concerned* plus *very concerned* plus *extremely concerned*); 0 = not concerned – *not at all concerned* plus *slightly concerned*). (2) Belief in mitigation potential (1 = agreement – *agree* plus *strongly agree*; 0 = other – *neither* plus *don't know* plus *disagree* plus *strongly disagree*). (3) Knowledge (continuous). (4) Age (continuous). (5) Gender (1 = male; 0 = female). (6) Education (1 = higher education; 0 = primary, high school and vocational training). (7) Political orientation (0 = left-wing, 1 = right-wing, 2 = *other* plus *don't know* plus *don't want to answer*). (8) Income (0 = < 300,001 DKK; 1 = 300,001–600,000 DKK; 2 = > 600,000 DKK; 3 = *don't know* plus *don't want to answer*). The baseline against which each variable is compared is that coded with the lowest number.

cemented by other results from our data, where we found that as many as 45% of respondents were not familiar with woody biomass for energy. Indeed, woody biomass also appears to be one of the least familiar energy sources, with solar and wind being better known, again a finding consistent with studies in other countries, both within and outside the EU (e.g., Refs. [51,52,67,68]). Similarly, other authors have found that biomass is perceived to have a secondary role in the diversification of primary energy for power generation, with other energy options being seen as more important (e.g., Ref. [44]). Undecidedness was also found in relation to the mitigation potential of woody biomass. Here only one third of respondents believed that woody biomass could help reduce GHG emissions, and two-thirds responded *I don't know* or *neither agree nor disagree*. The Danish public's undecidedness is surprising given the considerable use being made of woody biomass for energy in Denmark over a relatively long term, and the persistent promotion of woody biomass by policy makers and a broad range of industry stakeholders on the grounds of its environmental benefits, as compared with fossil fuels. However, attitude theorists have pointed out for a long time that most political issues are relatively non-salient for the average citizen, and that citizens have limited knowledge of, and interest in, many political issues [69,70]. While it is unlikely that the public's limited knowledge regarding the use of woody biomass for energy will be improved substantially, this does not mean that people are unable to form reasoned opinions. Other attitude research has shown that people with limited knowledge and interest are able to form opinions and prioritize on the basis of their general values, along with social position and demographic conditions [71].

In an effort to capture these general values – values that do not require, or depend upon, specialized knowledge or issue saliency – we employed the BWS methodology. Using this, we found that the main priorities for the Danish public were that the use of woody biomass for energy production does not lead to biodiversity loss, hindering of the development of other renewable energy sources, or increased GHG emissions. These priorities were widespread and independent of people's knowledge. In essence, then, Danish people think that environmental issues, and specifically sustainability, should be given priority over societal and/or economic impacts. The greater importance attached to these issues is supported by our finding that the majority of Danes are concerned about climate change, and by what might also follow from this – namely, that they support emission reductions and shifts away from fossil fuels. When asked about their level of agreement with arguments that appear in the public debate, the respondents reported higher levels of agreement with arguments associated with using other renewable energy alternatives, avoiding negative impacts on forests and biodiversity, ensuring sustainability and considering future generations' well-being. Thus, environmental concerns were also present in these findings. It should be noted that a high proportion of respondents were undecided over these agreement questions, especially in relation to items associated with alternative end-uses of woody biomass, cost-effectiveness of woody biomass resources and the use of felling residues. This clearly reflects the inherent complexities of the issues. Issues associated with the climate impact of woody biomass, together with biodiversity conservation, have been described as some of the main concerns about woody biomass in the broader literature (e.g., Refs. [31,72]). On the other hand, our results suggest that economic growth, employment opportunities and energy prices have less importance. The reason for this prioritization is perhaps that Danes do not perceive these concerns as a necessity. There is a contrast here with results reported by other studies (e.g., Refs. [37,73,74]), pointing to the existence of various socio-economic and political conditions that influence prioritization.

It would appear that the BWS task is capable of successfully eliciting priorities when it comes to such a complex topic, where capturing nuanced and informed opinion may not be realistic. Other studies have already demonstrated this capability in connection with other topics, including the preferences shaping consumers' ethical beliefs (e.g., Ref. [75]), health care choices (e.g., Ref. [76]), and attitudes toward the ecosystem and the economic benefits of lake restoration and conservation (e.g., Ref. [77]). In this way, the BWS methodology can be used to inform and guide those charged with developing inclusive energy policies that take due account of public concerns and preferences. In the Danish context it should be borne in mind that the 1998 Aarhus convention on the rights of the public to participate in environmental decision-making requires public concerns to be taken into account [78].

We found that younger people, and people concerned about climate change, as well as people believing in the mitigation potential of woody biomass, were more likely to report a positive attitude to the use of woody biomass for energy. People worried about climate change might feel a stronger desire to counteract its impacts and therefore accept woody biomass because they see it as an acceptable substitute for fossil fuels in the production of energy. The Danish government also sees woody biomass as acceptable, at least in a transitional perspective as the country moves toward a de-carbonized energy system. In line with our results, other studies have found that belief in the mitigation potential of an energy source and/or the possession of pro-climate views is associated with support for renewable energy sources (e.g., Refs. [66,79–82]). Similarly, Soliño et al. [43] find that perceiving biomass as a renewable energy source positively affects the probability of agreeing to pay for electricity produced from this energy source. In line with findings reported by Devine-Wright [83]; but also in contrast with those reported in other studies (e.g., Refs. [40,84–87]), we did not confirm that knowledge promotes positive attitudes toward the use of woody biomass for energy. As regards sociodemographic variables, we found that only age predicts positive attitudes. This is in keeping with results from

studies researching forest owners' willingness to supply woody biomass (e.g., Refs. [29,88]), but it also contradicts the finding, recently published by Solomon et al. [42] following their research into public support for increased biomass production for electric power in the USA, that age has no effect on such support. A decade ago Zyadin et al. [52] suggested that future research could investigate the influence of income and political orientation on attitudes toward renewable energy. However, we did not find either of these to have predictive power. Nor did gender appear to shape attitudes, as previous studies have also found (e.g., Refs. [42,88]). Our finding that education is insignificant challenges the results obtained by several other authors (e.g., Refs. [29,49,88]). It is possible that we were unable to confirm these associations because the variables *concern about climate change* and *belief in the mitigation potential of woody biomass* attenuated the effect of the sociodemographic variables in the reported regression analysis. However, when we ran a model from which these two variables were excluded all of the sociodemographic variables (except age, again) remained insignificant. The deviations from the wider body of literature are perhaps not surprising, as most of the existing literature on perceptions of woody biomass confines itself to forestland owners and other stakeholders acquainted with bioenergy rather than examining the broader society. Public attitudes might be more complex and multifaceted. A larger number of studies focusing on public attitudes toward woody biomass for energy will be required if we are to make a meaningful comparison.

It is important to consider several limitations of our study design. First, we had difficulty capturing nuanced views, because a high proportion of our respondents expressed undecidedness. Second, a quantitative cross-sectional design does not permit causal inferences to be straightforwardly made [65]. Not does it offer a complete explanation of the relevant attitudes' formation. Third, cognitive, psychological and/or sociodemographic factors omitted in our study may help to explain the attitudes we focused upon. Finally, the BWS methodology only elicits prioritizations among the attributes included in the design. Hence the ranking obtained is limited to, and relative among, the chosen attributes [64]. It follows that other attributes, not included in the study design we adopted, could have generated other prioritization scenarios. Further, different respondents may potentially use different decision rules when making choices, and they may have more, or less, consistent ways of choosing [89]. In either case, the precision with which the preferences are elicited using the BWS methodology would be weakened. Finally, while our sample represented the Danish population well regarding gender and region, and only showed minor deviations regarding age, it misrepresented education groups in the Danish population to quite a high extent. This is, unfortunately, not uncommon when recruiting respondents from online panels. However, it raises the question whether the reported results would have differed at all if the recruitment had been more representative as regards education. Additional analyses showed that educational differences had limited impact on concern about climate change, familiarity with and attitude toward woody biomass, and agreement with most of the arguments in the woody biomass debate. There were, however, differences regarding knowledge, as well as in belief in the mitigation potential of woody biomass and five of the standardized BW scores (see Appendix C for more details). It would appear that the observed differences are in all cases rather modest, and that the main pattern of results would have been very similar if education groups in Denmark had been more accurately represented.

On the basis of our results, we suggest that future policies, in which choices will have to be made among energy alternatives in the green energy transition, would benefit from careful consideration of public concerns and priorities regarding the use of woody biomass as a renewable source of energy. Neglect of the broader society's views can be a barrier to adequate policy development [41]. Conversely, their inclusion increases the legitimacy of energy solutions. Although some authors argue for improved awareness and knowledge (e.g., Refs. [31,38,40]), providing information to the public with the aim of expanding their knowledge does not necessarily help to form a particular attitude. Attitudes are complex. They comprise both beliefs and values on a particular topic, and therefore they are not based exclusively on factual information [90]. Besides, policy development does not necessarily depend on engaging with a public equipped with sound knowledge of a particular issue. In this vein, our results tend to confirm that public attitudes toward woody biomass energy are shaped more strongly by concerns about sustainability issues (e.g., climate mitigation potential of and risk of biodiversity loss caused by woody biomass) than they are by specialized knowledge of the issues.

The fact that the Danish public prioritizes the avoidance of negative environmental impacts of woody biomass energy over its societal and/or economic gains could be taken to mean that policy makers aiming to engage with the public in the discussion of Denmark's energy future should focus on policies minimizing negative environmental impacts of woody biomass use. This is in line with scholars and activists who envisage alternative energy futures in which economic growth is de-emphasized, and who call instead for reduced material and energy throughput in society (e.g., Ref. [91]). Neglect of the opinions and attitudes of the public as a crucial stakeholder group could hinder efforts to secure a just energy transition that takes due account of everyone involved and affected by its outcome.

5. Conclusions

The objectives of this survey study were to investigate knowledge, attitudes, concerns and priorities of the public around the use of woody biomass for energy, as well as factors influencing attitudes. Our findings offer insights into attitudes of the Danish public toward woody biomass. They show that the majority are undecided about its use for energy production, and that this is partly explained by a general lack of self-reported knowledge. Besides this, we found that it is predominantly environmental concerns associated with the use of woody biomass for energy that are given priority. This has important implications for policy-making. The study also provided a better understanding of what shapes attitudes. Several factors influence the formation of positive attitudes towards woody biomass. Younger people, people concerned about climate change, and people believing in the mitigation potential of woody biomass are more likely to be positive about this energy source.

Future studies should aim to capture more nuanced views. For this purpose, they could ask respondents about more specific woody biomass scenarios that include various alternatives and/or conduct qualitative research such as focus groups and qualitative interviews. That would provide a more comprehensive and granular picture of attitudes toward woody biomass energy of the kind that purely quantitative surveys cannot deliver. Qualitative research might also help us to empirically explore potential attributes for inclusion in future BWS questions, opening a new avenue for the development of this methodology in research into public perceptions of biomass energy. Moreover, given that published results on predictors of attitudes are mixed, and given also the potential existence of several other factors influencing attitudes, it is arguable that, as well as continuing to investigate the role of climate change views, knowledge, and sociodemographic factors in shaping attitude formation, we should explore the influence of further factors, such as values, environmental attitudes and perceptions of the benefits and adverse impacts of woody biomass use, in order to obtain a fuller picture.

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

CRediT authorship contribution statement

Paula Ugarte Lucas: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Christian Gamborg:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Thomas Bøker Lund:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Balanced Incomplete Block Design

Table A.1
Symmetrical[a] Balanced Incomplete Block Design[b] involving seven attributes. k = set of attributes; s = number of choice sets; m = number of attributes per choice set; r = number of times that each attribute appears; λ = number of times each pair of attributes appears.

Set ID	Attribute ID			
1	6	3	5	2
2	5	4	6	1
3	2	1	7	5
4	1	2	4	3
5	3	6	1	7
6	4	7	2	6
7	7	5	3	4

k = 7, s = 7, m = 4, r = 4, λ = 2.
[a] i.e., k = s.
[b] The distribution of attributes across the seven choice sets was generated using the Proc Factex code in SAS to ensure balance [92]. The design had a treatment D-efficiency of 87.5 and block D-efficiency of 100.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2022.05.075.

Appendix C. Educational differences

1. Familiarity with woody biomass

Results from the chi-square test revealed that there is no statistically significant association between education level and familiarity with woody biomass.

Table C.1

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Familiarity (%)	Yes	42.72	49.67	Non-significant ($p = .067$)
	No	48.69	41.53	
	I don't know	8.59	8.80	

2. Knowledge about woody biomass

Results from the chi-square test revealed that there is a statistically significant association between education level and knowledge about woody biomass.

Table C.2

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Knowledge (%)	Very poor	16.23	12.13	Significant ($p = .045$)
	Poor	30.07	32.72	
	Neither poor nor good	39.62	35.22	
	Good	11.46	15.95	
	Very good	2.63	3.99	

3. Concern about climate change

Results from the chi-square test revealed that there is no statistically significant association between education level and concern about climate change.

Table C.3

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Concern climate change (%)	Not at all concerned	5.37	5.33	Non-significant ($p = .123$)
	Slightly concerned	19.27	14.83	
	Moderately concerned	41.22	40.83	
	Very concerned	24.39	24.50	
	Extremely concerned	9.76	14.50	

4. Belief in the mitigation potential of woody biomass

Results from the chi-square test revealed that there is statistically significant association between education level and belief in the mitigation potential of woody biomass (measured as level of agreement with the statement "*The use of woody biomass for energy leads to less GHG emissions than the use of fossil fuels*").

Table C.4

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Belief mitigation potential (%)	Strongly disagree	2.63	2.49	Significant ($p < .01$)
	Disagree	5.97	6.48	
	Neither	29.36	22.43	
	Agree	24.34	32.23	
	Strongly agree	3.10	6.15	
	I don't know	34.61	30.23	

5. Attitude toward woody biomass

Results from the chi-square test revealed that there is no statistically significant association between education level and attitude toward woody biomass.

Table C.5

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Attitude (%)	Very negative	3.82	3.32	Non-significant ($p = .829$)
	Negative	11.22	13.29	
	Neither	47.02	44.35	
	Positive	29.36	30.23	
	Very positive	8.59	8.80	

6. Concerns about woody biomass for energy

Arguments 1–12 below correspond to those in Table 4 (Section 3.3). Results from the chi-square test revealed that there is a statistically significant association only between two of the 12 arguments covering concerns raised in the woody biomass debate and education level. These two arguments are (2) "*Woody biomass should only be used until renewable energy alternatives such as sun or wind come on a larger scale*" and (10) "*Woody biomass should only be used for energy if it doesn't hamper the ability of future generations to decide how forests, land and resources should be used*".

Table C.6

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
Argument 1 (%)	Strongly disagree	1.19	1.66	Non-significant ($p = .186$)
	Disagree	3.58	3.16	
	Neither	17.66	14.29	
	Agree	40.81	41.86	
	Strongly agree	22.67	28.24	
	I don't know	14.08	10.80	
Argument 2 (%)	Strongly disagree	0.24	1.50	Significant ($p < .05$)
	Disagree	2.39	3.49	
	Neither	21.96	16.28	
	Agree	39.14	39.70	
	Strongly agree	21.24	25.75	
	I don't know	15.04	13.29	
Argument 3 (%)	Strongly disagree	0.48	0.66	Non-significant ($p = .068$)
	Disagree	3.58	1.99	
	Neither	16.47	14.62	
	Agree	43.44	47.18	
	Strongly agree	22.67	26.74	
	I don't know	13.37	8.80	
Argument 4 (%)	Strongly disagree	4.30	1.83	Non-significant ($p = .120$)
	Disagree	15.99	14.29	
	Neither	32.22	32.89	
	Agree	18.14	21.59	
	Strongly agree	7.40	9.30	
	I don't know	21.96	20.10	
Argument 5 (%)	Strongly disagree	0.72	1.00	Non-significant ($p = .705$)
	Disagree	3.58	5.81	
	Neither	24.11	23.42	

(*continued on next page*)

(*continued*)

		Education level		
		Primary, high school, vocational training	*Higher education and PhD*	Chi-square test
	Agree	37.95	37.54	
	Strongly agree	17.42	16.45	
	I don't know	16.23	15.78	
Argument 6 (%)	Strongly disagree	1.19	1.99	Non-significant ($p = .926$)
	Disagree	7.88	7.97	
	Neither	30.79	29.24	
	Agree	30.55	29.73	
	Strongly agree	10.74	11.13	
	I don't know	18.85	19.93	
Argument 7 (%)	Strongly disagree	2.15	2.33	Non-significant ($p = .588$)
	Disagree	3.34	5.15	
	Neither	17.90	19.44	
	Agree	43.20	44.02	
	Strongly agree	20.05	17.61	
	I don't know	13.37	11.46	
Argument 8 (%)	Strongly disagree	0	1.00	Non-significant ($p = .294$)
	Disagree	1.91	2.16	
	Neither	33.65	29.57	
	Agree	24.58	26.74	
	Strongly agree	8.35	8.97	
	I don't know	31.50	31.56	
Argument 9 (%)	Strongly disagree	2.39	2.33	Non-significant ($p = .144$)
	Disagree	7.40	9.47	
	Neither	31.03	26.58	
	Agree	30.31	37.04	
	Strongly agree	14.08	12.79	
	I don't know	14.80	11.79	
Argument 10 (%)	Strongly disagree	0.95	0.50	Significant ($p < .01$)
	Disagree	1.19	1.66	
	Neither	14.56	10.13	
	Agree	38.90	41.69	
	Strongly agree	29.12	36.71	
	I don't know	15.27	9.30	
Argument 11 (%)	Strongly disagree	3.10	3.32	Non-significant ($p = .256$)
	Disagree	9.07	9.14	
	Neither	30.79	30.90	
	Agree	31.03	36.54	
	Strongly agree	10.02	8.64	
	I don't know	15.99	11.46	
Argument 12 (%)	Strongly disagree	3.34	1.50	Non-significant ($p = .333$)
	Disagree	7.88	9.14	
	Neither	29.59	32.39	
	Agree	29.83	28.24	
	Strongly agree	7.88	8.97	
	I don't know	21.48	19.77	

7. Priorities associated with woody biomass for energy

Results from the Spearman's rank-order correlation showed that there was a statistically significant association between education level and the attributes associated with biodiversity loss, renewable energy sources, climate change mitigation, increased energy prices, and economic growth and employment, but not with the items associated with recreational use of forests and locally sourced biomass.

Table C.7

		Education level			
		Primary, high school, vocational training	*Higher education and PhD*	Rho	Sig. (2-tailed)
Mean standardized BW score	*Biodiversity loss*	0.26	0.35	.086	.006
	Renewable energy sources	0.26	0.31	.069	.029
	Climate change mitigation	0.17	0.29	.130	<.001
	Recreational use of forests	−0.11	−0.14	-.033	.293
	Increased energy prices	−0.07	−0.21	-.112	<.001
	Locally sourced	−0.14	−0.17	-.023	.458
	Economic growth and employment	−0.36	−0.43	-.074	.018

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