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Worlds apart? Investigating acceptance and usage demands of carbon-based cosmetics and clothing across European countries

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Abstract

Background Global warming and the increasing risk of natural disasters force us all to act. As the reduction of carbon dioxide (CO_2) emissions has been proven effective but insufficient on its own, Carbon Capture and Utilization (CCU) technologies emerged to fill the gap. Using CCU technologies, CO_2 is captured and further processed into valuable products instead of being emitted into the atmosphere.

Method This study investigates the prevailing public perception of such CCU-based products by the example of clothing and cosmetics. We applied the method of conjoint measurement to experimentally examine context-related factors (=attributes) in different usage settings and explored the consumers' decision profiles for or against the usage of CCU-based products (cosmetics and clothing). Conjoint measurements were realized as an online experiment, addressing acceptance patterns and preferences in four European countries (Germany, Norway, Spain, and Poland). In addition, we assessed general attitudes and affective assessments of the CCU products. A total of $N=828$ participants took part in the study, and the international subsamples were comparable.

Results Results revealed that health compatibility is the main adoption-driving factor in the decisions for or against the use of the products. Still, attributes like the environmental impact, product quality, and information flow play an important role as well, even though to a lesser extent. Participants from different countries significantly differ in their cognitive and affective evaluations of acceptance-related attributes.

Conclusions The outcome provides insights into differences in Pan-European comparison and helps to understand the public motives and country-specific terms of use for CCU-based products, effectively establishing recommendations for policy and governance.

Keywords Public perception, Social acceptance, Carbon capture and utilization, CCU-based products, Conjoint analysis

Background

With air and ocean temperatures measuring an all-time high in 2023 [1], climate change continues to pose a tremendous threat to the entire global population. The CO_2 emissions released in the production of a wide range of consumer goods are, among other things, a contributor to our current environmental crisis. That is why it is crucial to find more pro-environmental forms of production in industries, targeting CO_2 emissions especially. This entails questioning linear production methods that are

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both the root cause of CO_2 emissions and an ever-growing amount of waste. This line of thought inspired the development of the circular economy (CE), which strives to conserve natural resources and create more sustainable production methods [2]. The approach of CE is based on the intention to move away from the 'end-of-life' concept and instead focuses on the reuse, recycling, and recovery of materials [3]. A subordinate concept has eventually developed, the circular bioeconomy (CBE), which focuses even more on recycling of biological resources. Here, biological waste is to be recycled into valuable materials and ultimately used to produce new consumer goods [4]. Over the past decades, various approaches have emerged in science to meet this challenge. Carbon Capture and Utilization (CCU) is a process designed to contribute to the implementation of a CBE. The term CCU describes the process of capturing exhaust carbon dioxide for further processing into valuable raw materials to keep it from being emitted into the atmosphere. Literature contains various methods for capturing CO_2 and for processing it into the materials in question, which will be mentioned in more detail later on in this paper. These materials can then be used to manufacture a variety of sustainable products. However, innovative technologies and the resulting products must be adopted by end consumers, which is why this research examines the acceptance of two exemplary products manufactured using CCU. In the following, we briefly explain the sustainability of CCU, address the context of the study conducted, and explain the current status regarding the acceptance of CCU products.

Sustainability due to carbon capture and utilization

Today, more than ever, there is a need for action regarding environmental disasters and global warming. So far, measures to reduce CO_2 emissions have been implemented that have been proven effective but insufficient on their own. Hence, CCU technologies emerged to fill the gap. The CCU technology shifts the perception of CO_2 from being considered a harmful waste product to recognizing it as a resource that can be repurposed into valuable raw materials. There are many possible application areas for CCU; Peres et al. [5] mention mineralization in concrete curing, chemical synthesis in pharmaceuticals, and refrigeration in the food industry, to name a few. Furthermore, the conversion of CO_2 can be achieved using various processes. Besides the before mentioned mineralization, there are also biological conversion, thermocatalytic hydrogenation, electrochemical reduction, and finally photo-(electro) chemical reduction; for more information see [6]. The sustainability of CCU technologies has already garnered plenty of scientific attention and, according to Falcone et al. [7], there is no universal approach that can be used to analyze the sustainability, as the criteria for assessing sustainability can differ from product to product. To date the sustainability of CCU and resulting products is mostly researched with regard to environmental, economic, and societal aspects [8]. Furthermore, numerous works focus on the life-cycle assessment of CCU (e.g., [9–11]). Among other things, it is determined that the sustainability of the CCU technology in comparison to conventional production processes is highly dependent on using renewable energy sources [12]. In addition, the use of CCU for feedstock chemicals emerges as the CCU application with most environmental benefits [13]. Overall, CCU was found to hold opportunities in achieving the United Nations Sustainable Development Goals (SDGs), provided that an appropriate framework is created on the part of the legislation [14]. The European Union places great importance on this endeavor, which is why it has designated CCU as a pivotal technology in its pursuit of achieving climate neutrality by 2050 [15], and consequently, is providing funding for projects dedicated to exploring its diverse applications.

Context of the study

As part of the European Union's efforts to curb CO_2 emissions, the CO_2SMOS project is funded by Horizon 2020. The interdisciplinary project aims to develop new technologies for producing sustainable bio-products by converting CO_2 into added-value chemicals, in particular high-performance biopolymers. For the conversion, electrochemical and catalytic processes are deployed, and CO_2 is captured from renewable sources, e.g., biomass. This approach based on CCU is designed to deliver long-lasting, sustainable solutions for bio-based industries through circular economy and enable negative emissions within the industry. To achieve the competitiveness of CCU products against conventional ones, it is crucial to incorporate the preferences and needs of potential end-users into their design from the outset. This is only possible if social perception and current acceptance levels in the general public are investigated at an early stage. The findings might help to inform the technical development where potential acceptance pitfalls might exist and, on the other hand, help to develop appropriate public information and communication strategies. This paper therefore aims to investigate the affective and cognitive perception of two exemplary products, namely clothing and cosmetics, across four European countries, and to identify possible trade-offs regarding their acceptability.

Public perception and acceptance of CCU-based products

Understanding and addressing public concerns and attitudes towards innovative technologies like CCU is

essential to garner the support and cooperation needed for their widespread adoption and success in combating global carbon emissions. However, it is necessary to not only focus attention on acceptance regarding the technology, but to incorporate specific products into the research design. To date, several articles can be found in the literature that examine the general acceptance of CCU technology (e.g., [16, 17]), however, research into tangible CCU-based products is less prevalent. Isolated studies can be found on the acceptance of specific use cases, such as CCU-based mattresses [18, 19], fuels [20, 21], and insulation boards produced with CO_2-derived foam [22, 23]. Accordingly, there are only initial results regarding the acceptance of individual CCU products. In the context of the mattress for example, perceived health risks like rashes are addressed, which could supposedly be triggered by close contact with the product [19]. Nevertheless, CCU technology presents a significantly broader spectrum of potential applications, yielding diverse end-products beyond the scope of existing literature. Consequently, it remains possible that specific CCU products may exhibit unique acceptance factors distinct from those currently recognized. CCU technologies have the capability to yield polymers that serve a multitude of purposes in conventional industrial production. This paper more closely investigates the acceptance of clothing and cosmetics, representing two end-products made from CCU-based plastic—commonplace items directly connected to the consumer's life and experience. Compared to the products already examined in previous literature, CCU-based clothing and cosmetics are in direct contact with the human body during use. Some cosmetics, like creams, are even created to be partially absorbed by the skin. This creates a sensitive and fragile usage situation, whose investigation will be essential for the further development of CCU products.

Due to the innovative nature of the CCU technology, there is no body of previous research regarding driving factors for purchasing or using CCU-based cosmetics and clothing. However, many previous works have studied influencing factors for purchasing sustainable cosmetics and clothing in a broader sense. Gonçalves et al. [24] found that consumers are more inclined to buy and use sustainable cosmetics if they perceive their advantages and benefits to be stronger. Furthermore, they state that environmental engagement fortifies the perception of the advantages in buying sustainable cosmetics. Hence, environmentally concerned consumers will be more likely to buy said products. According to Sadiq et al. [25], this also applied for people concerned about their health. Ethical considerations [26] represent another factor influencing decisions for purchasing sustainable cosmetics. Accordingly, authors suggest that promoting products can be achieved by addressing these concerns through labeling, e.g., for ecological manufacturing.

As to sustainable clothing, personal attitudes towards it have the greatest influence on purchasing behavior [27]. There is no clear consensus in the literature regarding price. There are studies in which economic risks have no significant influence on the decision to purchase sustainable clothing [27], and there are other studies in which price negatively correlates with the willingness to buy sustainably [28]. However, the second study mentioned explicitly dealt with fashion items made from recycled plastic waste, which may have influenced participants perception of the value of the items. Beyond pricing, Nguyen et al. [28] identify the quality of the fashion products to influence consumers decision for or against purchasing. This view is also shared by Chi et al. [29], who found price and performance to be deciding factors in the purchasing eco-friendly sportswear. However, they also explicitly mention that the items of clothing must also visually appeal to consumers, fit well and be considered as versatile.

Besides the acceptance of the final product, other factors can have an impact on adoption. It is an undisputed truth that both cognitive and experiential processes play a decisive role in this context [30–32]. The latter aspect became increasingly important in the early 2000s when affect began to be studied scientifically. Within the framework of these investigations, Slovic et al. [33] developed the affect heuristic, which describes intuitive and instinctive automatic processes that people use to make decisions. When confronted with situations or objects, individuals unconsciously draw upon a body of experience that enables them to evaluate them quickly and efficiently. Furthermore, the authors note that affect itself influences cognitive decisions about benefits and risks. They argue that a decision about a positive or negative evaluation is made unconsciously, which is then rationally substantiated. Since the affect heuristic is integrally based on previous experience and attached feelings, it remains to be clarified to what extent affective decisions hold for the assessment of innovative (technical) products, like the CCU products under investigation in the present work. King & Slovic [34] addressed this very question, demonstrating that there is a negative relationship between risk assessment and benefit perception, whose effectiveness is curbed by cognitive processes, and that the affect heuristic is also valid in relation to product innovations based on three studies. They conclude that affect serves as a basis for assessing risk and benefit, and that feelings towards an innovation play a role in its assessment as good or bad. Nonetheless, they also observe that a trade-off consideration exists regarding product characteristics, where certain risks or benefits

may be overshadowed by the overall evaluation of the product, be it positive or negative. The affect heuristic has been used extensively as a theoretical construct for public acceptance and was validated in different usage settings and products, e.g., in food and packaging [35], automated vehicles [36], nature-caused hazards [37]. For an overview, see Gupta et al. [38].

Research questions and aims

Based on the portrayed background, the following research questions arise for a deeper understanding of the rationales of the potential consumers' adoption and use of the CCU-based products as exemplary chosen for the present study:

- What is the general public's perception and the affective appraisal of CCU products? (RQ1)
- How do other context-related factors influence the potential consumers' decisions for or against the usage of the CCU-based products? (RQ2)
- Do consumers from different European countries significantly differ in the acceptance-related assessments of CCU-based products? (RQ3)

To realize these objectives, we surveyed an international target group addressing four European countries: Norway, Germany, Poland, and Spain. The above-mentioned consortium of the CO_2SMOS project was responsible for the selection of these countries justifying the choice with (1) the geographical balance and analysis of the differences in mentality between West, North, East, and Central Europe; (2) the different levels of innovativeness regarding green technologies; and (3) the market significance of the countries.

Methods

Our research approach was realized in two steps, combining a qualitative focus group pre-study and a quantitative decision simulation (conjoint measurement) as a main study. In the qualitative process, we examined the viewpoints of eight individuals from Germany without specialized knowledge regarding CCU products (=laypeople) and five experts approaching the topic of CCU from different perspectives. Using focus group workshops, we asked the participants which requirements, i.e., motives and barriers, would drive or hinder their adoption of such products [39]. Based on our findings accompanied by related literature research, we conceptualized usage settings of a validating conjoint measurement (CM) study, which thus serves as an extension of the German view by a pan-European perspective and allows us to gain deeper insights into the potential consumers' preferred attribute configurations (for details see "The selection of acceptance-relevant attributes" section).

Research approach and the method of conjoint measurement (CM)

The approach of CM (also conjoint analysis) is a powerful method that was initially used in the economic field, especially in marketing research, to evaluate innovative products and to define price levels [40–42]. This method quantifies judgmental data and enables researchers to determine trade-offs among attributes of a new product or technology based on responses of stated preferences and stated choices [43]; this allows for studying individual preferences or decision-making processes [44] of potential customer groups. In concrete terms, predetermined attributes and their levels are used to generate real or hypothetical product configurations to be evaluated by participants. Based on the overall preference judgments, as expressed by the participants, it is then estimated which contributions the various attributes make to the overall preference [45]. This way, the overall decision to use or not use a novel product can be decomposed, and the most decisive attribute can be identified.

We used choice-based conjoint analysis (CBCA) that enables imitating complex decision processes in which several attributes appearing together in different scenario configurations influences the final decision. By this, we examined how participants from different European countries assess previously determined acceptance-relevant factors for CCU-based clothing and cosmetics. A proper identification and thoughtful selection of relevant attributes and their levels is crucial in the planning, preparation, and implementation of a conjoint study [46]. As it impacts the validity and generalizability of the findings, we aimed for a limited complexity of the attributes that are relevant from the social and communication science perspective.

The selection of acceptance-relevant attributes

The final selection of attributes and their levels in this study is based on three sources: in the first step, we conducted literature research on acceptance in the field of CCU to ensure an appropriate consideration of the relevant criteria for the social perception and adoption of CCU. Next, we conceptualized a focus group study with potential laypeople users representing the majority of future customers to reveal their opinions, requirements and needs on acceptable and affordable CCU-based products. And in the third step, we conducted focus group workshops with different experts in the field, such as an expert in sustainability in construction, an energy economist as well as experts in life cycle assessment, biochemical ecology, and acceptance research, ensuring the

involvement of economic, technical, and ethical aspects in the subsequent validating study with the conjoint analysis (for all details of the preceding qualitative study read [39]). For the quantitative study, we finally have chosen four attributes: product quality, health compatibility, product information, and environmental certification. Each of the four attributes has different levels, which were composed into different usage scenarios. In Table 1, attributes and their levels are presented.

To illustrate how the attributes and the levels are composed into decision tasks, Fig. 1 depicts an example of a choice task. In each choice task, the participant sees four usage alternatives composed of randomly assigned attribute levels and must decide which of the four options is preferred. The conjoint tasks were embedded in an online survey instrument. Its structure and components are described in the next section.

Design of the survey

Data were collected in late spring of 2023 employing a standardized online survey, using the professional platform Sawtooth Software (Lighthouse Studio, version 9.15). The survey was originally designed in German. In the first step, the content was translated into the respective languages of the participating countries by a professional, certified translation institution and, in the second step, it was tested in all four languages by methodological experts for comprehensibility and methodological properness. Before starting the online survey, participants were informed about the average length of the survey and our high standard of data protection, meaning that none of their answers could be referred to them personally. At this point, they were also asked to consent to the terms of data protection and indicate being of legal age. The procedure and content of the study was carefully reviewed and finally approved by The Ethics Committee (Division 7.3) "Empirical Human Sciences" at the Faculty of Humanities at RWTH Aachen University (ID: 2022_17_FB7_RWTH Aachen).

1) *Introduction part.* In the beginning of the survey, we provided a proper background for our study, pointing out the current global situation and the growing need for novel strategies allowing to mitigate the effects of global warming and the resulting consequences of the prevailing climate change. We outlined that employing modern technical solutions makes it possible to capture carbon dioxide at the point of origin and to process it through a proper treatment into carbon-containing products, such as clothing or cosmetics. After this introduction, respondents provided their sociodemographic information, i.e., age, gender, education, place of residence, and the circumstances under which they are living. To make sure that all participants have a comparable basic knowledge, we briefly introduced the term 'CCU' as a procedure for reducing CO_2 emissions and at the same time using CO_2 as a raw material for manufacturing different products.
2) *Evaluation of attitudes.* In the second step, respondents evaluated attitudinal constructs such as *risk disposition* (6 items, Cronbach's $\alpha = 0.73$; e.g., "I am willing to take risks"), *technical innovativeness* (adapted from [47]; 4 items, Cronbach's $\alpha = 0.89$; e.g., "I think it's interesting to try new technical products"), *environmental awareness* (adapted from [48, 49]; 8 items, Cronbach's $\alpha = 0.83$; e.g., "I try to avoid waste through unnecessary packaging, plastic bags, etc."), and *environmental self-efficacy* (based on [50]; 3 items; Cronbach's $\alpha = 0.70$; e.g., "I can contribute to environmental and climate protection through my everyday behavior"); all items of these constructs are presented in Appendix, Table 4. At the end of this part, we asked participants to evaluate questions regarding their *general acceptance* of CCU technology and utilization of CO_2-based products (6 items; Cronbach's $\alpha = 0.82$; e.g., "I would use products that are based on CO_2"); items were adapted from [51] and are summarized in Fig. 3. All ratings were performed on 6-point Likert scales ranging from 1 (=I fully disagree) to 6 (=I fully agree).
3) *Conjoint tasks.* In the third part of the survey, we applied the choice-based conjoint (CBC) approach collecting participants' preferences on the acceptance-driving factors for the use of CCU-based products; in our study, we provided CCU-based clothing and cosmetics as examples and each participant of the study took part in both CBCs. The presented choice tasks (consisting of four possible alternatives with no "None"-option as presented in Fig. 1) consisted of a combination of four attributional characteristics: 1) product quality, 2) health compatibility, 3) product information, and 4) environmental certification. First, we introduced all attributes and attribute levels of the conjoint analysis to the participants. The choice tasks were generated in a randomized way for both CCU-based cosmetics and clothing, i.e., there was no predefined sequence of one or the other application in order to avoid sequence effects. After each choice task, we asked participants to choose from four alternatives the one scenario that they prefer most or feel most comfortable with (information given to participants is presented in Appendix, Table 5). A fully crossed study design would require combinations of all possible attribute levels (in our study: $4 \times 2 \times 3 \times 3 \times 3 = 216$ for each application

Table 1 Overview of the examined acceptance-related attributes and their levels

Product quality	 Comparable quality to conventional products	In this case, the quality of the CO_2 product does not differ from previously known products.
	 Better quality in comparison to conventional products	Due to special product properties, the CCU represents a quality advantage compared to conventional products, this can be, for example, higher resistance, better degradability, or the like.
Health compatibility	 Minimum guarantee of health compatibility	The safety and health compatibility is verified in scientific laboratory studies and confirmed by an accredited, widely recognized specialist institution.
	 Calculated risk	Here, general health standards are adhered to, so that direct danger to health can be ruled out.
	 No information about health	The health compatibility of the product is assessed individually without further information on the subject.
Product information	 Information directly available	The information about the product is directly visible on the packaging. Here, the end customer is informed about the manufacturing route, usability, quality characteristics and, if applicable, health compatibility.
	 Information linked	Here, the information for the end customer is not printed on the product, but the access to all information about the product is provided by means of a link.
	 Pure product naming	No further information or sources of information about the product are named.
Environmental certification	 Scientific institution	Scientific institute or university systematically investigates the effectiveness and sustainability of the product.
	 Statement of the manufacturer	Statements made by the manufacturer regarding the sustainability of the product.
	 Environmental associations	An association of people committed to environmental protection and nature conservation evaluates the sustainability and environmental impact of the product.

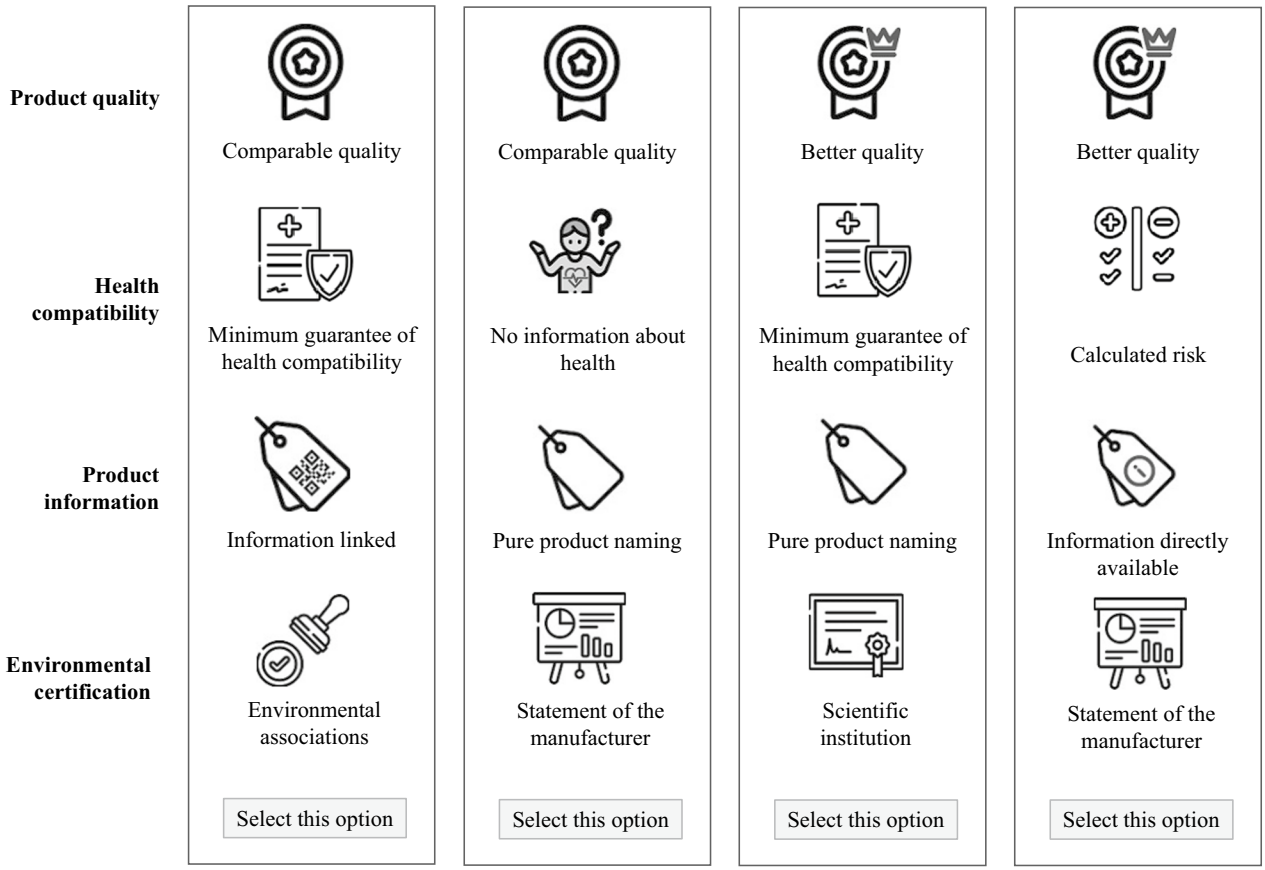

Fig. 1 Example of a choice task (acceptance of CCU-based cosmetics): the participant selects one of four presented alternatives

example), which would have overly burdened participants' attention span. However, the software enables analysis of a reduced number of decision situations by having each participant go through a predetermined number of randomized decision situations. To ensure a proper test quality and validity, we tested the number of necessary decision situations using an efficiency test [52]: an efficiency value of 99% and a standard error of < 0.05 confirmed that the randomized reduced design of six decision situations provides comparable results to a fully crossed study design.

4) *Affective assessments.* In the fourth part of the survey, we examined participants' affective assessments on the exemplary CCU-based products (i.e., clothing and cosmetics) using semantic differentials [53]. The method allows for spontaneous evaluations between two poles of one dimension, i.e., between two opposing adjectives. In concrete terms, respondents placed their opinions regarding the products and their characteristics between the pairs of acceptance-related adjectives such as "attractive" vs. "unattractive", "health compatible" vs. "hazardous to health", or "environmentally friendly" vs. "environmentally harmful". These opposing terms formed the respective poles of the six-point scales on which respondents were asked to rank their opinions.

Statistical analyses

Using Hierarchical Bayes analysis that enables the modeling of individual respondent decision behavior and allows for the simulation of these decision processes pro and/or against the CCU-based products, we calculated the relative importance of the attributes and the part-worth utilities of attribute levels (choice-based conjoint = CBC; bars indicate standard deviations). The advantage of the Bayesian method consists in the assumption that probability is operationalized as a degree of belief, and not a frequency, as is done in classical statistics [52]. The descriptive and inferential statistical analyses were calculated using IBM SPSS Statistics software (version 27). We performed descriptive statistics for the (self-)assessments and evaluations of adoption-related attitudes using means (*M*) and standard deviations (*SD*), and we provide standard error bars

in the graphs. The internal consistency of the scales was inspected by means of Cronbach's Alpha ($\alpha \geq 0.7$). Analyses of variance (ANOVA) were run to examine differences between countries and key values were taken from the Wilks-Lambda. In case of the violation of the variance homogeneity condition, the Welch test is reported. Repeated measures ANOVA tested within-subject comparisons. Effect sizes are reported using guidelines proposed by Cohen [53], i.e., 0.01 = small, 0.06 = moderate, 0.14 = large effect. For the validation of the CBC results, we used semantic differentials [54]. The level of statistical significance (p) was set at 5%.

Sample description

Our research aimed to survey opinions of adults (18 years and older) from the respective populations of four different European countries (i.e., Germany, Norway, Poland, and Spain). To reach representative samples of the participating countries, we collected data using an online panel of a market research institute and used quotas on age (young: 18–35 years vs. middle-aged: 36–60 years vs. older: 61+years) and gender (females vs. males). After data cleaning, excluding all incomplete data sets, data sets invalid due to speeding, as well as data sets with implausible (bad quality) response patterns from further statistical analyses, we included a total of $N = 828$ respondents, who were paid for participating in the study, for the final statistical analyses. The subsamples in the respective countries were comparable in size: Germany $n = 198$, Norway $n = 198$, Spain $n = 207$, and Poland $n = 225$. In the following, we report about the whole sample and all detailed sociodemographic data resulting for the respective countries are presented in Table 2.

The age of participants ranged from 18 to 87 years and the average age was 46.5 years ($SD = 17.1$). The sample was gender-balanced with 49% male ($n = 406$) and 51% female participants ($n = 422$). At 47% ($n = 389$), almost half of the respondents reported to complete tertiary education (i.e., university degree, doctoral study) and the second largest part of the sample reported to complete the post-secondary education, i.e., specialized education or specialized baccalaureate (35%; $n = 290$). The smallest proportion of the respondents (18%; $n = 149$) indicated to hold primary and secondary education, i.e., lower secondary school/elementary school/secondary school diploma. In the participating countries, the tertiary education pathway was clearly the most prevalent among the respondents.

When asked about their place of residence, most respondents indicated living in the city (54.1%; $n = 448$) and several lived on the outskirts of the city (25.5%; $n = 211$); the remaining 20.4% of the survey participants ($n = 169$) stated to live in rural areas. The distributions in the respective countries are comparable, although among Spaniards and Poles most participants lived in cities, while proportions of the German and Norwegian samples were distributed across all three categories of place of residence.

Regarding participants' living conditions, one-third each of the whole sample reported living with a

Table 2 Demographic characteristics of the whole sample ($N = 828$) and in the four European countries

Demographic characteristics	All ($N = 828$)	Germany ($n = 198$)	Norway ($n = 198$)	Spain ($n = 207$)	Poland ($n = 225$)
Age	$M = 46.5$ ($SD = 17.1$)	$M = 47.1$ ($SD = 17.7$)	$M = 47.9$ ($SD = 18.5$)	$M = 47.1$ ($SD = 16.4$)	$M = 44.1$ ($SD = 16.8$)
Gender	(%)	(%)	(%)	(%)	(%)
Female	51.0	50.0	49.5	50.2	53.8
Male	49.0	50.0	50.5	49.8	46.2
Education	(%)	(%)	(%)	(%)	(%)
Primary education	18.0	33.3	9.1	1.4	27.6
Secondary education	35.0	35.4	46.5	38.2	21.8
Tertiary education	47.0	31.3	44.4	60.4	50.7
Residential area	(%)	(%)	(%)	(%)	(%)
(Inner) city	54.1	35.4	42.4	37.7	69.8
On the outskirts	25.5	34.8	30.8	33.6	13.8
In the countryside	20.4	29.8	26.8	13.2	16.4
Living conditions	(%)	(%)	(%)	(%)	(%)
With a partner	35.3	39.4	38.4	28.5	35.1
With a partner and/or child(ren)	33.2	24.7	29.8	42.0	35.6
Alone	23.1	26.8	27.8	18.4	20.0
Flat-sharing community	6.2	6.1	4.5	8.7	5.3
With five or more persons	4.7	3.5	3.0	4.3	7.6

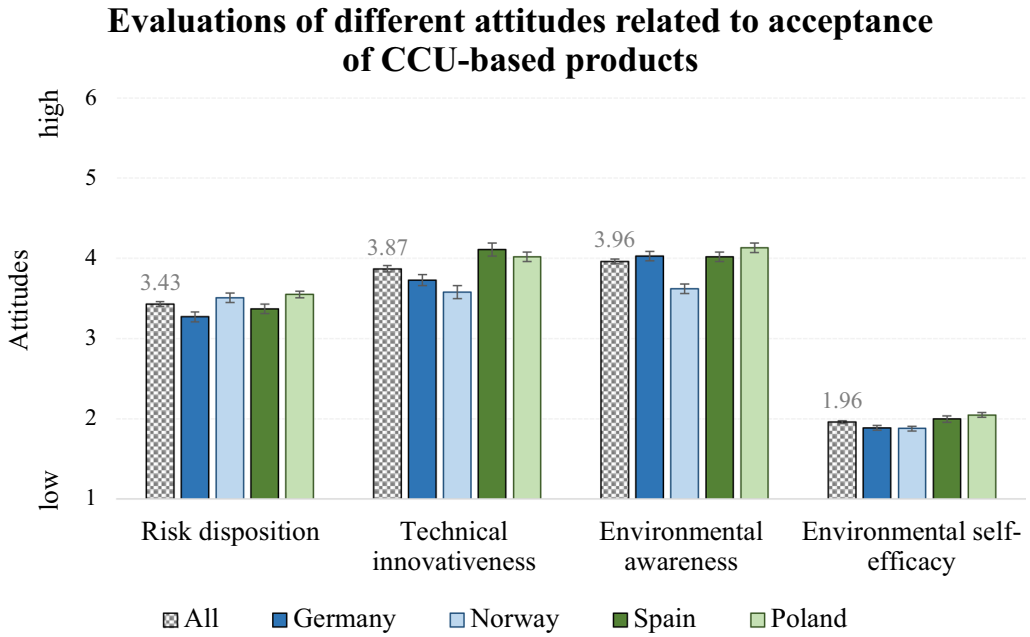

Fig. 2 Attitudes related to the adoption of CCU-based products in the whole sample ($N=828$) and in the participating European countries

partner (35.3%; $n=292$) and living with a partner and/or child(ren) (33.0%; $n=275$). Moreover, 23.1% ($n=191$) indicated to live alone or in a flat-sharing community (6.2%; $n=51$) and 4.7% stated living in a household with five or more persons ($n=39$). The patterns in the participating countries were comparable.

In addition, we examined individual assessments of risk disposition, technical innovativeness, environmental awareness, and environmental self-efficacy to provide deeper insights into attitudinal characteristics that might be related to the adoption of CCU-based products. According to data, with a mean (M) of 3.4 ($SD=0.8$; $min=1$, $max=6$) our respondents were on average moderately risk-tolerant, slightly interested in technical innovations ($M=3.9$, $SD=1.1$), and only moderately environmentally aware ($M=4.0$, $SD=0.9$); their environmental self-efficacy barely reached the mean of 2.0 points ($SD=0.5$). Internationally, we found small differences between the participating countries in the attitudinal expressions (risk disposition: $F(3,447.1)=5.5$, $p\leq0.001$, $\eta^2=0.02$, technical innovativeness: $F(3,824)=10.5$, $p\leq0.001$, $\eta^2=0.04$, environmental awareness: $F(3,824)=13.5$, $p\leq0.001$, $\eta^2=0.05$, and environmental self-efficacy: $F(3, 824)=5.8$, $p\leq0.001$, $\eta^2=0.02$). The details on the attitudes are depicted in Fig. 2.

Results

In this section, we describe the general perceptions on CCU-based products, and we present conjoint analysis utilities and relative importance of factors considered relevant for the acceptance and use of CCU-based products [39]. In addition, we present affective evaluations of the products to consider the decisions for, or against, the use of the products not only from the rational and argumentative perspective of the potential users, but also based on their affect heuristics, since beliefs and decisions are often not (only) rationally but also emotionally based. Special attention is thereby paid to the comparison of, and differences between, the four above-mentioned European countries.

General perceptions of CCU-based products

In the first step, we analyze how different Europeans generally perceive and evaluate CCU-based products. We examined this general acceptance in accordance to constructs used in the seminal Technology Acceptance Model [51], i.e., perceived usefulness, and the intended use, of such products, and we also directly asked if respondents deemed these products acceptable. Figure 3 depicts the resulting means in the participating countries.

Most means that are lying above the scale's midpoint (>3.5), show that the respondents agree on the usefulness of CCU-based products and intend to use them. Analog, the item about rejecting the use faced disagreement in all countries, confirming the favorable attitude. An ANOVA revealed small but significant differences in the international sample for the following statements:

- "I would use products that are based on CO_2" ($F(3,453)=2.7$, $p=0.042$, $\eta^2=0.01$): Poles declared on

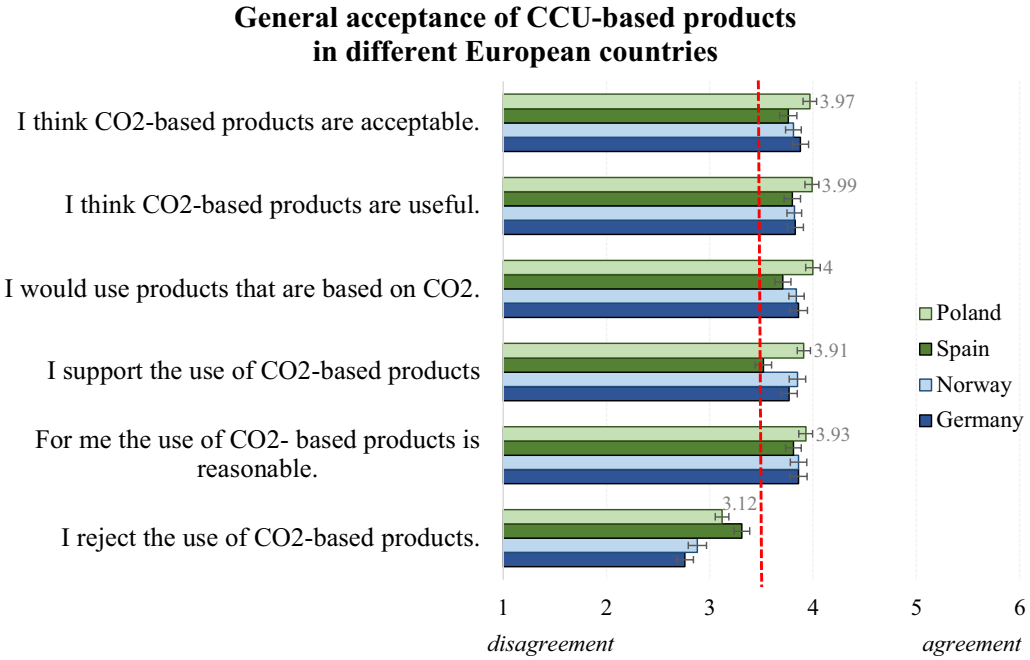

Fig. 3 The general acceptance of CCU-based products in different European countries ($N = 828$)

average the highest intention to use ($M = 4$, $SD = 1$) and Spaniards the lowest ($M = 3.7$, $SD = 1.1$);

- "I support the use of CO_2-based products" ($F(3,453.7) = 5.2$, $p = 0.002$, $\eta^2 = 0.02$): Polish participants reached on average the highest mean ($M = 3.9$, $SD = 1$) and Spaniards the lowest ($M = 3.5$, $SD = 1.1$);
- "I reject the use of CO_2-based products" ($F(3,453.5) = 8.6$, $p \leq 0.001$, $\eta^2 = 0.03$): Germans rejected this statement the most ($M = 2.8$, $SD = 1.2$), while Spaniards were the least likely to agree with it ($M = 3.3$, $SD = 1.2$).

We can thus conclude that the international participants have a principally accepting attitude towards CCU products, but they slightly differ in their willingness to use them.

Conjoint study results for the trade-offs of the acceptance of CCU-based products

Using the CM, we examine in the next step the attribute importance scores and level values of the acceptance-relevant factors for the total sample, and then we compare them in more detail between the countries participating in the study. Thereby, the relative importance of attributes delivers information about which attribute influences the participants' decision the most, while the part-worth utilities indicate which attribute level is estimated highest and lowest and to what extent an attribute level contributes to the overall decision [52].

Relative importance of acceptance-relevant factors for using CCU-based products

A Hierarchical Bayes analysis (HBA) determined the relative influence of the four examined attributes for the selection decisions. Figure 4 depicts that for the accepted use of both CCU clothing with 40.7% ($SD = 14.2$) and cosmetics with 42.9% ($SD = 13.7$) the *health compatibility* makes the strongest relative contribution, followed by environmental certification (clothing: 21.6%, $SD = 11.4$; cosmetics: 21.1%, $SD = 12.3$) and *product information* (clothing: 21.8%, $SD = 10.2$; cosmetics: 21.1%, $SD = 10.1$). The attribute '*product quality*' resulted in the weakest relative contribution to an accepted use of CCU-based clothing (16.4%, $SD = 13.7$) and cosmetics (14.4%, $SD = 8.8$) within our study.

In addition, we compared the contribution scores of the examined attributes between the exemplary CCU-based products using a one-way repeated measures ANOVA. The analysis revealed that clothing and cosmetics significantly differ in their acceptance contributions regarding health compatibility ($F(1,827) = 18.5$, $p \leq 0.001$, $\eta^2 = 0.02$) and product quality ($F(1,827) = 16$, $p \leq 0.001$, $\eta^2 = 0.02$) with health compatibility being more relevant for cosmetics than for clothing and product quality being more important for the accepted clothing than for cosmetics. The environmental certification and product information did not differ significantly in their contributions to the accepted use of these CCU-based products.

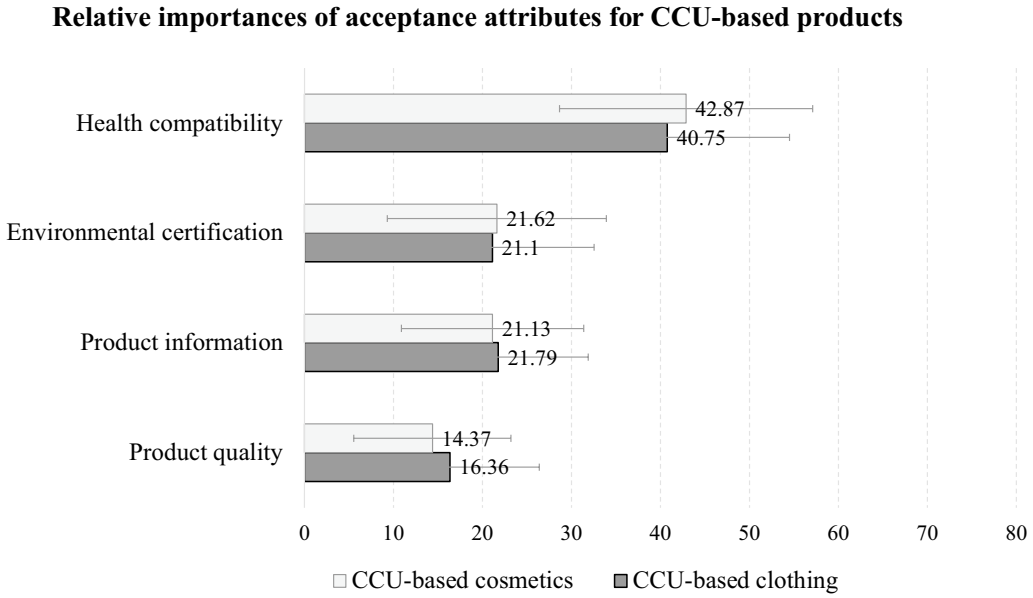

Fig. 4 The relative importance of attributes for accepted CCU-based clothing and cosmetics across all four European countries ($N = 828$)

Comparison of assessments across the involved European countries

In the next step, we observed how participants in different European countries evaluated the attributes relevant to the acceptance, and we analyzed whether they significantly differed in their opinions. Figure 5 summarizes the country-specific outcomes for the relative importance of the examined attributes in CCU-based clothing and cosmetics.

The inferential statistics demonstrate that the participating Europeans significantly differ in their assessments of the four acceptance-driving attributes for the perceptions of **CCU-based clothing**:

- Health compatibility ($F(3,454.5) = 10.8$, $p \leq 0.001$, $\eta.^2 = 0.04$)
- Environmental certification ($F(3,451) = 25.5$, $p \leq 0.001$, $\eta.^2 = 0.08$)

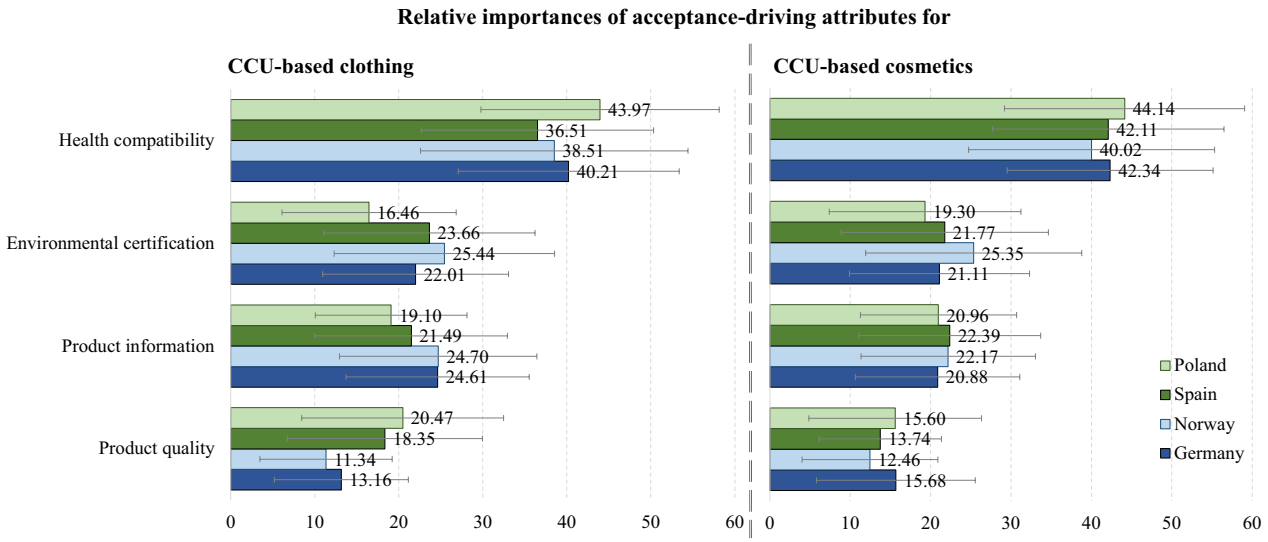

Fig. 5 The relative importance of the acceptance attributes for CCU-based products in different European countries for clothing (left) and cosmetics (right) ($N = 828$)

- Product information ($F(3,455)=15.1$, $p\leq0.001$, $\eta.^2=0.05$)
- Product quality ($F(3,455)=38.3$, $p\leq0.001$, $\eta.^2=0.12$).

According to the effect sizes, the biggest differences concern the product quality: Poles (20.5%, $SD=12$) and Spaniards (18.3%, $SD=11.6$) scored considerably higher in the relative importance than Germans (13.2%, $SD=8$) and Norwegians (11.3%, $SD=7.9$) regarding clothing. In addition, the effect of environmental certification on the acceptance of CCU-based clothing was moderate; here, Norwegians (25.4%, $SD=13.1$) have attributed much more relevance to the environmental certificates than Poles (16.4%, $SD=10.4$), Germans (22%, $SD=11.1$), and Spaniards (23.7%, $SD=12.6$). Small effect sizes were found for health compatibility and product information attesting less variability between the nations.

For the perceptions of **CCU-based cosmetics**, significant differences between the countries resulted in the evaluation of the attributes, even though the effects were small:

- Environmental certification ($F(3,454.3)=8$, $p\leq0.001$, $\eta^2=0.03$)
- Product quality ($F(3,454.3)=5.8$, $p\leq0.001$, $\eta^2=0.02$)
- Health compatibility ($F(3,455.8)=2.6$, $p\leq0.001$, $\eta^2=0.01$).

Regarding product information, ANOVA revealed no significant differences in the international sample ($F(3,453.4)=1.8$, *n.s*).

Thus, we can conclude that Europeans considerably differ in their assessment of the relevance of acceptance-driving factors for CCU products, suggesting that potential European users have different prerequisites or requirements for these products depending on their country of origin. But we also see that the differences depend slightly on the product type.

Acceptance on the attribute levels

To gain deeper insights into the nature of acceptance-promoting and acceptance-weakening factors, we now focus on the respective levels of the examined attributes. Using again the HBA, we consider part-worth values to examine how the different levels contributed to the attractiveness of the attributes and test, at the same time, whether there are inter-European differences in the assessments of these. This allows us to identify the tipping points between acceptance and non-acceptance in each of the attributes. Figure 6 summarizes the mean part-worth values (zero-centered) for all attribute levels for the acceptance of CCU-based clothing. For the interpretation of the values, it is important to relate them to each other rather than understand them in absolute terms. For instance, a negative part-worth value is not synonymous with a negative influence on the selection decision but shows the relative extent to which a given attribute level inhibits the acceptance of the considered product; the interpretation is analogous for positive values, thus informing about which attribute level is acceptance-promoting.

Beginning with *product quality* as an attribute for **CCU-based clothing**, participants' selection decisions are promoted by the better quality of the product compared to a conventional one (overall 22.6, $SD=31$). The values for different European countries differed significantly ($F(3,454.1)=9.8$, $p\leq0.001$, $\eta^2=0.03$) with Spaniards reaching the highest (26.9, $SD=34.1$) and Norwegians reaching the lowest utility values (12.8, $SD=24.5$). Regarding the *health compatibility* of the clothing, the minimum guarantee of health compatibility (44.9, $SD=47.9$) and the calculated risk (31.5, $SD=41.1$) promote acceptance, while no information about health strongly reduces it (−76.4, $SD=59.5$). The participating countries were in agreement about the necessity of the minimum guarantee of health compatibility ($F(3,449.5)=1.9$, *n.s*), but significant differences emerged for calculated risk ($F(3,456.9)=7$, $p\leq0.001$, $\eta^2=0.02$) and missing information about health ($F(3,454.6)=6.1$, $p\leq0.001$, $\eta^2=0.02$). Within the attribute *product information*, the levels information directly available (IDA:10.8, $SD=36.7$) and information linked (IL: 20.5, $SD=32.1$) promote acceptance, while pure product naming (PPN: −31.3, $SD=34$) rather weakens the decision to choose CCU-based clothing. Here, differences between the different countries were revealed for all three attribute levels (IDA: $F(3,446.6)=5.8$, $p\leq0.001$, $\eta^2=0.02$, IL: $F(3,450.9)=5.3$, $p\leq0.001$, $\eta^2=0.02$, PPN: $F(3,445.8)=9.8$, $p\leq0.001$, $\eta^2=0.04$) and in this context, German participants—among the other nations—reached the highest positive values for information directly available (18.1, $SD=28.3$) and information linked (25.3, SD = 33.6), and the highest negative utility value for pure product naming (−43.4, $SD=39.8$). Eventually, in the context of *environmental certification* only the scientific institution (20.5, $SD=37.3$) emerged to contribute to the accepted use of CCU-based clothing, while the statement of the manufacturer (−22.7, $SD=29$) was perceived as an acceptance-weakening factor; environmental associations have rather neutral effect on the acceptance (2.1, $SD=44.4$). According to the inferential statistics, the participants of different countries significantly vary in their opinions on these levels (scientific institution: $F(3,450)=6.7$, $p\leq0.001$, $\eta^2=0.02$; statement of the manufacturer: $F(3,443.1)=30$, $p\leq0.001$, $\eta^2=0.07$; environmental associations: $F(3,447.1)=5.1$, $p=0.002$, $\eta^2=0.01$). Considering the

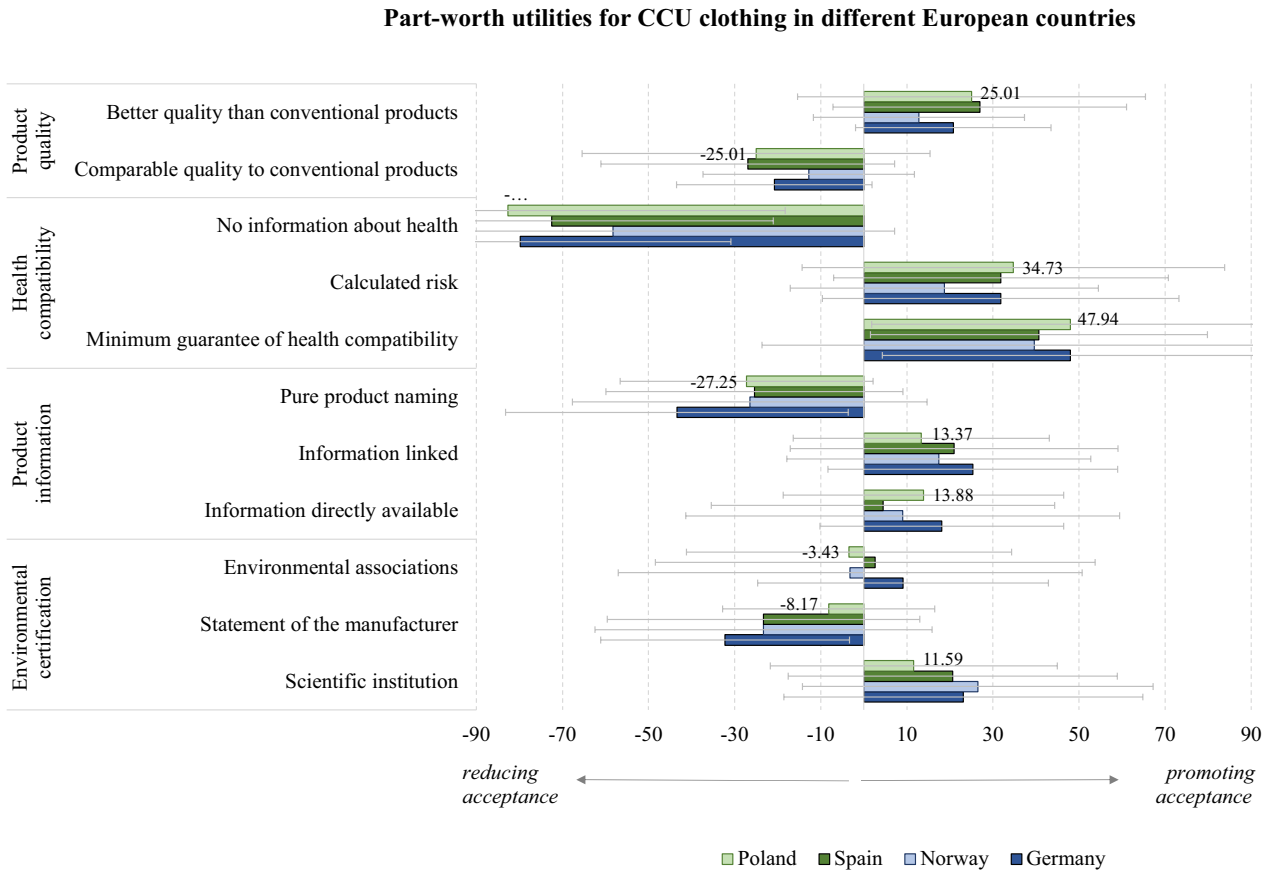

Fig. 6 Part-worth utilities for the aspects shaping acceptance assessments of CCU-based clothing in different European countries ($N = 828$)

effect sizes, moderate differences refer to the manufacturer's statement; here, particularly for German users the manufacturer's statements (–32.3, $SD = 28.9$) seem to be not credible enough reducing acceptance while, for instance, Polish potential users are significantly less bothered by it (–8.2, $SD = 24.6$).

Similarly, we analyzed the attribute level values considering the **CCU-based cosmetics**. Figure 7 depicts the mean part-worth values for all attribute levels affecting the acceptance of these products positively or negatively. The profile is comparable, and the attribute levels show the same directions as above. For cosmetics, however, slightly fewer differences emerged between the participating Europeans.

Likewise, better *quality* (19.4, $SD = 27.6$) in comparison to the conventional cosmetic products was preferred for the acceptance of CCU-based cosmetics over comparable quality (–19.4, $SD = 27.6$), but the mean utility values resulting for different Europeans differed significantly ($F(3,447.1) = 5.1$, $p = 0.002$, $\eta^2 = 0.01$). As to *health compatibility*, no information about health (–74.4, $SD = 66.7$) again strongly weakens the acceptance: especially Germans assessed this aspect as detrimental (–84, $SD = 51.3$), while Norwegians (–58.1, $SD = 68.2$) reacted on average significantly less vehemently $F(3,455.2) = 6.1$, $p \leq 0.001$, $\eta^2 = 0.02$). On the other side, a minimum guarantee of health compatibility (47.3, $SD = 53.6$) and a calculated risk (27.3, $SD = 46$) promote acceptance of cosmetic products. As to the first one, Europeans agree on that aspect ($F(3,452.4) = 2.4$, *n.s.*)—Poles and Norwegians reach similar means, and Spaniards and Germans too—but considerable differences resulted for the aspect of calculated risk ($F(3,454.9) = 6.1$, $p \leq 0.001$, $\eta^2 = 0.02$): the mean values differed most between Polish (31.7, $SD = 51.8$) and Norwegian participants (14.9, $SD = 44.2$). The direction of the *product information* levels was again analog to the ones of clothing: information directly available (12.8, $SD = 34.1$) or information linked (19, $SD = 32.9$) promote the decision upon cosmetic products, but a pure product naming has the opposite effect (–31.9, $SD = 33$), even though the different countries significantly differ in this regard ($F(3,455.5) = 7.1$, $p \leq 0.001$, $\eta^2 = 0.03$). Finally, *environmental certification* as requirement for the acceptance of CCU-based cosmetics resulted in a comparable contribution profile as for clothes: certification from scientific institution (20.4, $SD = 39.3$) promotes

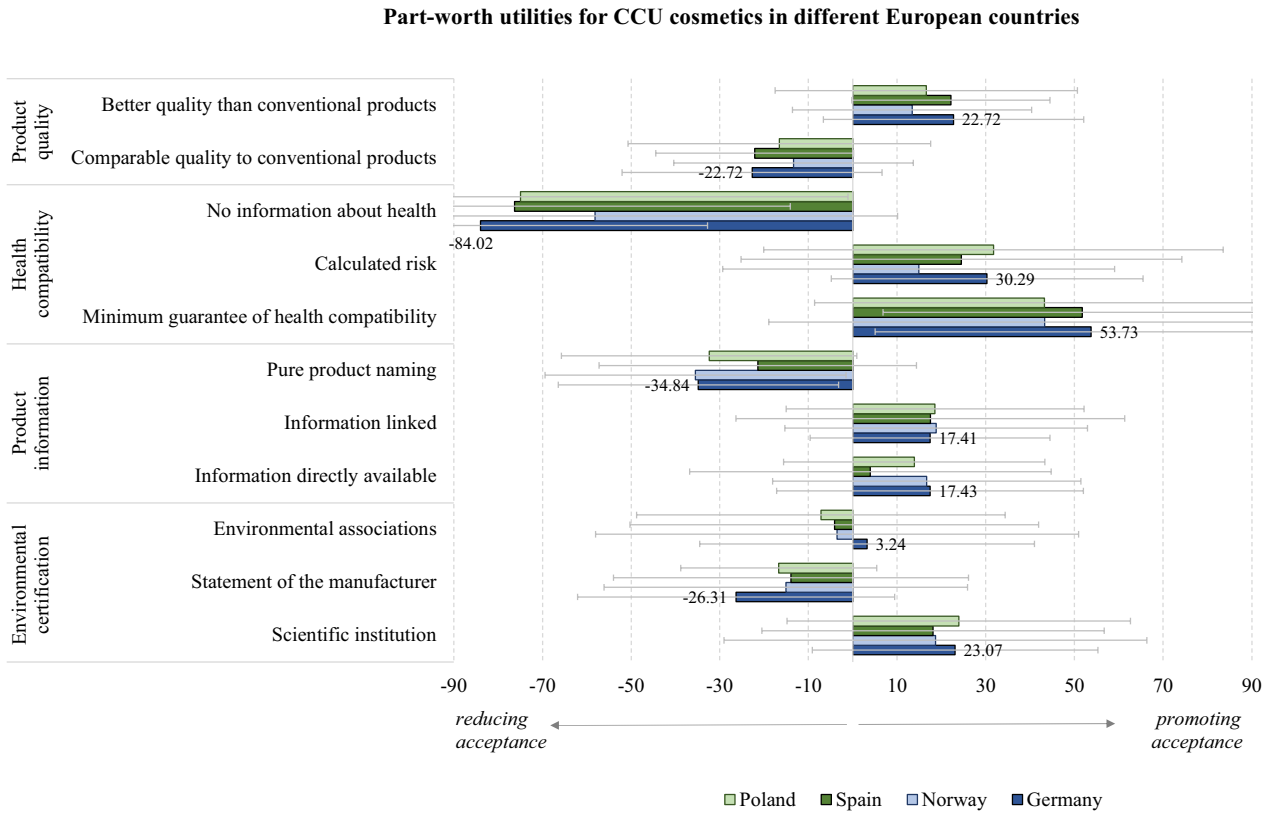

Fig. 7 Part-worth utilities for the aspects shaping acceptance assessments of CCU-based cosmetics in different European countries ($N = 828$)

and the statement of the manufacturer (−17.8, $SD = 33.2$) weakens acceptance of the products; statements of the environmental associations are perceived again rather neutral (−2.6, $SD = 46.4$). Between the countries, differences emerge solely with regard to the manufacturer's statement ($F(3,428) = 4.8$, $p = 0.003$, $\eta^2 = 0.02$) with Germans reaching the highest negative mean value (−26.3, $SD = 35.8$).

Concluding these outcomes so far, we can state that the comparability of the profile directions in both application examples, i.e., clothing and cosmetics, suggests that the requirements of the acceptance attributes for different CCU products can be generalized to a certain extent. Nevertheless, there are considerable differences in the requirements of potential users in Pan-European comparison.

Affective assessments of CCU-based products

In addition to the trade-offs in acceptance-relevant features assessed in the choice experiment of the CM, we captured affective evaluations describing CCU-based clothing and cosmetics. The profiles of the country-specific means for these application examples are depicted in Fig. 8.

It can be seen that both clothing and cosmetics are evaluated predominantly positively, even though the international sample differed significantly in their average judgments (clothing: $F(33,2448) = 4.58$, $p \leq 0.001$, $\eta^2 = 0.06$; cosmetics: $F(33,2448) = 3.88$, $p \leq 0.001$, $\eta^2 = 0.05$). From the resulting profiles, Spaniards and Poles rated the CCU-based products most positively, while Norwegians, followed by Germans, were more skeptical, although still positive, about clothing and cosmetics based on CO_2. One characteristic was judged significantly different from the other—the price of the products. Here, the profiles of German, Polish, and Spanish respondents leaned more toward concerns regarding higher spendings on CCU-based clothing and cosmetics. Inferential statistics on the significance of the differences and the magnitudes of these effects can be found in Table 3.

Summarizing, the participating countries differ significantly in their affective assessments of the CCU-based products. Roughly, Spaniards often scored most positive in affective descriptions, while Norwegians were most neutral in their opinions.

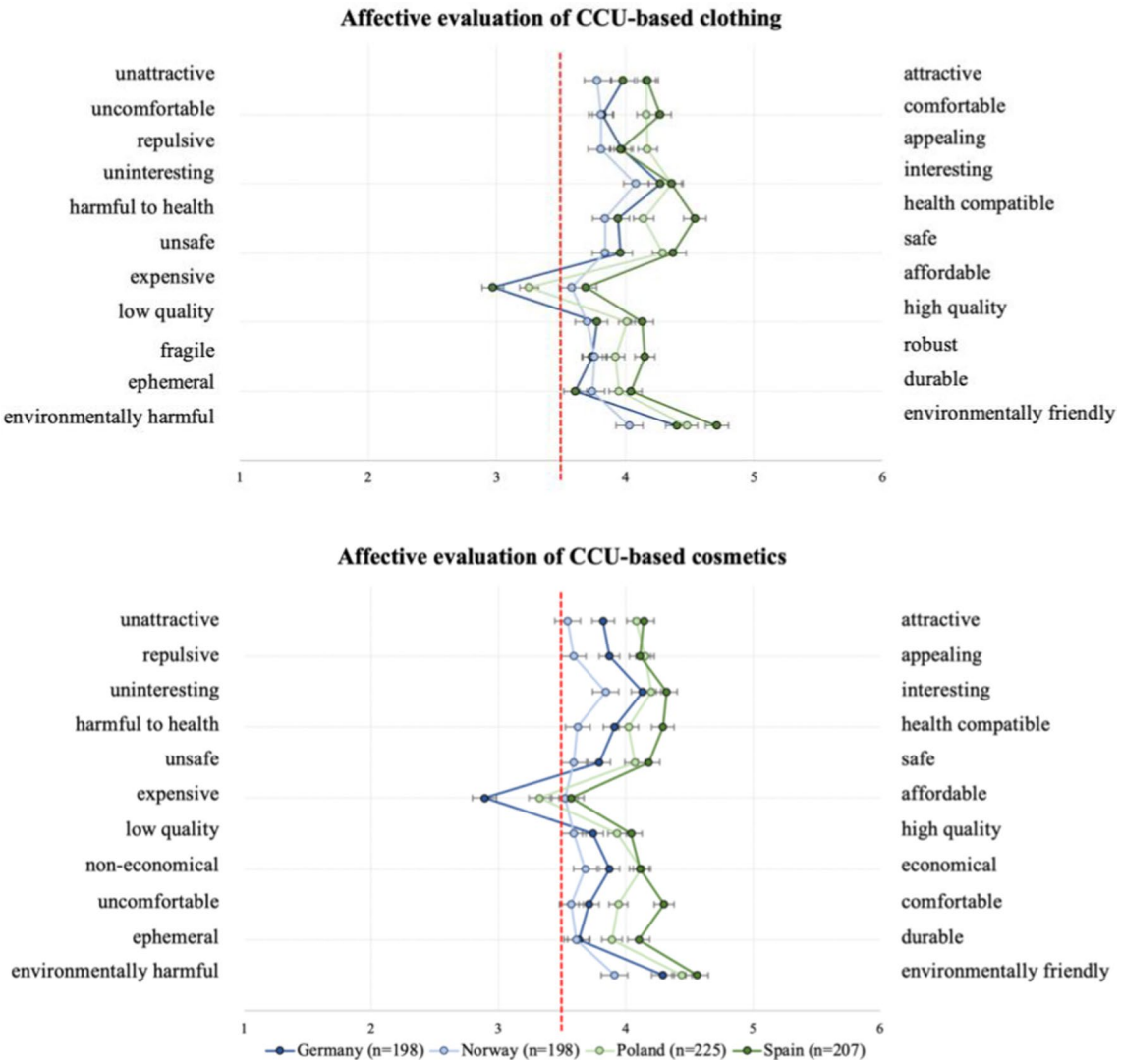

Fig. 8 Semantic differentials for CCU-based products in different European countries: clothing (top) and cosmetics (bottom)

Discussion

To date, research dealing with the potential of CCU still mainly focuses on the development, technical feasibility, and efficiency improvement of CCU technologies (e.g., [5, 55, 56]). As Vreys and colleagues [57] aptly put it, technological advancement aims to enable CCU to compete with current conventional, fossil-fuel-based products and lowering CO_2 emissions during the production process at the same time. CCU technologies have great potential to limit carbon dioxide global emissions, decreasing CO_2 emissions and slowing the greenhouse effect (e.g., [5, 58–60]). There are multiple opportunities how CO_2 can be utilized in several processes (e.g., in the chemical and oil industry, food industry, mineralization, power, pharmaceuticals, pulp and paper steel, and much more) and therefore fabricate marketable products in and for human life [61, 62]. However, the social impacts of the CCU technology products on the perspectives of end users—with all their varying perceptions, opinions, needs, and motivations but also different socialization patterns and culturally anchored backgrounds—are still underexplored, and not yet systematically considered, in the overall evaluations within the technology development. Nevertheless, the public voice should not be neglected when it comes to the successful adoption and further optimization of CO_2 capture and utilization processes in the European societies in the future, as social acceptance is a crucial determinant for any policy and government institutions as well as for companies and their product rollout approaches. Without broad

Table 3 Inferential statistics on the affective assessments of CCU-based products in different European countries

Affective characteristics of CCU-based products	Statistics of differences	
	Clothing	Cosmetics
Attractive vs. unattractive	$F(3,824) = 4.90, p = 0.002, \eta^2 = 0.02$	$F(3,824) = 10.07, p \leq 0.001, \eta^2 = 0.03$
Comfortable vs. uncomfortable	$F(3,824) = 8.92, p \leq 0.001, \eta^2 = 0.03$	$F(3,824) = 15.14, p \leq 0.001, \eta^2 = 0.05$
Appealing vs. repulsive	$F(3,824) = 3.46, p = 0.016, \eta^2 = 0.01$	$F(3,824) = 9.52, p \leq 0.001, \eta^2 = 0.03$
Interesting vs. uninteresting	$F(3,824) = 2.43, p = 0.064$, *n.s*	$F(3,824) = 5.42, p \leq 0.001, \eta^2 = 0.02$
Health compatible vs. harmful to health	$F(3,824) = 13.17, p \leq 0.001, \eta^2 = 0.05$	$F(3,824) = 9.75, p \leq 0.001, \eta^2 = 0.03$
Safe vs. unsafe	$F(3,824) = 9.48, p \leq 0.001, \eta^2 = 0.03$	$F(3,824) = 9.13, p \leq 0.001, \eta^2 = 0.03$
Affordable vs. expensive	$F(3,824) = 12.89, p \leq 0.001, \eta^2 = 0.05$	$F(3,824) = 10.26, p \leq 0.001, \eta^2 = 0.04$
High quality vs. low quality	$F(3,824) = 6.17, p \leq 0.001, \eta^2 = 0.02$	$F(3,824) = 5.58, p \leq 0.001, \eta^2 = 0.02$
Robust vs. fragile	$F(3,824) = 5.30, p \leq 0.001, \eta^2 = 0.02$	–
Durable vs. ephemeral	$F(3,824) = 5.13, p = 0.002, \eta^2 = 0.02$	$F(3,824) = 6.79, p \leq 0.001, \eta^2 = 0.02$
Environmentally friendly vs. environmentally harmful	$F(3,824) = 11.06, p \leq 0.001, \eta^2 = 0.04$	$F(3,824) = 9.43, p \leq 0.001, \eta^2 = 0.03$
Economical vs. non-economical	–	$F(3,824) = 7.02, p \leq 0.001, \eta^2 = 0.02$

consumer acceptance, there may not be a reliable end-market for CCU-based products, hindering the economic viability and potential mitigative benefits of CCU [63].

Although there are several studies on the purchasing behavior of sustainable cosmetics (e.g., [25, 64, 65]) and clothing/fashion (e.g., [27, 66, 67]) in the broader sense, hardly any studies focus on the acceptance, social perception, and driving factors for the purchase or use of CCU-based cosmetics and clothing. Within the presented empirical approach, we therefore examined the social perception of exemplary CCU-based clothing and cosmetics and experimentally investigated among four European countries—Germany, Norway, Spain, and Poland—how acceptance-relevant attributes of these products contribute to the potential users' decisions about the adoption and consequently the (non-) use. Using the CM, we analyzed the expressions of context-specific attributes and their levels for both the whole international sample and the particular countries separately. In the following, we discuss the key outcomes responding to our main research questions.

Key outcomes in response to the research questions

Regarding the general acceptance of CCU technology, all European participants advocate for using products that employ CO_2 in their production: in terms of acceptance criteria, both perceived usefulness and direct acceptability in the sample reached mean values that indicate a positive attitude. This result corroborates findings from previous research on public acceptance and willingness to purchase CCU-products [68]. According to our finding, the willingness to use the products slightly differs depending on the country of origin of the potential users. For example, Poles show a significantly higher willingness to use the CCU products and support the idea of CO_2 incorporation in everyday items more strongly than Spanish participants. In contrast, comparing these countries with Germans and Norwegians (and between the two latter), the differences are weaker if at all existing.

In the case of the affective assessments of concrete CCU products––in terms of our study clothing and cosmetics––Spanish participants find the products more appealing as compared to the general acceptance evaluation. Among other nations, they reach the highest average values for eco-friendliness, comfort, and health compatibility when rating the properties of CCU-based cosmetics, and they also score highest for robustness and safety when it comes to CCU-based clothing. Thus, this outcome demonstrates first that the affect heuristic is valid concerning product innovations like the ones considered in this study and confirms previous research [34, 69]. Second, it suggests that the affective evaluation can alternate the perceptions, although it remains unclear to which extent. In the context of affective ratings, Norwegians' average values of the characteristics provided (=pairs of adjectives) are more neutral than the ones from participants of other nations, especially the CCU-based cosmetics: here, probably the affect itself influences the cognitive decisions related to possible/perceived risks. As such, the health-related concern that direct skin contact with CCU-based materials may bring possible adverse health effects [18, 19] could have hindered a more positive assessment. This outcome is also congruent with previous results: a recent study by Prieri and colleagues [68] that examined the influence of product category on people's willingness to use

and buy CO_2-derived products showed that participants were more willing to use CO_2-derived fuels than products being in direct interaction with the body, like food or beverages, suggesting a certain caution towards health risks. Hence, responding to our RQ1 so far, we can state that CCU-based products are generally given a positive attitude in the public, and the affective perceptions, even if slightly differing in the selected European countries, build quite a solid basis for the intended use of these products and contribute to capturing and re-using the environmentally destructive CO_2.

Undoubtedly, individual attributes of CCU-based products shape the decision to pursue and use a concrete product and considerably influence the user's decisions. Our findings on the relative importance of the acceptance-relevant attributes and their levels on the decisions pro-CCU-based clothing and cosmetics demonstrate that *health compatibility* strongly influences the decision about the adoption of CCU-based clothing and cosmetics and, in particular, the use of innovative products [18, 70], which also aligns with the previous works by Sadiq et al. [25] who found that people concerned about their health are especially interested in buying sustainable cosmetics. According to our results, the attributes *environmental certification* and *product information* make fewer but comparable contributions, and *product quality* contributes even weaker to that decision. Other research in this area has shown that certification reputation can significantly influence consumer behavior toward sustainable products [71]. Studies regarding sustainable cosmetics [26] and sustainable clothing [27] revealed that ethical considerations and concerns about greenwashing present a strong predictor for purchase intention, and product as well as environmental information are necessary for supporting consumers in their decision-making [29]. Thus, the authors recommended promoting the products by addressing ethical and environmental concerns with adequate labeling.

The Europeans participating in the study significantly differ in their relevance assessment of acceptance-driving factors for CCU products, however, the power of these differences also depends on the product. Considering CCU-based clothing, respondents differed strongly in the expectations of product quality and requirements on environmental certification. Differences regarding product information and health compatibility were lower, attesting less diverging expectations between the participants of our pan-European sample. As opposed to that, CCU-based cosmetics induced less, and considerably weaker, differences between the participating nations. In this context, we found only weak effects for environmental certification, product quality, and health compatibility, and there was agreement regarding product information. In terms of our research questions, we can thus conclude that context-related factors influence the potential consumers' decisions to varying extent (RQ2) and the focus clearly lies on health; this finding corroborates earlier studies on different CCU products for the German population [18–20]. In different European countries, the acceptance varies depending on the product, and different focal points, i.e., product attributes, are considered as a basis for or against the CCU product (RQ3). In the following, we look at these country-specific differences in even more detail, additionally discussing the findings on the different levels of the examined attributes.

Country-specific requirements in the acceptance of CCU-based products

For a successful adoption of CCU-based products in Europe, analysis of differences between the national and international socio-political acceptance is important for the (future) developments. Since Europe represents different cultures and social structures, it is necessary to survey subsamples from different European regions to obtain representative results. To achieve as diverse a sample as possible, Spain was therefore chosen to represent the westernmost countries of Europe, Norway accordingly as a northern country, Poland as the eastern representative, and Germany as the prototypical central European country. So far, we have roughly hinted at the differences between the various participating nations, but it is worth taking a closer look at the requirements in each participating country as well, as we found divergences on all levels of statistical analyzes.

Beginning with *Spanish* participants, we consider a subsample with the highest education among the countries studied—people who live mainly in or near cities and, in most cases, with their partner (and children). They scored highest in technical innovativeness and, as a nation, reached a comparably high mean in environmental awareness. In the context of general acceptance, we have encountered a neutral attitude about supporting the use of CCU-based products despite their positive assessments of the perceived usefulness. In comparison, Spaniards also averaged the highest refusal rate of the utilization of CCU-based products. However, considering the affective evaluations of CCU-based clothing and cosmetics, they achieved the most positive evaluation in almost all categories. Thus, concretization, in contrast to the general estimation of the use, has produced contrary results. Looking closer at the trade-offs on the individual attribute levels, it becomes clear that, among the other nations, Spaniards attached the highest importance to the innovative clothing being of better quality than conventional products. Both for the use of clothing and cosmetics manufactured using the innovative CCU technology,

Spaniards reported to require a minimum guarantee of health compatibility. In addition, information linked and certification from scientific institutions (and in the case of clothing confirmation of associations) favors the decision to use these products. As opposed to that, lacking information about health and missing other product properties combined with sole assertions on the part of the product manufacturer lead to a decision against using the product. This finding closely connects to the results of other research that people tend to distrust information given by manufacturers or companies as the only information provider [69, 72]. Apparently, the public requires a more independent and neutral assessment of the innovations and impute––especially in the case of industry, manufacturing, and policy––to pursue other motives (financial benefits, re-election purposes) than the objective evaluation of a product also with respect to the social consequences [22, 23].

Continuing with *Norwegians*, we collected responses mostly from well-educated individuals who live with partners or family both in or near cities and in the outskirts; one-third of the subsample indicated to live alone. Compared with other participating countries, they scored the lowest average values in technical innovativeness and environmental awareness but achieved a significantly higher risk disposition value. As to the general acceptance, Norwegians showed positive attitudes and acceptability, and they slightly acknowledged the usefulness of the CCU-based products. Considering the affective evaluations of specific products, among other nations, Norwegians assessed the investigated products in most restrained manner, still assessing CCU-based clothing slightly more positive than cosmetics. Considering the acceptance-driving attribute levels, a minimum guarantee of health compatibility or at least a calculated risk are the most important prerequisites of using the products. The remaining requirements are information about the product linked (or directly available), increased quality in comparison to the conventional products, and an important aspect shaping the acceptance is the certification from a scientific institution––in the international comparison, the Norwegians reached the highest value for clothing in this context. Against the decision to use the products speak quality comparable with the standard products, lack of health information, pure product naming, and manufacturer's statement as a certificate for the product. Overall, compared to other nations, the attribute levels are usually weaker.

The *Polish* subsample was on average the youngest among the participating nations. Half of the respondents reported to hold higher education, and the other half distributed over primary and secondary education. Two-thirds of the subsample indicated living in the city, and about the same proportion reported living with a partner (and children). Compared to other examined nations, Polish participants reached the highest means as to environmental awareness and risk disposition, and their results suggest high technical innovativeness. Regarding the general acceptance of CCU technology and products, Poles scored the highest in perceived usefulness, intention to utilize the products, and their general acceptability. Also, the profiles resulting from the affective assessments of concrete applications confirm Poles' favorable attitude. According to the trade-off analysis, the decision about using/purchasing CCU-based clothing strongly depends on, firstly, health compatibility––a minimum guarantee and calculated risk are acceptable while missing information about health is a frustrating and demotivating aspect––and, secondly, on the quality increase in comparison to the standard products. Product information linked, or directly available, and somehow weaker the certification from a scientific institution also positively contribute to adoption of CCU-based clothing. Pure product naming, statements of the manufacturer, or a certificate originating from associations have the opposite effect. We observed comparable trade-offs for the particular attribute levels for CCU-based cosmetics, solely the importance of the scientific certification increases concerning this application.

Finally, the *German* subsample consisted of participants with different education levels who predominantly live with a partner and/or child(ren) in (or near) cities and the outskirts. The German respondents were environmentally aware, but in the international comparison, they scored lower than other nations in risk disposition, environmental self-efficacy, and technical innovativeness. Generally, they perceived CCU technology as useful, reasonable, and acceptable. Germans were willing to use the products, and their affective assessments of the products were mostly positive. Like the other Europeans, health compatibility was the Germans' main driver for the accepted CCU products: here, the requirement of a minimum guarantee for heath was the highest among the participating countries in both exemplary CCU applications; calculated risk also promoted acceptance while no information about health considerably reduced it. Other acceptance motivators were product quality surplus value and direct or linked information about the product. As to environmental certification, Germans relied on scientific institutions, but unlike other Europeans, they also acknowledged the certification from the environmental associations. In Germany, this is probably due to the widespread use of the consumer information market "Stiftung Warentest". This institution outsources the tests of the products worldwide to external, neutral testing institutes so that the product's

test results are independent, trustworthy, and, therefore, acceptance-promoting.

In summary, all participating nations exhibit mostly positive affective attitudes towards these products––even though they also fear high pricing––and favorable public perception. Nevertheless, considerable differences result in different product attributes between the participating countries. Even though a large amount of research on CCU technologies and products exists, and most of it concerns the economic consequences, studies barely focus on comparison between different countries or cultures in the context of social perception and acceptance. A cross-cultural comparative analysis from a study on sustainable clothing [67], which contrasted the perspectives of US and Chinese Millennials, revealed––comparably to our empirical findings––both similarities and differences in sustainability knowledge and values between the young consumers from both countries. Here, the profound influence of culture on values, attitudes, and purchase intention helps to understand consumer behavior in the cross-cultural context. Another research on the potential of carbon capture, utilization, and storage (CCUS) on the decarbonization of the industry sector found many differences in socio-political acceptance (evaluated among other indicators) between three European countries: France, Spain, and the Netherlands [73]. Proving that each country has its influencing concepts on socio-political acceptance, the author recommends evaluating the role of the industrial CCUS for each European country separately. Following this and concerning our findings on social perception of the examined CCU products, it is worth analyzing the respective market in detail and taking country-specific values and beliefs into account to make appropriate recommendations for manufacturers and develop customized communication for future consumers, having thus a positive impact on climate change in the long term.

Limitations and future research directions

Despite gaining new knowledge about the adoption of CCU technology and its innovative products, as exemplified above, we still want to point out some methodological restrictions and discuss the need for future research.

Selection of attributes in CM

The first possible shortcoming might arise from the empirical approach used in the presented study. Each methodology considerably influences the investigated phenomenon in the multifactorial decision space. Based on the literature research and our prior explorative interview study on this topic, we have chosen attributes perceived as relevant by the potential users of CCU products (laypersons) and considered impactful by interviewed experts in the field. However, the list of the factors and attribute levels used in the conjoint analysis is not to be perceived as exhaustive. It is necessary to consider that a different set of attribute levels may lead to deviating results and would possibly provide further insights into the topic. According to our results, acceptance patterns differ in part for different products, which is why future studies should identify product-specific factors appropriately tailored to the specific target users in the decision simulations.

Gap between the attitudes and behavior

A frequently encountered restriction in the acceptance assessment of the prospective usage settings is the gap between attitudes and actual behavior influenced by different contextual factors and other uncertainties [74, 75]. Therefore, as a method-inherent characteristic, it is not possible to accurately predict the future behaviors of potential users of CCU products. Still, the empirical approach of CBCA enables us to draw at least approximately the complexity of the actual decision-making behavior and brings a significant added value in this context. Future efforts should capture the real usage when CCU-based products enter the market and are widely accessible for consumers.

Unrevealed impact of user profiles

So far, we have analyzed the potential national/cultural impacts on acceptance and preferred usage settings in the described four countries. As of now, an open question remains of whether––at the individual level––1) the user characteristics such as risk disposition and perceived self-efficacy, as well as 2) attitudes towards technical innovativeness and environmental awareness along with sociodemographic factors exert a significant impact on the (non-/)use of CCU-based everyday products. If so, then the cultural impact of nationalities and socioeconomic circumstances would be of lesser importance, but the identification of user profiles could help to understand how to diligently steer information, communication, and public education. Previous research (e.g., [18, 21, 23]) revealed that for the adoption of CCU products, user profiles deliver helpful information about the consumers, e.g., the impact of personality traits, and behavioral and attitudinal patterns. Thus, as an extension of research in the field it would be a valuable addendum to identify user profiles for the here-studied CCU-based cosmetics and clothing to develop individually tailored public information, communication, and education formats.

Direct comparison of different CCU products in one frame of reference

While CCU-based cosmetics and clothing have not yet been investigated in terms of public perceptions, and represent a novelty of this paper, an overall evaluation concept of different products should be planned and applied in future studies. Meanwhile, a variety of acceptance studies on different CCU-based products is researched, ranging from fuels (e.g., [76]), insulation materials [22, 23], mattresses [18, 19], to infrastructure [77, 78]. However, it is not yet possible to directly compare the acceptance levels of the different products. From a social point of view, context-dependent benefits and concerns could influence the acceptance of these products: products close to personal life and experience, such as cosmetics and clothing, are more vulnerable to health- and hygiene-related concerns than for instance fuels, for which comfort and affordability are more important. For building materials in the own house, sustainability and product quality could be especially relevant. For infrastructure, concerns about the deterioration of one's backyards, visual esthetics, and quality of life could come to the fore. Therefore, research and industry should aim for an (empirical) assessment of these products in one frame of reference to get an acceptance assessment in the context.

Integration of other (European) nations

Moreover, it should be considered that the countries under study were selected somehow arbitrary, and the differences between other nations may be even more profound or not present at all. For this reason, it would be useful to inquire in much more depth into the profiles of "approvers" and "rejecters" of CCU technology, taking the attitudinal and contextual factors for the decision-making processes into consideration in addition to the sociodemographic conditions of the respondents. So far, we have focused on a European perspective, considering comparably wealthy and technology-oriented countries (even though there are differences). But it is also undeniable that integrating and supporting developing countries in the use of renewable energies (therein CCU-based products) is a major step to reduce the climate change and alleviate the negative effects of fossil resources consumption [79]. Nevertheless, in terms of the social perspective it is not only a matter of energy access but there remain completely blind spots regarding cultural frames that affect societal goals and acceptance of renewable energy and its use. In addition, highly relevant are also different resource availabilities (e.g., mineral resources, technical possibilities, financial capacities) and questions of "who consumes?" and "who pays?" including political responsibility [80, 81]. These aspects are an urgent research duty to advance efforts for the global use and development of renewable energy technologies and the marketability of CCU-based products.

Conclusions

This research study provides empirical evidence of the general public's acceptance of exemplary CCU-based products, examining representative subsamples of four European countries. The cross-cultural comparisons showed that all participating European nations perceived CCU technology and its products as useful, interesting, attractive, and acceptable. We have learned that the higher the environmental awareness and technical innovativeness of the (potential) consumers, the higher their willingness/intention to utilize the sustainable products. At the same time, from the examined attributes, health compatibility emerged as the central acceptance-driving factor for the adoption of CCU technology. Still, the environmental impact, product quality, and the information flow, even though to a lesser extent, play an important role in the intention to use the products as well. As demonstrated in the exemplified CCU-based clothing and cosmetics, potential users from different European countries have been revealed to considerably differ in their requirements and, thus, acceptance patterns. A deeper understanding of such differences and specific acceptance profiles enables the development of effective and tailored communication messages in the public. Thus, for a successful rollout of CCU-based technologies and products, the industry, supported by national governments, should actively identify the local public's needs to fulfill them [73]. To spread knowledge about the sustainability of the technology and to build future consumers' trust, it is recommended to initiate local debates or information campaigns, develop appropriate communication strategies, and issue guidelines based on the concrete demands of the users. The governmental duty in this context is on the one side to consequently frame research concepts that explore the national CO_2 utilization potential and largely facilitate the socio-political acceptance of the CO_2-reducing technology in the society and to support the progress of the development in the field by supporting policies, resulting recommendations, and legal framework on the other. Moreover, the integration of the social science perspective and methods in the deployment of the energy-efficient and CO_2-reducing CCU technology, as performed in this research, enables a prompt perception of potential pitfalls and risks [82]. The use of social acceptance patterns paves the way for efficient public information strategies [83] to adjust public knowledge to the needs of the (potential) consumers and thus to contribute to a successful energy transition [20, 84].

Appendix

See Tables 4 and 5

Table 4 Abbreviations, specific phrasing and descriptive statistics of attitudinal constructs; all constructs were measured by 6-point Likert scales ranging from 1 (=I fully disagree) to 6 (=I fully agree)

Abbr.	Construct/Item	*M*	*SD*
Risk	**Risk disposition** (Cronbach's α = 0.73) - I am willing to take risks - I like to put something on stake - I live by the device "Who doesn't risk anything will never gain anything" - I am very cautious when making plans and executing them - I don't like daring decisions - I would dare doing something risky	3.4	0.9
Innovation	**Technical innovativeness** (Cronbach's α = 0.89) - I think it's interesting to try new technical products - I am often the first in my social circles to test new products - I often search for new information on products that could be interesting for me - I regularly scout for new products	3.9	1.1
Awareness	**Environmental awareness** (Cronbach's α = 0.83) - I try to avoid waste through unnecessary packaging - I always overcome long distances by train - When buying textiles, I make sure that they are not containing pollutants - I generally avoid air travel - I watch out to not take very long hot showers to keep my usage of warm water at a minimum - I'd rather wear a warm pullover than heat up the room very much - When buying domestic appliances, I look for the ones needing less energy - I aim to buy products that have a low impact on the environment in production and usage	4.0	0.9
Efficacy	**Environmental self-efficacy** (Cronbach's α = 0.7) - I can contribute to environmental and climate protection through my everyday behavior - If I wanted to, I could change my mobility behavior in a way that would reduce my CO_2 emissions significantly - If I wanted to, I could change the energy consumption of my apartment in a way that would lower my CO_2 emissions significantly	2.0	0.5

Table 5 Information provided to the participants beforehand the choice tasks in conjoint measurement

	Instructions for the CCU-based products
CCU-based clothing	*"With CCU technology, it is possible to produce textile fibers on a CO_2 basis. Thus, conventional fibers, which are produced by means of fossil raw materials, can be replaced. CCU-based clothing is similar in properties to conventional clothing made of polyester.* *In the following, you will be presented with different product variations of clothing made using the CCU technology. In each case, we ask you to select the variation that you would be most likely to choose in a real purchase situation."*
CCU-based cosmetics	*"CCU technology can also be used to manufacture CO_2-based products in the cosmetics sector. For example, it is possible to manufacture creams on the basis of CO_2. This replaces conventional waxes. These usually consist of substances of natural origin or kerosene, which is produced from petroleum. In the case of creams manufactured using the CCU process, CO_2-based waxes are used in production. In the following, different variations of characteristics referring to cosmetic products produced by CCU are presented. We ask you to select from the available variations the one you would be most likely to choose in a real purchase situation."*

Abbreviations

ANOVA	Analysis of variance
CBCA	Choice-based conjoint analysis
CBE	Circular bioeconomy
CE	Circular economy
CO_2	Carbon dioxide
CCU	Carbon capture and utilization
CM	Conjoint measurement
HBA	Hierarchical Bayes analysis
IDA	Information directly available
IL	Information linked
PPN	Pure product naming
M	Mean
n.s.	Not significant
p	Level of significance
SD	Standard deviation
SDG	Sustainable Development Goals

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writing—original draft preparation: W.W., and I.H.; writing—review and editing: W.W., I.H., and M.Z.; visualization: W.W.; supervision: M.Z.; project administration: M.Z.; funding acquisition: M.Z. All authors have read and agreed to the published version of the manuscript.

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Declarations

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