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Industrial End-Users' Preferred Characteristics for Wood Biomass Feedstocks

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Abstract: The use of sustainably sourced biomass is an important tool for mitigating the effects of climate change; but biomass is far from being a homogeneous resource. The aim of this study was to examine the decision-making process of industrial end-users considering biomass procurement. An online, two-part survey generated responses from 27 experienced professionals, representing a portfolio of facilities varying in size, technology, and biomass types, across Australia, Canada, Finland, and Sweden. A PAPRIKA conjoint analysis approach was used to analyze the data so that the attributes that influenced procurement decisions could be weighted and ranked. The results provided an insight into end-users' views on factors including facility location, size, and biomass storage, handling, and procurement for different wood-based industrial services. The most important decision-making attribute appeared to be the type of biomass assortment, at individual, national, and aggregated levels. Of seven sub-categories of biomass assortments, sawdust (35%) was the most preferred type followed by stem wood chips (20%) and energy wood (15%). We concluded that, from the end-user's perspective, a pre-defined biomass assortment is the most important factor when deciding on feedstock procurement at a bioenergy facility. These results help us better understand end-users' perceptions of biomass properties in relation to their conversion processes and supply preferences and can inform product development and the securement of new niches in alternative business environments by existing and future biohubs.

Keywords: biohubs; expert analysis; conjoint analysis; PAPRIKA method; bioenergy

1. Introduction

Sustainably sourced biomass has an important role to play in climate change mitigation and adaptation strategies by providing a supply of renewable carbon to the economy. Stable and secure sustainable biomass supplies are needed for energy independence as well as for de-fossilizing the economy [1]; in addition, de-fossilization driven by climate change mitigation strategies is expected to increase the demand for biomass further.

This higher demand is driven not only by combustion and combined heat and power (CHP) plants but by more sophisticated conversion streams [2], highlighting the need for sustainable biomass assortments of consistent quality with easily controllable characteristics [3]. Most biochemical producers relying on woody biomass require consistent high-quality feedstock; for example, biomass refinery plants using gasification and pyrolysis conversion technologies are more sensitive than traditional combustion plants to particle size, ash content, and moisture content [3,4]. However, differences in biomass feedstock, as a result of local forest conditions, energy production traditions, and supply chains [5], can influence the regional preferences of feedstock end-users.

At a regional level, logistic biohubs are increasingly being recognized as an important part of an efficient raw material supply chain for pulp, paper, and biomaterial industries [6–9]. The business models for biohubs and their functionality depend greatly on, for example, the type, amount, and quality of industrial feedstock demand as key measures for optimizing raw material utilization [10–12]. For the whole supply chain, from forest to final product, to work efficiently, a good understanding of suppliers' capabilities and customers' needs is also needed [13].

All biomass conversion processes require comminution and some level of other pretreatment, such as drying, sieving, etc. The quality of wood chips can be defined in the same way as pre-defined assortments such as wood pellets or energy wood by their moisture and ash content, type, particle size, and heating value [14]. Inconsistencies in biomass quality between individual deliveries as well as between biomass suppliers cause the most problems for process control at facilities, even once they have been adjusted for specific biomass properties and their variation [15–18]. On the supply side, handling a comminuted biomass of various particle sizes and moisture content has a considerable effect on biomass storage, drying, loss, and self-ignition [19–24].

This highlights the need for a better understanding of how facilities perceive different aspects of pre-defined biomass assortments and specific biomass characteristics in order to streamline biomass supply and demand in regional biohubs. Key biomass characteristics include moisture content, particle size, and ash content [14] as well as availability and supply [25]. Depending on the biomass conversion process used, the requirements for specific biomass properties can vary; in general, large-scale, bubbling, fluidized bed boilers are the least sensitive to moisture content, ash and particle size, and variation compared with smaller grate-type boilers [26].

The aim of this study was to describe and assess end-users' preferences regarding biomass feedstock characteristics and to analyze the key factors that influence procurement. The goal was to determine end-users' perceptions of different wood-based industrial facilities, rank the features of business models in terms of facility location, size, and biomass storage, handling, and procurement, and determine relative weights and ranking for biomass attributes based on the opinions of experienced professionals from bioenergy facilities across different countries.

2. Materials and Methods

2.1. Survey Design and Data Collection

In order to characterize different biomass feedstocks and assess the end-users' preferences, a list of attributes and associated levels was created after a series of discussions held in 2020. The attributes were defined as properties, features, or characteristics of biomass feedstock that had two or more categories or levels of performance or output, resulting in a final list of 10 attributes with two to seven levels (Table 1). A wide range of levels was deliberately used, to maximize the output of the survey.

Table 1. Attributes of biomass feedstock and their associated levels.

Attribute		Attribute Level	
A1	Type of biomass assortment you prefer	L1	Agricultural residues and by-products
		L2	Logging residue and tree part chips
		L3	Bark
		L4	Energy wood (low-quality roundwood)
		L5	Stem wood chips
		L6	Pulpwood
		L7	Sawdust
A2	Assortment availability in the supply region	L1	Low: <25% of your facility's production needs
		L2	Medium: 50% of your facility's production needs
		L3	High: 75% of your facility's production needs
		L4	Very high: 100% of your facility's production needs
A3	Price	L1	Higher than the market average
		L2	Market average
		L3	Lower than the market average
A4	Supply security/accessibility of an assortment	L1	Low: access can regularly be disturbed
		L2	Medium: seasonal variation can affect access
		L3	High: access is all year round
A5	Average range in particle size	L1	The higher end of your maximum acceptable range
		L2	The lower end of your minimum acceptable range
		L3	Middle of your acceptable range
A6	Variation in moisture or dry content between deliveries	L1	High variation
		L2	Low variation
A7	Variation in particle size between deliveries	L1	High variation
		L2	Low variation
A8	Variation in ash content between deliveries	L1	High variation
		L2	Low variation
A9	Percentage moisture content (not dry content)	L1	The higher end of your maximum acceptable range
		L2	The lower end of your minimum acceptable range
		L3	Middle of your acceptable range
A10	Percentage ash content	L1	Your maximum accepted level
		L2	Your expected level or lower

These attributes formed the basis of a two-part survey. The first part included 28 general-purpose questions concerning the location of the facility, the conversion technologies used, total capacity or biomass demand, etc. In addition, the first part included questions regarding biomass properties (ash, moisture content, and particle size, and their acceptable range and values), storage, supply, and billing. The questions were framed to guide the respondents towards the second part of the survey [27], which was based on a PAPRIKA conjoint analysis approach, to define weights and ranks for the biomass attributes [28]. The respondents were asked to rank the levels for each predefined attribute in terms of importance (or attractiveness) at the beginning of the survey, before pairwise comparisons of hypothetical alternatives were presented (see Appendix A Figure A1).

A database of experienced bioenergy facility professionals (one per facility) was constructed to cover the range of targeted end-user profiles, with contributions from the International Energy Agency's (IEA) Bioenergy network in Australia, Canada, Croatia, Finland, and Sweden. To be included in the database, the professionals had to represent a bioenergy facility and have at least 1 year's experience in, for example, logistics, business development, process engineering, and supply of biomass. Of the resulting 100 professionals, the average length of experience in their current position was 8 years, ranging from 1 to 37 years. The facilities represented covered a range of conversion technologies, including different sizes of heat plants, CHP plants, and integrated combustion plants with gasification, pyrolysis, or pelletizing. The online survey was sent out to the potential respondents from 7 July to 19 October 2021.

2.2. Data Methods

The results of the survey were analyzed in two steps: first, descriptors of the main variables were used to characterize the facilities and biomass feedstocks; second, applying a PAPRIKA conjoint analysis approach, the biomass attributes were weighted and ranked. Conjoint analysis is a survey-based statistical technique that that can be used to determine how the different attributes that make up an individual product or service are valued by respondents [29], based on a controlled set of hypothetical alternatives (sometimes called concepts, profiles, or products) created from a combination of levels from all or some of the constituent attributes. A PAPRIKA approach (for technical development, see [28]) is based on pairwise ranking of potentially all undominated pairs of all possible alternatives. An undominated pair refers to a pair of alternatives where one is characterized by a higher ranked category for at least one attribute and a lower category for at least one other attribute than the other alternative.

For this survey, the respondents were asked to rank or rate the attributes of the different feedstocks under consideration using a pairwise comparison to determine weights for the attributes (part-worth utilities) based on their expert knowledge and judgment involving trade-offs between the attributes. The questions were based on partial alternatives, starting with only two attributes at a time, in contrast to the full-alternatives method, which presents all attributes together at once. Each question was based on a choice between two hypothetical alternatives defined by two attributes at a time, presuming that the other attributes were equal to the one presented. The analysis resulted in an implicit valuation of the weights or part-worth utilities of the attributes [30], which was estimated using 1000minds software (see https://www.1000minds.com/ (accessed on 1 December 2021)). More details about the PAPRIKA method are presented in Appendix B.

3. Results

3.1. Characterization of the Facilities' Biomass Supply

Of the 100 facilities and professionals approached, 27 completed the first part of the survey (the general-purpose questions) and 20 completed the whole survey (a response rate of 27% and 20%, respectively). The respondents came from Australia, Canada, Finland, and Sweden, and their responses covered the whole range of targeted biomass end-use conversion technologies and included facilities of different sizes (Table 2). The main biomass conversion technologies represented were combustion, pelletizing, gasification, and torrefaction, as well as pyrolysis, lignin extraction, and hydrothermal liquefaction. Biomass conversion technologies such as pyrolysis, gasification, torrefaction, and lignin extraction were often integrated into other processes or were part of bigger complexes with multiple end products that could be considered biorefineries.

A wide range of biomass assortments was used, the most frequent being sawdust, energy wood, and pulpwood (Table 3). There was no apparent consensus among the combustion plants under 5 MW for a particular assortment; instead, it appeared that the plants were adapted for different assortments even within the same country. None of the smaller combustion plants used bark, possibly because of the challenge in achieving consistent quality parameters. However, bark use was widespread in the larger combustion plants or when combustion was a part of gasification, pyrolysis, or pelletizing. A similar pattern was seen with wood pellet production. Pellet plants in Canada focused mainly on sawdust, while, in Sweden, the use of bark and stem wood complemented the drying processes and raw material base. Pellet plants with integrated lignin and sugar extraction (for the production of bioethanol) as well combustion reported up to seven other assortments on their procurement list.

Table 2. Number of facilities by country and biomass conversion technology.

Biomass Conversion Technology	No. of Facilities per Country				Total
	Australia	Canada	Sweden	Finland	
Combustion ≤ 5 MW	1	4	2	1	8
Combustion 6–20 MW			2		2
Combustion 21–50 MW			1		1
Combustion > 50 MW, Pyrolysis, Lignin extraction			2	3	5
Combustion ≤ 5 MW, Gasification/Pyrolysis	2				2
Pelletizing / Torrefaction, Lignin extraction, Sugar extraction		2	3		5
Pelletizing, Combustion 21–50 MW			2		2
Hydrothermal Liquefaction	2				2
Total	5	6	12	4	27

Table 3. Averaged percentage of biomass characteristics (*n* = 27), grouped by conversion technology and country.

Biomass Conversion Technology	Country	Pulpwood	Energy Wood	Stem Wood Chips (White Chips)	Logging Residue Chips (Brown/Green Chips)	Logging Residues	Bark	Sawdust and/or Shavings	Agricultural Residues and/or By-Products	Other
Combustion ≤ 5 MW	Australia							100		
	Canada	100	75	25	25	25		50	25	50
	Finland	100	75	25	25	25		50	25	50
	Sweden	50		100		50				
Combustion 6–20 MW	Sweden		50	50		50	100	100		
Combustion 21–50 MW			100		100	100	100			
Combustion > 50 MW, Pyrolyses, Lignin extraction	Finland		100	100	100	33	100	100		33
	Sweden	100	100	50		50	100	100		
Combustion ≤ 5 MW, Gasification/Pyrolysis	Australia	100	100	100	50	50	100	100	100	
Pelletizing, Torrefaction, Lignin extraction, Sugar extraction to produce ethanol	Canada	50	50		50	50	50	100	50	
	Sweden			33			67	100		
Pelletizing, Combustion 21–50 MW	Sweden	50	50	50	50	50	50	100		
Hydrothermal Liquefaction	Australia				50	50	50	50	100	50

Most facilities had a good understanding of generally defined assortments, but their views on specific biomass properties, such as ash content levels, particle size, and moisture content, were rather unclear and weakly defined. However, although specific particle size definitions were unclear, it was evident that extremes in particle size, either oversized or too fine, caused the most problems in processing (Table 4). The accepted range of moisture content was very wide, although most facilities received their feedstock within 10% of their estimated optimal parameters.

Table 4. The averaged percentage of facilities using a given biomass assortment, by conversion technology and country. MC: moisture content. *: max–min.

Biomass Conversion Technology	Country	% Facilities Receiving Non-Comminuted Feedstock	% Facilities Performing Comminution	Particle Characteristic Causing Most Problems, % Facilities				Range * MC, % facilities	Difference in Ideal MC vs. Received MC, % Facilities
				Oversized	Too Fine	Particle Shape	Other		
Combustion ≤ 5 MW	Australia	0	0	100	0	0	0	33	−9
	Canada	35	80	75	50	0	0	33	9
	Finland	95	0	100	0	0	0	50	0
	Sweden	50	0	100	50	0	0	15	−2.5
Combustion 6–20 MW	Sweden	57	100	100	0	50	0	30	−6.5
Combustion 21–50 MW		0	0	100	0	0	0	25	0
Combustion > 50 MW, Pyrolysis, Lignin extraction	Finland	2	33	66	33	0	0	Max 60	5/NaN
	Sweden	55	100	100	50	0	0	25	
Combustion ≤ 5 MW, Gasification/Pyrolysis	Australia	35	0	100	0	0	0	31	NaN
Pelletizing, Torrefaction, Lignin extraction, Sugar extraction to produce ethanol	Canada	0	100	50	50	0	0	43	12
	Sweden	1	100	33		33	40	0	0
Pelletizing, Combustion 21–50 MW	Sweden	5	100	50	100	50	0	19	−2/NaN
Hydrothermal Liquefaction	Australia	50	100	100	0	0	0	28	6

In general, smaller combustion plants received the most non-comminuted (i.e., not chipped) biomass and often did not perform comminution on site. In some cases, this was because they were outsourcing this service. Larger facilities reported receiving less non-comminuted biomass, but they did perform comminution on site. A notable exception to this was lignin extraction and combustion, where pulpwood was the main assortment for the biorefinery that dominated the complex.

The procurement of raw materials for production was a significant part of each facility's daily operations, and the length of the procurement contract was part of the supply risk evaluation and price optimization process. There were no large differences between the countries in the lengths of procurement contracts awarded. The most common contract periods were for up to 1 or 3 years, each representing 44% of the range (Figure 1). Small combustion plants (≤5 MW) in Canada had the widest range of contract periods, with almost a quarter of the facilities having varied preferences. In general, newer facilities and those involving biorefinery products or processes were associated with longer procurement contracts, whereas well-established facilities mostly preferred mid- to mid-long-term contracts in order to adapt more easily to changing market situations.

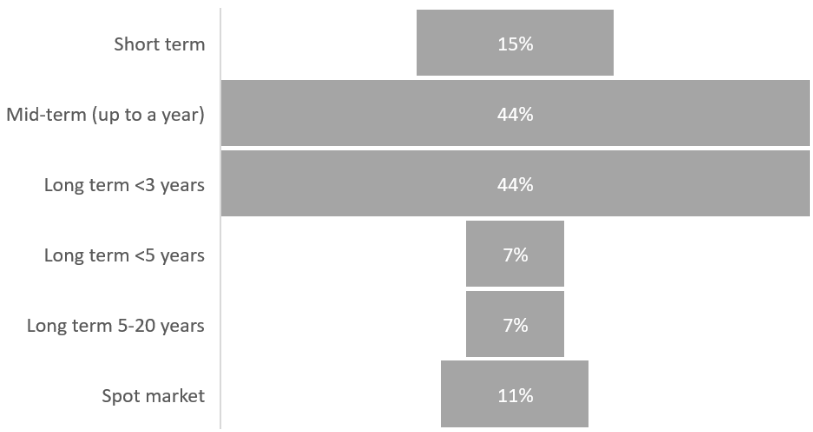

Figure 1. Preferred biomass supply contract period among the surveyed bioenergy facilities (n = 27).

Nearly half of the facilities (48%) showed a preference for receiving electronic bills before the feedstock arrived and to know what was being delivered, while a third (33%) preferred to receive feedstocks from third-party accredited suppliers whose delivered volumes could be trusted, making re-measurement at the gate unnecessary.

The most common problem reported regarding biomass storage, by 50% of the facilities in Canada and Finland, 40% in Australia, and 33% in Sweden, was a lack of space (Figure 2). Other common problems associated with storage were biomass loss, self-ignition, and environmental restrictions. Environmental restrictions were especially common in Australia and Canada, as reported by 20% and 33% of the facilities, respectively. Sweden reported the fewest problems associated with storage, with 50% of their facilities reporting no problems at all.

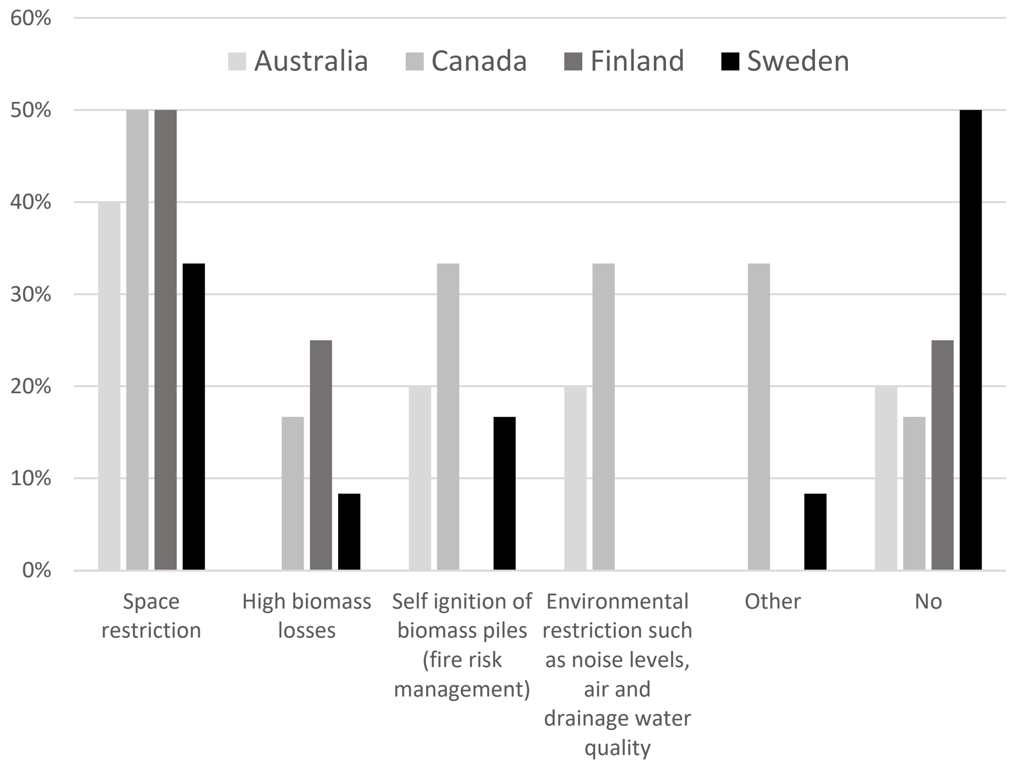

Figure 2. The most common problems associated with biomass storage as reported by the surveyed bioenergy facilities (n = 27).

High biomass losses were a particular problem for large combustion plants (over 50 MW) in Sweden and Finland. These large CHP plants were usually located relatively close to cities where land available for storage yards was limited. However, self-ignition and environmental restrictions were a particular problem in Canada where even 25% of the small combustion plants had issues. To mitigate some of the problems related to storing biomass at their own facilities, 25% of the Swedish, 40% of the Australian, 67% of the Canadian, and 75% of the Finnish respondents were willing to rent out extra storage, with 24 h access 7 days a week for all involved in the facility (Figure 3). Most preferred to rent extra storage to address their space restrictions rather than delegate suppliers to handle the biomass on their behalf. Respondents in Australia and Canada (60% and 33%) were the most willing to outsource some of their storage to suppliers and share the risks involved in biomass storage. In contrast, none of the respondents from Sweden was willing to outsource the handling of stored biomass to a supplier without direct control over it.

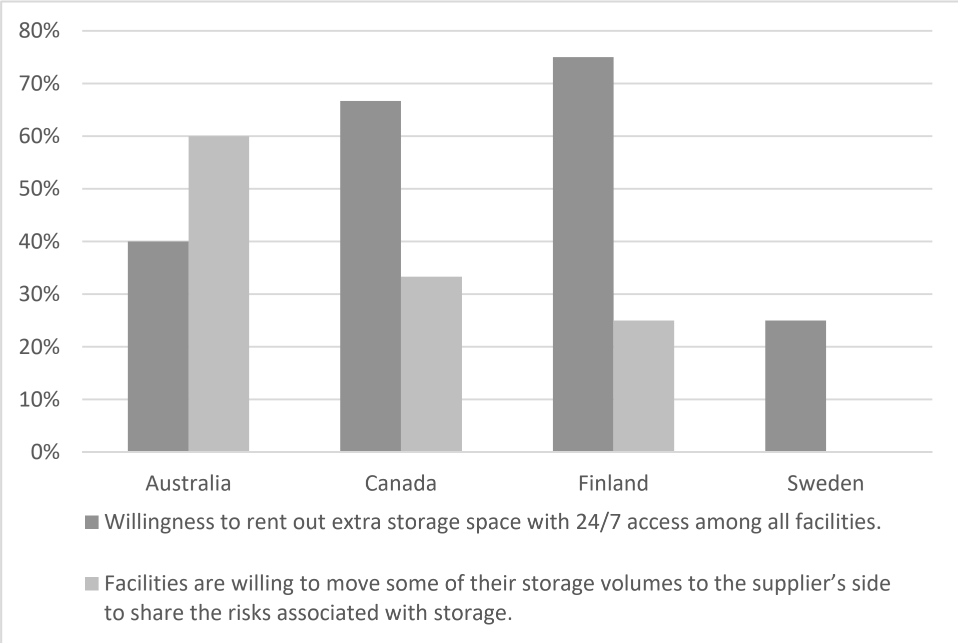

Figure 3. Willingness to rent out extra storage space with 24/7 access among all facilities and to move some of their storage volumes to the supplier to share the risks associated with storage.

3.2. Feedstock Preferences

Only 20 facilities were included in the analysis of feedstock preferences because seven responses were only partially complete and, therefore, could not be used (for details of the facilities included and codes used in the study, see Table A1). The estimated individual weightings indicated that the type of biomass assortment (attribute A1) had the largest influence on the respondents' preferences (Figure 4). This attribute had the highest aggregated weight (average 29.6%) and was ranked as the most important by 18 of the 20 respondents. The remaining two respondents (DM19 and DM10) ranked attribute A1 as second and seventh (the lowest weighting, at 5.7%), respectively.

Aggregating the data by country (Figure 5) indicated a stronger preference for biomass assortment (attribute A1) in Finland and Sweden than in Canada. An aggregation for the Australian facilities could not be determined because of the lack of variability (there was only one respondent). The attribute ranked second was assortment availability within the supply region (attribute A2, weight = 14.8%), and the third was price (attribute A3, weight = 11.8%). All other attributes had weights lower than 10%, apart from the lowest ranked attribute, which was ash content (A10, weight = 4.2%).

Within attribute A1, sawdust (L7) was the preferred type of biomass assortment, with seven respondents (35% of all respondents) ranking it first, although there was some variability (Table 5). Stem wood chips were preferred by four respondents (20%), while energy wood was ranked first by three respondents (15%). Interestingly, each biomass assortment was the preferred choice of at least one respondent. (The estimates for weighting all attributes and levels are presented in the Appendix A, Tables A2–A5).

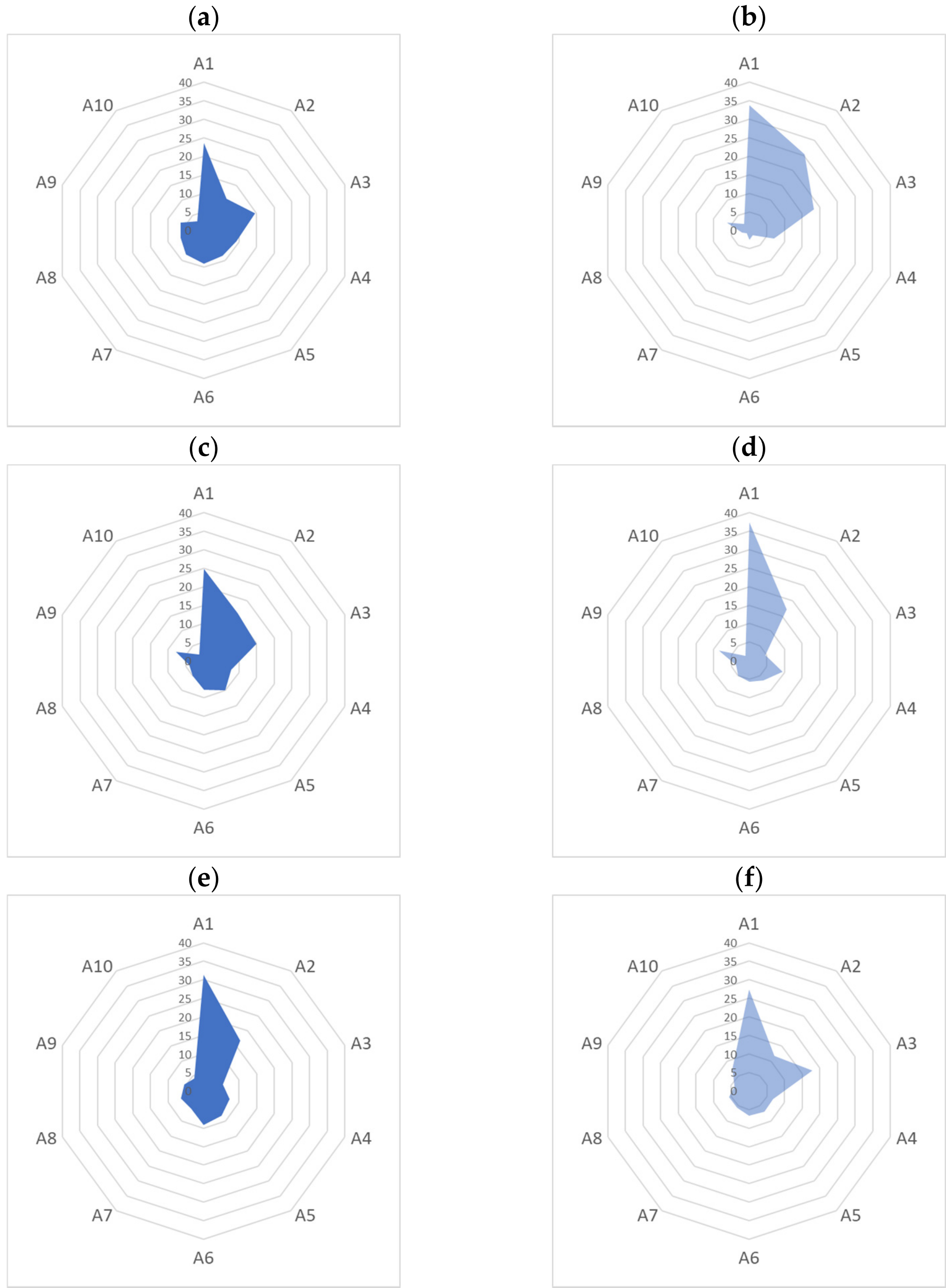

Figure 4. Country profiles for biomass feedstock preferences based on the attributes considered and the size of the facility (combustion). The estimated weights for the attributes are expressed as percentages. (Canada *n* = 4, *n* = 1, Finland *n* = 1, *n* = 3, Sweden *n* = 2, *n* = 5, values for ≤5 MW and >5 MW, respectively). For definitions of the attributes, see Table 1. (**a**) Canada (≤5 MW), (**b**) Canada (>5 MW), (**c**) Finland (≤5 MW), (**d**) Finland (>5 MW), (**e**) Sweden (≤5 MW), (**f**) Sweden (>5 MW).

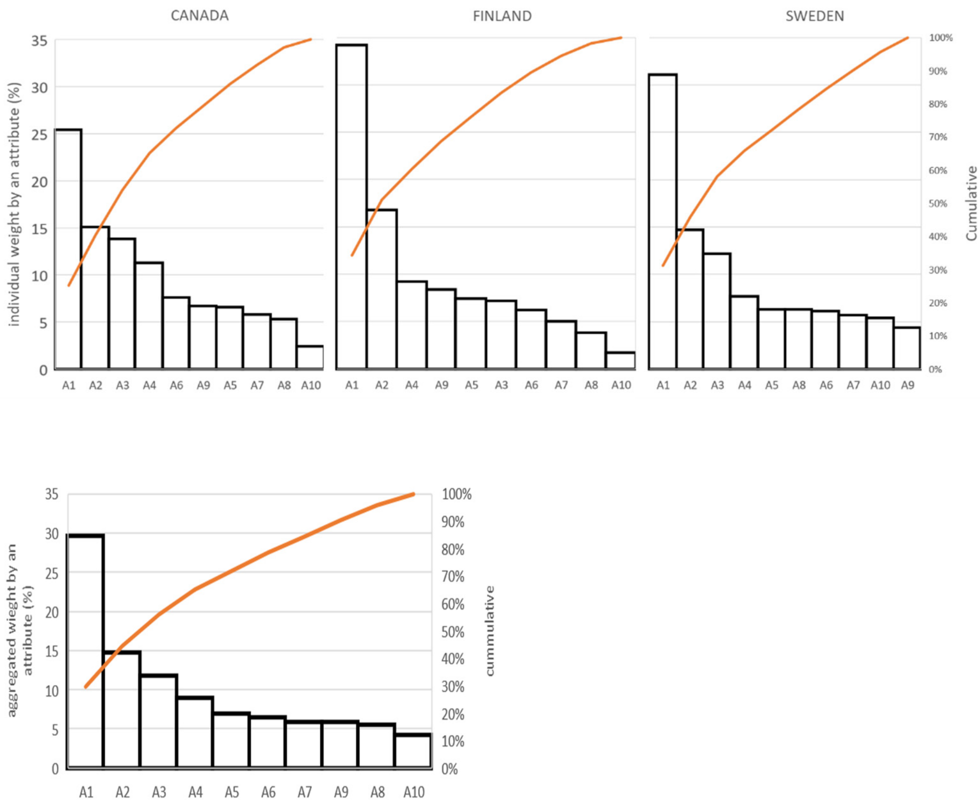

Figure 5. Weighting and ranking of the preferred biomass feedstock attributes, aggregated by country and total values (n = 20; definitions of attribute codes are given in Table 1).

Table 5. Type (level) of biomass assortment (attribute A1) ranked first by the respondents (codes and descriptions of the bioenergy facilities are described in Table A1. AU: Australia, CA: Canada, FIN: Finland, SE: Sweden).

		Expert/Facility	Number (%)
L1	Agricultural residues and by-products	DM12-AU	1 (5%)
L2	Logging residue and tree part chips	DM14-SE, DM17-FI	2 (10%)
L3	Bark	DM7-SE, DM16-CA	2 (10%)
L4	Energy wood (low-quality roundwood)	DM5-SE, DM9-CA, DM15-CA	3 (15%)
L5	Stem wood chips	DM2-SE, DM8-SE, DM19-FI, DM20-FI	4 (20%)
L6	Pulpwood	DM1-CA	1 (5%)
L7	Sawdust	DM3-CA, DM4-SE, DM6-SE, DM10-CA, DM11-SE, DM13-SE, DM18-FI	7 (35%)

4. Discussion

The characteristics of biomass feedstocks are key factors that affect the decision-making process along the supply chain. This study analyzed the preferred biomass feedstock characteristics of professionals from a variety of bioenergy facilities. Four countries with significant bioenergy developments were included, representing a well-established bioenergy sector covering a wide range of conditions and technologies. Canada has some of the largest areas of forested land, with solid biofuels representing about 133 TWh, and it was the second-largest exporter of wood pellets in 2017, representing 11.9% of total global exports [31]. Despite their smaller land areas, Finland and Sweden are pioneers in the use of advanced wood biofuels. In both these countries, bioenergy has become the largest energy source, surpassing oil, and wood fuels represent around 100 TWh and 140 TWh, respectively [32,33]. They are world leaders in the use of solid biomass, with the highest per capita energy use [34], and provide important regional biohubs in pellet production and consumption [35]. In Australia, solid biofuels contribute 50 TWh to the country's energy supply, which, compared with its area of forested land, indicates a large potential to increase over the next few years [36].

The respondents represented a wide range of bioenergy facilities, including the most common biomass conversion technologies at the market level. For this type of study, the representativity and reliability of the results are linked to the selection and relevance of the respondents involved. The pool of potential respondents was chosen to include senior and experienced decision makers who could provide qualified assessments. However, as in any study based on surveys, there were obvious challenges and limitations: despite targeting a large data set of professionals, the response rate was lower than expected. The study was carried out during the coronavirus pandemic, when, globally, much work was carried out from home and access to field studies at industry sites was largely restricted. One of the most accessible methods for continuing research during the pandemic was carrying out surveys; but, for the potential respondents, fatigue arising from receiving multiple surveys from different research groups and adapting to different work environments might have affected the response rate. However, even though there was only one response each from larger biorefineries using pulpwood and their by-products for biofuel and biomaterial production, the survey reached a wide and representative range of small to big heat and CHP plants as well integrated combustion plants with gasification, pyrolysis, and pelletizing (Table 2), providing sufficient empirical data for a better understanding of the mechanisms of biorefinery and integrated processes that can affect feedstock demand and its preferred properties.

The analysis of expert preferences is a complex task, often carried out using pairwise comparison, which was the approach taken here. Conjoint analysis has been used for choice modeling and discrete choice experiments and is widely used in the social sciences for marketing research and designing new products. The advantage of choice-based methods is that choosing, unlike scaling, is a natural task, of which we all have considerable experience; it is also both observable and verifiable [37]. The main premise is that the decision maker evaluates the overall desirability of a complex product based on a function of the value of its separate yet conjoined parts [30]. In this study, the use of attributes and levels to characterize biomass feedstocks and then to rank the main preferences was a simple and clear approach that facilitated a categorization of the heuristics used by the end-users when evaluating feedstock alternatives and making their choices [30].

Based on work proposed initially by mathematical psychologists [38] Green and Rao, [39] applied the notion of conjoint measurement to discover which product attributes are more important to consumers. The same approach has been used in the forest sector, for example, for the definition of policy instruments [40], forest contracts [41], forest conservation programs [42], initiatives to foster investments in the forest sector [43], and forest machine manufacturing [44]. There are alternative methods for addressing similar research questions based on similar data sets. For example, the Analytical Hierarchy Process (AHP) was combined with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in a study of the characteristics of biomass for gasification [45]. However, conjoint analysis has several advantages that justify its use: the overall questions are less demanding because the respondents do not need to produce complex preference assessments and they are not presented with a long list of pairwise comparisons [46]. Questions are repeated with different pairs of hypothetical alternatives, all involving different combinations of attributes, until enough information about the preferences has been collected to weight the attributes accordingly. In addition, the PAPRIKA method can be described as an 'adaptive' conjoint analysis because each time a choice is made it formulates the next question based on the previous choices, facilitating an interaction with the respondent. In contrast to the AHP methods, the number of pairs to be explicitly ranked is minimized by identifying and eliminating all those pairs implicitly ranked as corollaries of the explicitly ranked pairs via the transitive property of additive value models [28]. This allows more complex sets of attributes and levels to be considered that would otherwise result in exponential numbers of pairwise comparisons [44]. The responses can then be subjected to mathematical analyses based on linear programming (see [28]) to calculate 'part-worth utilities', weighting the relative importance of the attributes and providing a solid methodological basis for further analysis.

Expert-based analyses do not need a large number of responses because they are not based on frequentist methods. A qualified assessment can represent the common practices carried out across a large facility, and our number of respondents is in accordance with similar studies. For example, Kulišić et al. [47,48] had 35 and 41 respondents when assessing biofuel policy preferences in Croatia and the BIOEAST region, respectively. Fernandez-Tirado et al. [49] had 12 respondents when analyzing biodiesel alternatives in Spain, and Schillo et al. [50] had 33 respondents when analyzing biofuels policies in Canada. Previous studies have also addressed the issue of representivity and the number of responses needed to perform these types of assessments, highlighting expertise as the most important factor to take into account. Even a single expert may suffice as a basis for analysis, and efforts to add additional experts can, in fact, compromise the accuracy of a study if their expertise is not well balanced [51]. In this sense, the number of experts involved is in line with similar studies and provides a valid basis for analysis, provided the due caution.

The results revealed a wide range in the relative importance placed on biomass assortment attributes, suggesting that each biomass supplier has to look after specific end-user needs, with some concentrating on a single assortment and others considering a larger variety. The broader the accepted assortment is, the greater is the possibility for mixing and matching different biomass sources to deliver an optimal feedstock to the end-user with effects in the procurement and operational costs for logistics operators [52]. The availability of specific raw material assortments for particular industrial processes depends largely on the geographic location of the facility itself, the predictability of feedstock accessibility, and the surrounding wood-based industrial facilities capable of supplying certain biomass by-products, e.g., bark, sawdust, or shavings [5], as well as the industrial process applied, such as combustion, gasification, pyrolysis, etc. Depending on the industrial process and the location of the facility, some of the biomass assortments may have to be upgraded to improve their quality and bulk density or/and their supply streams may need to be divided into more precise assortments to optimize the profitability of each biomass unit by delivering the best-suited biomass for a particular industry at the best price [15,53]. Thus, not only can extra value be added to the biomass itself, but, under certain conditions, long-distance transportation from biohubs to the industrial plant can be improved with the use of railroads, waterways, or high-payload trucks, reducing traffic intensity and air and noise pollution in populated areas [10,54,55]. Biohubs and terminals are especially important to operators in terms of buffering peak congestion in response to increased logging volumes and mitigating damage as logging moves into increasingly fragile terrains. Terminals can help reduce periods of peak congestion and facilitate the transportation of raw material out of the forest under the best possible weather conditions.

While there are well-established centralized biomass measurement systems in Sweden and Finland, facilities in Australia and Canada are more open to digital measurement and delivery services. Among the countries represented, the Finnish respondents were the most reluctant to move towards electronic billing and measurements outside the receiving facilities, highlighting the importance of the type of biomass feedstock for most decision makers, particularly in Finland and Sweden. This suggests that biomass assortment standards, especially for energy production, are more established in Nordic countries and that decision makers associate many biomass properties directly with a specific assortment. In contrast, biomass suppliers in Australia and Canada can more readily negotiate biomass supply according to specific biomass requirements if they can control its quality.

In recent years, Nordics have seen the development of large forest industry terminals specializing in either industrial roundwood or biomass for energy supplies [6,8,56]. At the same time, Nordic countries have experienced an upscaling of existing forest industry facilities (mainly pulp and paper mills) with the addition of adjacent biorefinery units. This has opened up opportunities to store, modify, and upgrade the quality and bulk density of biomass at one joint biohub or terminal and to deliver several biomass assortments, such as roundwood, logging residues, bark, chips, pre-processed biomass, etc., in bulk [8,56–58]. The different operating environments of biomass suppliers and receivers can provide opportunities for various emerging business models for supplying renewable carbon products alongside a political consensus to reduce or eliminate fossil carbon. Business models indicate how a company can add value to a product, and circular business models can also add value to secondary biomass [59].

Another area offering challenges and opportunities is biomass storage and handling, especially in Australia and Canada, where decision makers are more open to sharing their knowledge and handing over some control to suppliers. More than 30% of all facilities reported limited storage capacity followed by a number of other biomass handling-related issues, such as biomass loss as a result of biological activity, self-ignition, and, especially in Australia and Canada, environmental restrictions. If possible, 25% to 75% of the facilities would like to rent out extra storage space to address this problem, but most of them are reluctant to hand full responsibility for the stock over to the supplier.

Biomass handling at suppliers' terminals, with trusted load measurements, is an interesting area for the development of biohubs, especially in Australia and Canada, where decision makers are much more interested in sharing knowledge and risks with suppliers and are more open to digital payment and measurement services. In combination with smaller combustion and gasification facilities, there is a niche for expert biomass suppliers and smaller, more diversified biohubs. Procurement contract periods are also more diverse in Canada and Australia, where, in addition to shorter-term and mid-term contracts (up to 1 year), decision makers also show a preference for long- and very-long-term supply contracts (of up to 20 years). In contrast, facilities in Sweden and Finland mostly prefer 1-year or up to 3-year contract periods, while facilities during their start-up period and with integrated biorefineries such as gasification and pyrolysis prefer to have longer biomass supply contracts than bigger, well-established facilities. However, because of the relatively low number of responses for each country and technology used, caution must be used when generalizing the results presented here.

Finally, while there was consistent agreement among the respondents regarding many attributes such as low ash, moisture content, and particle size variation, as well as high biomass availability and supply security at a low price, there were a few other factors some respondents took into account. For example, four respondents for mid-sized combustion plants, including one with a pelletizing facility and pellet plant and a small combustion plant in Canada, preferred ash content to be at its maximum acceptable level for their processes, even though it was considered to be the least important attribute. The preferred moisture content level and particle size range also showed a wide range of preferences among facilities, conditioning the options for wood size reduction [60]. Even among the pellet factories in Sweden and Canada, one might prefer a higher moisture content while another might prefer a medium content, suggesting that some facilities also took in by-products such as bark for their drying processes, etc. Lower grades of biomass can, in fact, be used to help control the main product operations' processes [61].

In the long run, the preferences of end-users will be subject to changes in the overall development of the sector and will have an influence on the associated supply chains. Trends already show greater competition for high-quality, homogenous, and consistent biomass, such as debarked roundwood, sawdust, and shavings, and developments on chipping processes and planning as well as additional sieving of comminuted material could help keep the competitive profile of primary residues [62–65]. These sieved, sorted, and, if needed, mixed biomass assortments could be delivered to the right end-user, at the right time and location, via biomass terminals or biohubs. In addition, biorefining processes could build in resilience to biomass heterogeneity and provide opportunities for traditional wood-based industries to make strategic partnerships, move from being secondary biomass suppliers, and transform into a biohub that is able to separate, upgrade, and optimize biomass deliveries at a central node in the supply chain (see [8,65]).

5. Conclusions

The aim of this study was to examine the decision-making processes used by end-users for biomass procurement. The results show that end-users have a good understanding of the general attributes of pre-defined forest biomass assortments, such as roundwood logs, bark, or logging residues; however, the specific properties of a particular biomass assortment, such as variation in ash content, are less well understood in the context of daily production activities.

Pre-defined biomass assortments have an expected and well-understood range of biomass properties and, from an end-user's perspective, are the most important factor when deciding on feedstock procurment for a bioenergy facility. The results presented here help us better understand end-users' perceptions of biomass properties for their conversion processes and supply preferences and should help existing and future biohubs create new niches in alternative business environments and position themselves for effective product development.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

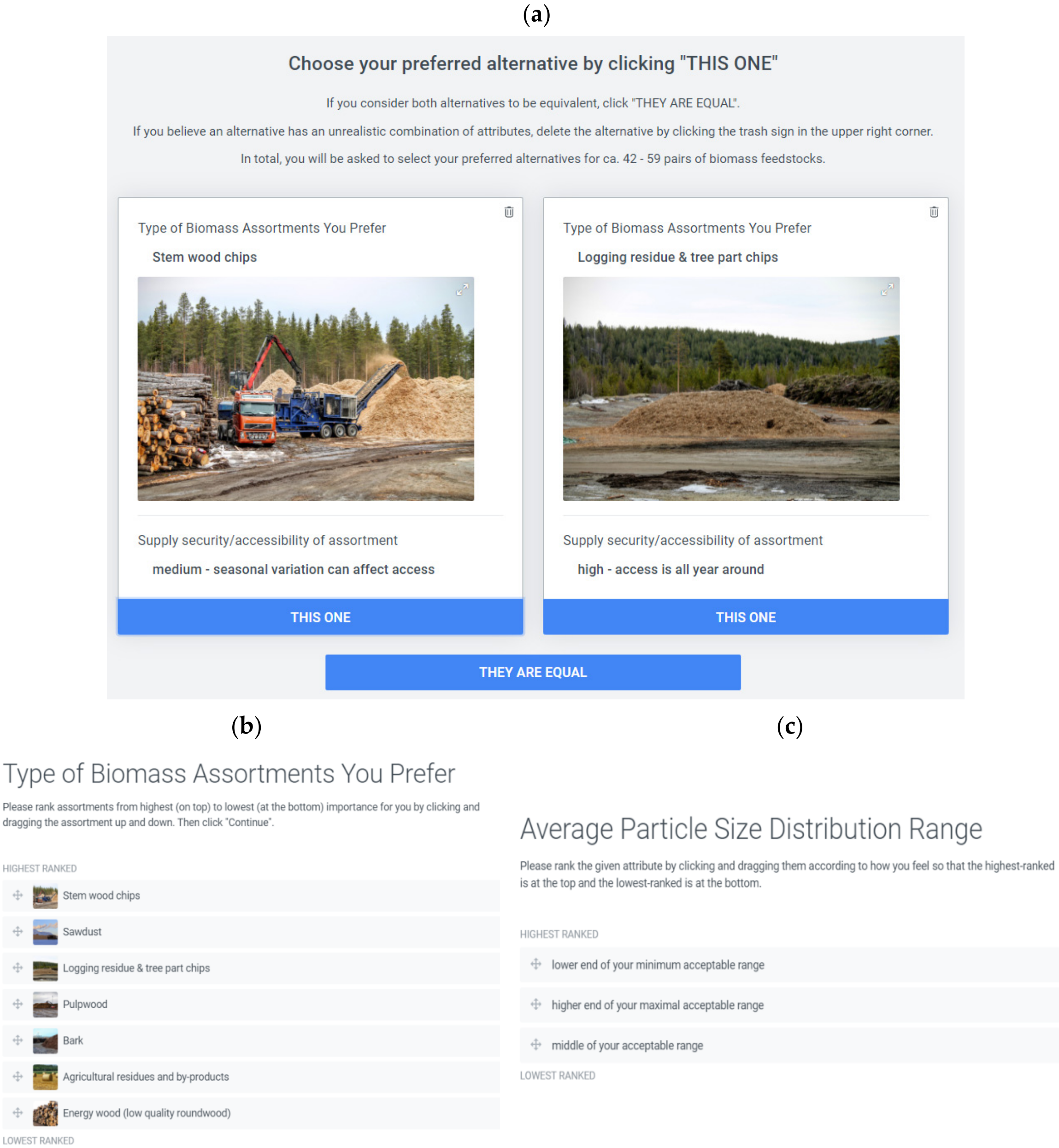

Figure A1. Examples of the layout and question formats included in the survey. Sets of alternative responses were presented to the participants, in pairwise format (**a**) or to be ranked (**b**,**c**) according to preference.

Table A1. Country of origin, biomass conversion technology, and facility capacity, as represented by the respondents to the preference survey (*n* = 20).

Respondent Code	Country	Bioenergy Facility
DM1	Canada	Combustion ≤ 5 MW
DM2	Sweden	Combustion ≤ 5 MW
DM3	Canada	Pelletizing, Torrefaction
DM4	Sweden	Pelletizing
DM5	Sweden	Combustion > 50 MW
DM6	Sweden	Combustion 6–20 MW
DM7	Sweden	Combustion 6–20 MW
DM8	Sweden	Combustion ≤ 5 MW
DM9	Canada	Combustion ≤ 5 MW
DM10	Canada	Combustion ≤ 5 MW
DM11	Sweden	Pelletizing
DM12	Australia	Hydrothermal Liquefaction
DM13	Sweden	Pelletizing, Combustion 21–50 MW
DM14	Sweden	Combustion 21–50 MW
DM15	Canada	Combustion ≤ 5 MW
DM16	Canada	Pelletizing, Lignin extraction, Sugar extraction to produce ethanol
DM17	Finland	Combustion > 50 MW
DM18	Finland	Combustion ≤ 5 MW
DM19	Finland	Combustion > 50 MW, Biorefinery
DM20	Finland	Combustion > 50 MW

Table A2. Weighting of attributes by respondent, country, and group, presented as a % of all attributes. For definitions of the attributes, see Table 1.

Respondent/Facility Code	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
DM1-CA	34.6	20.6	13.9	6.6	8	1.7	2.4	6.3	4.5	1
DM3-CA	24.1	23.7	6	23.7	3.4	6.4	1.1	3.8	7.5	0.4
DM9-CA	33.1	6.6	2.9	14.8	16.3	7.8	7.6	2.1	7.4	1.4
DM10-CA	5.7	8.5	29.8	14.6	2.2	14.8	14.8	5.9	2	1.7
DM15-CA	21	6	12	1.1	7.9	12	7.9	12	12.4	7.9
DM16-CA	33.7	25.3	18.3	7.1	1.6	2.6	1	1.9	6.4	2.2
DM2-SE	30.9	21.9	6.3	10.9	9	7.4	3.9	0.8	8.6	0.4
DM4-SE	32.9	10.6	9.2	7.2	7.2	7.2	9.2	1.7	5.5	9.2
DM5-SE	19.2	13.5	5.8	5.8	15.4	5.8	5.8	7.7	5.8	15.4
DM6-SE	21.8	9.9	21.3	8.3	3.6	10.5	10.2	5.8	4.4	4.1
DM7-SE	41	11.5	26.4	6.5	1.7	3.7	0.6	3.4	2.2	3.1
DM8-SE	31.9	11.8	4.6	3.6	7.4	10.8	7.6	12	2.3	8
DM11-SE	36.5	14.8	5.8	6.1	4.2	5.2	4.5	18.1	3.2	1.6
DM13-SE	24.8	21.9	21.9	14.3	1.8	1.9	7.3	0.9	4.6	0.5
DM14-SE	41.3	16.3	8.7	6.5	6.5	2.2	2.2	6.5	3.3	6.5
DM12-AU	21.7	6.7	13.3	6.7	11.7	5	11.7	5	5	13.3
DM 17-FIN	50.3	16.1	5.6	9.9	1.2	5.6	1.9	6.8	1.2	1.2
DM 18-FIN	24.8	15.8	14.9	7.9	9.9	7.9	5.0	4.0	7.9	2.0
DM 19-FIN	24.4	25.2	6.5	10.6	6.5	7.3	6.5	2.4	8.1	2.4
DM 20-FIN	37.4	10.2	1.9	8.3	12.1	3.9	6.8	1.9	16.5	1.0
Canada	25.4	15.1	13.8	11.3	6.6	7.6	5.8	5.3	6.7	2.4
Sweden	31.1	14.7	12.2	7.7	6.3	6.1	5.7	6.3	4.4	5.4
Australia	21.7	6.7	13.3	6.7	11.7	5	11.7	5	5	13.3
Finland	34.2	16.8	7.2	9.2	7.4	6.2	5.0	3.8	8.4	1.7
Group	29.6	14.8	11.8	9.0	6.9	6.5	5.9	5.5	5.9	4.2

Table A3. Ranking of attributes, by respondent, country, and group. For definitions of the attributes, see Table 1.

Respondent/Facility Code	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
DM1-CA	1	2	3	5	4	9	8	6	7	10
DM3-CA	1	2–3	6	2–3	8	5	9	7	4	10
DM9-CA	1	7	8	3	2	4	5	9	6	10
DM10-CA	7	5	1	4	8	2–3	2–3	6	9	10
DM15-CA	1	9	3–5	10	6	3–5	6	3–5	2	6
DM16-CA	1	2	3	4	9	6	10	8	5	7
DM2-SE	1	2	7	3	4	6	8	9	5	10
DM4-SE	1	2	3–5	6–8	6–8	6–8	3–5	10	9	3–5
DM5-SE	1	4	6–10	6–10	2–3	6–10	6–10	5	6	2–3
DM6-SE	1	5	2	6	10	3	4	7	8	9
DM7-SE	1	3	2	4	9	5	10	6	8	7
DM8-SE	1	3	8	9	7	4	6	2	10	5
DM11-SE	1	3	5	4	8	6	7	2	9	10
DM13-SE	1	2–3	2–3	4	8	7	5	9	6	10
DM14-SE	1	2	3	4–7	4–7	9	9	4–7	8	4–7
DM12-AU	1	6–7	2–3	6–7	4–5	8–10	4–5	8–10	8–10	2–3
DM 17-FIN	1	2	5–6	3	8–10	5–6	7	4	8–10	8–10
DM 18-FIN	1	2	3	5–7	4	5–7	8	9	5–7	10
DM 19-FIN	2	1	6–8	3	6–8	5	6–8	9–10	4	9–10
DM 20-FIN	1	4	8	5	3	7	6	8	2	10
Canada	1	2	3	4	7	5	8	9	6	10
Sweden	1	2	3	4	5	7	8	5	10	9
Australia	1	6–7	2–3	6–7	4–5	8–10	4–5	8–10	8–10	2–3
Finland	1	2	6	3	5	7	8	9	4	10
Group	1	2	3	4	5	6	7–8	9	7–8	10

Table A4. Weighting of attribute level by respondent, presented as a %. DM1–10, respondent code. For definitions of attributes and levels, see Table 1.

Attribute	Attribute Level	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
A1	L1	0	0.1	0	0	0	0	0	0	0	3.3
	L2	29.2	18.3	24.0	5.5	11.5	5.4	16.3	25.5	11.4	1.8
	L3	11.3	2.4	6.4	11.0	16.0	10.8	41.0	16.1	16.7	0
	L4	34.8	8.6	2.1	16.4	19.2	17.7	29.8	6.5	33.1	4.5
	L5	33.4	30.9	16.7	21.9	7.1	21.5	31.5	31.9	16.5	2.5
	L6	34.6	0	23.7	27.4	12.6	21.8	26.7	20.0	21.7	0.9
	L7	20.9	0.4	24.1	32.9	13.5	21.8	35.8	12.2	16.6	5.7
A2	L1	0	0	0	0	0	0	0	0	0	0
	L2	6.6	5.9	7.9	1.4	5.8	1.9	2.0	1.0	2.3	5.6
	L3	12.5	14.8	15.8	3.8	9.6	5.8	4.8	8.2	4.9	7.1
	L4	20.6	21.9	23.7	10.6	13.5	9.9	11.5	11.8	6.6	8.5
A3	L1	0	0	0	0	0	0	0	0	0	0
	L2	7.0	3.5	1.9	1.7	3.8	18.5	14.6	3.6	1.9	14.9
	L3	13.9	6.3	6.0	9.2	5.8	21.3	26.4	4.6	2.9	29.8
A4	L1	0	0	0	0	0	0	0	0	0	0
	L2	4.5	7.8	7.9	2.1	3.8	5.5	2.5	1.1	8.0	8.6
	L3	6.6	10.9	23.7	7.2	5.8	8.3	6.5	3.6	14.8	14.6
A5	L1	0	0	0	0	15.4	0	0	0	1.2	0
	L2	6.6	2.3	1.5	4.5	0	0.6	0.8	3.8	0	2.2
	L3	8.0	9.0	3.4	7.2	11.5	3.6	1.7	7.4	16.3	1.3
A6	L1	0	0	0	0	0	0	0	0	0	0
	L2	1.7	7.4	6.4	7.2	5.8	10.5	3.7	10.8	7.8	14.8

Table A4. *Cont.*

Attribute	Attribute Level	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
A7	L1	0	0	0	0	0	0	0	0	0	0
	L2	2.4	3.9	1.1	9.2	5.8	10.2	0.6	7.6	7.6	14.8
A8	L1	0	0	0	0	0	0	0	0	0	0
	L2	6.3	0.8	3.8	1.7	7.7	5.8	3.4	12.0	2.1	5.9
A9	L1	0	0	0	0	0	0	0	1.1	0	0
	L2	4.5	8.2	6.8	4.1	3.8	2.2	2.2	0	2.5	2.0
	L3	2.4	8.6	7.5	5.5	5.8	4.4	2.0	2.3	7.4	1.1
A10	L1	1.0	0	0.4	0	0	0	0	0	0	0
	L2	0	0.4	0	9.2	15.4	4.1	3.1	8.0	1.4	1.7

Table A5. Weighting of attribute level by respondent, presented as a %. DM11–20, respondent code. For definitions of attributes and levels, see Table 1.

Attribute	Attribute Level	DM11	DM12	DM13	DM14	DM15	DM16	DM17	DM18	DM19	DM20
A1	L1	0	21.7	0	2.2	0	5.3	0.0	0.0	0.0	0.0
	L2	9.1	13.2	22.5	41.3	10.9	16.5	50.3	16.8	21.9	18.7
	L3	18.1	3.2	23.3	14.4	4.5	33.7	25.2	22.1	3.3	4.4
	L4	16.6	1.7	22.3	23.9	21.0	8.3	16.8	18.8	10.2	27.2
	L5	25.1	0	22.1	32.6	20.0	8.7	41.9	19.8	24.4	37.4
	L6	15.2	0.5	15.3	0	17.2	8.0	8.4	10.3	0.7	33.0
	L7	36.5	6.7	24.8	6.5	1.4	0	33.5	24.8	17.9	10.2
A2	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	6.5	3.3	14.9	6.5	1.5	9.0	1.9	7.9	6.5	6.8
	L3	9.0	5.0	17.3	7.6	3.0	17.9	9.3	11.9	17.9	8.3
	L4	14.8	6.7	21.9	16.3	6.0	25.3	16.1	15.8	25.2	10.2
A3	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	5.5	6.7	7.4	2.2	7.9	7.7	4.3	10.9	4.1	1.5
	L3	5.8	13.3	21.9	8.7	12.0	18.3	5.6	14.9	6.5	1.9
A4	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	2.3	1.7	7.4	4.3	0.7	3.8	3.7	4.0	3.3	4.4
	L3	6.1	6.7	14.3	6.5	1.1	7.1	9.9	7.9	10.6	8.3
A5	L1	4.2	0	0	0	0	1.6	0.6	0.0	4.1	0.0
	L2	0.6	11.7	0.7	4.3	4.5	0.3	0.0	4.0	0.0	3.9
	L3	0	5.0	1.8	6.5	7.9	0	1.2	9.9	6.5	12.1
A6	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	5.2	5.0	1.9	2.2	12.0	2.6	5.6	7.9	7.3	3.9
A7	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	4.5	11.7	7.3	2.2	7.9	1.0	1.9	5.0	6.5	6.8
A8	L1	0	0	0	0	0	0	0.0	0.0	0.0	0.0
	L2	18.1	5.0	0.9	6.5	12.0	1.9	6.8	4.0	2.4	1.9
A9	L1	3.2	0	4.6	0	0	0	0.0	0.0	0.0	0.0
	L2	0	5.0	0	3.3	12.4	6.4	0.6	5.0	8.1	3.9
	L3	1.3	3.3	2.5	2.2	4.5	3.5	1.2	7.9	6.5	16.5
A10	L1	0	0	0.5	6.5	0	0	0.0	0.0	0.0	0.0
	L2	1.6	13.3	0	0	7.9	2.2	1.2	2.0	2.4	1.0

Appendix B Description of PAPRIKA Method in 1000minds Software

The PAPRIKA method involves the respondents answering a series of simple pairwise comparison questions, based on their expert knowledge and subjective judgment. Each question is based on choosing between two hypothetical alternatives on only two attributes at a time and involving a trade-off (in effect, the other attributes are assumed to be the same). Each time a respondent answers a question, PAPRIKA *adapts*. Based on a respondent's previous answers, PAPRIKA creates new question for the respondent to answer. Such simple questions are repeated with different pairs of hypothetical alternatives until enough information about a respondent's preferences has been collected. Examples of the questions are presented in Figure A2 (https://www.1000minds.com accessed on 6 May 2022).

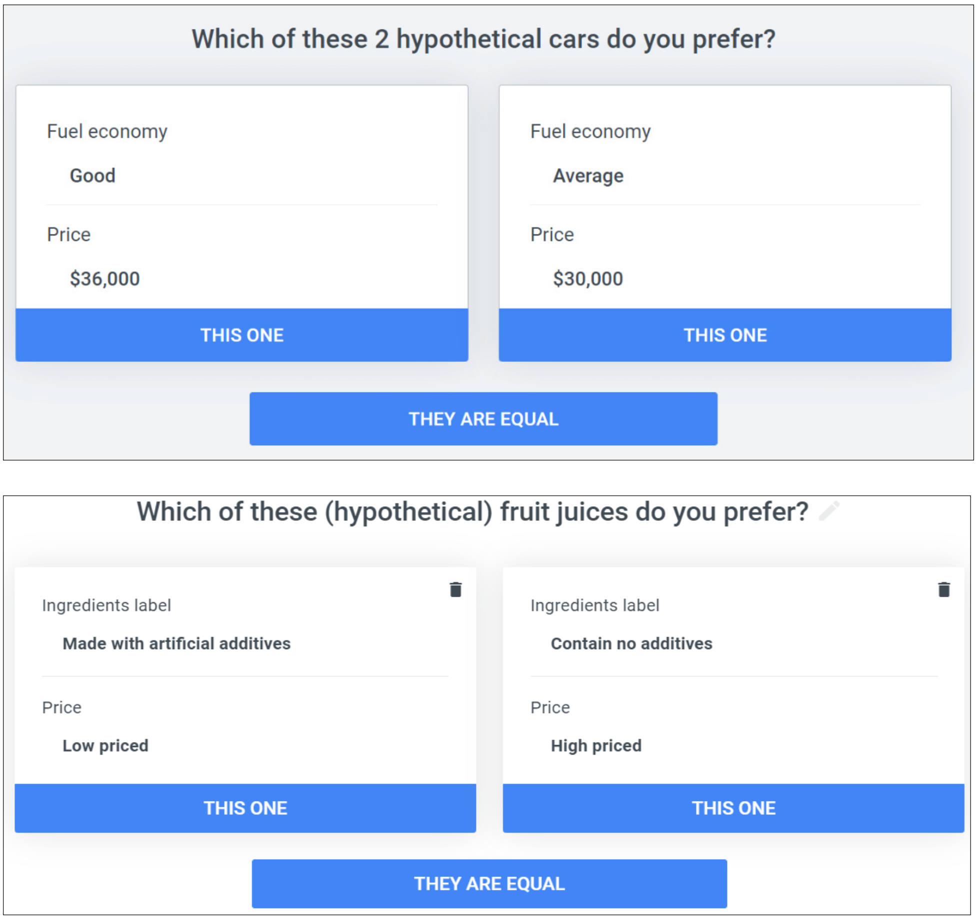

Figure A2. Examples of questions within the 1000minds software.

PAPRIKA's questions are based on '*partial* alternatives' beginning with just two attributes at a time in contrast to the '*full*-alternatives' methods, which involve all attributes together at once. Choosing one alternative from two, defined on only two attributes at a time, is easier than choosing one alternative from three or more or choosing between alternatives defined on more than two attributes. Consequently, the questions in PAPRIKA are less cognitively/psychometrically demanding for respondents and, therefore, the answers have greater validity and reliability.

Each time a respondent pairwise ranks a pair of alternatives, PAPRIKA immediately identifies all other pairs of hypothetical alternatives that can be pairwise ranked and eliminates them. It does this by applying a logical property known as 'transitivity'. This elimination procedure ensures that the number of questions is minimized (see examples in Table A6). From a respondent's answers, mathematical methods based on linear programming are used to calculate 'part-worth utilities', representing the relative importance (weights) of the attributes to the respondent.

Table A6. The necessary number of pairwise rankings (https://www.1000minds.com accessed on 6 May 2022).

Decision-Making Scenario	Alternatives	All Possible Pairwise Rankings	Unique Undominated Pairs (To Be Pairwise Ranked)	PAPRIKA Pairwise Rankings
8 criteria, 4 levels each	4^8 = 65,536	2,147,450,880	402,100,560	~95
10 criteria, 4 levels each	4^{10} = 1,048,576	549,755,289,600	68,646,770,676	~160
12 criteria, 5 levels each	5^{12} = 244,140,625	29,802,322,265,625,000	3,674,775,327,316,600	~900
20 criteria, 4 levels each	4^{20} = 1,099,511,627,776	604,462,909,806,765,000,000,000	9,502,402,095,174,090,000,000	~1200

In addition, more detailed and technically oriented information is available from these external sources.

- An overview of PAPRIKA and 1000minds can be found at https://www.1000minds.com, accessed on 6 May 2022.
- The technical details of PAPRIKA are presented in the journal article by Hansen et al. [28], 2008. P. Hansen and F. Ombler (2008), "A new method for scoring multi-attribute value models using pairwise rankings of alternatives", in the *Journal of Multi-Criteria Decision Analysis* 15, 87–107.

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