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Risk perception and acceptance of CDU consumer products in Germany.

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Abstract

Carbon dioxide utilization (CDU) has the potential to contribute to global CO_2 emission reduction efforts. Research and developmental activities mainly focused on technical feasibility so far, neglecting the public perception and acceptance of the CDU technology and its products. Therefore, this study focused on the conceptualization and quantification of CDU risk perception and acceptance. First, qualitative focus group discussions were run, where the sub-dimensions of CDU-product-associated risks were determined (health-, product quality-, environmental-, and sustainability risks). Second, in a quantitative online survey, the impact of single CDU risk sub-dimensions on general CDU risk perception was quantified and related to CDU product acceptance. CDU risk perceptions, which were mainly determined by health- and environmental risks, were low and CDU acceptance positive. Individual differences (gender, technical self-efficacy, level of information) in CDU risk perceptions were identified and guidelines for a successful rollout and communication of CDU products were derived.

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Keywords: Carbon dioxide usage; empirical; focus groups; survey; risk perception; acceptance; health risks; individual differences

1. Introduction

Worldwide research efforts are directed on the global reduction of CO_2 in order to mitigate climate change. Carbon dioxide utilization (CDU) has the potential to contribute to these CO_2 emission reduction efforts. Currently, the transformation of carbon dioxide as renewable feedstock into useful chemicals such as polymeric and construction materials is made commercially feasible, even though the factual rollout of CDU products on the market is at an early stage yet. Potential applications and products based on CDU are plastic products, cement and fuel production, or enhanced oil recovery. Thus, CDU has the potential to limit or reduce atmospheric releases of CO_2 by providing saleable products for the industrial and end-user sector. Beyond the factual potential of CDU products, still, the social acceptance of CDU product needs - especially for the consumer market - to be analysed thoroughly. Therefore, apart

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from the technical feasibility of CDU technologies, CDU research needs to integrate the public perception of CDU technologies and products, which can make the difference between success or failure of this technology on the market.

2. CDU-Technology and public perception

2.1. Carbon dioxide capture and usage (CDU)

Since the 1980s, CCS (Carbon Capture and Storage) has been researched and industrially implemented worldwide aiming at a reduction of CO_2 emissions by capturing CO_2 from power plants in order to contribute to climate protection goals [1]. In particular, in the US, Canada, and Asia, numerous large-scale industrial CCS plants were implemented and correspondingly large amounts of stored CO_2 exist [2]. As there are already large amounts of stored CO_2 today and there will be no infinitely capacity for CO_2 storage in the future, potential ways of CO_2-utilization are intensely discussed and developed worldwide.

Physical utilization, chemical utilization, and the production of inorganic materials are three feasible types of CO_2-utilization that are presently discussed: inorganic materials are for example, calcite and hydrotalcite, in which CO_2 is firmly bound [3]. Within the physical utilization, CO_2 can be used in a very different manner: for instance, as refrigerant, as extinguishing agent, or in cleaning processes [1] as well as for the carbonation of beverages [4], and as inert gas for the conservation of fruit and vegetables [5].

The technical possibilities of the chemical utilization of CO_2 are also very diverse, but, in contrast to the other two types of utilization, it allows a long-term or partly permanent storage of CO_2. The production of urea, methanol, cyclic carbonates, and salicylic acid represent some chemical applications [1], [6]. Especially the production of carbonates and polycarbonates as type of CO_2-utilization is notably promising for a variety of reasons [1]: CO_2 is a nearly unlimited available resource and establishes economic and ecological savings of fossil resources; concurrently, it enables access to high sales volumes and demands in the plastics sector due to a variety of applications of plastic products that can be manufactured by CO_2-utilization.

For this purpose, plastic substances such as polyol, polypropylene, and polyurethane can be produced based on CO^2 [1], [7] by splitting the carbon block (C1): CO_2 can provide a basis for the manufacturing of those plastic raw materials and subsequently, they can be processed into building materials, e.g., insulations, as well as household articles, such as mattresses [8].

Previous life-cycle-assessment studies regarding CO_2-utilization for polyurethane figured out that chemical CO_2-utilization does not result in a significant reduction of the global CO^2 emissions budget. However, significant amounts of fossil resources (mostly oil) and CO_2 emissions - resulting from the manufacturing - can be saved compared to the manufacture of conventional products. [4]. Summarizing the technical perspective, CO_2-utilization for plastic products implicates considerably economic and ecological benefits: on the one hand, costs of and dependency on expensive fossil resources can be reduced, while, on the other hand, less CO_2 emissions and fewer use of fossil resources can relieve the environment and can at least contribute to combat climate change.

2.2. Technology acceptance and risk perception

The example of Carbon Capture and Storage (CCS) shows, that missing public acceptance impedes the successful rollout of a technology [9]. Accompanied by public protests, the regulatory approval, sufficient funding, or the choice of CCS sites was hampered and postponed due to missing public acceptance. However, since CDU strongly differs from CCS with regard to its underlying technical procedures and final product outcomes, existing knowledge about CCS acceptance cannot be simply transferred to the CDU context. Looking at CDU, related research mostly focused on aspects of technical development (e.g., [10]) or its integration into future energy systems. Research on public acceptance and perception of CDU focused on perceived benefits and risks of the technology itself; thereby differentiating between conceptual, technological, and societal issues [11]. However, a detailed investigation of CDU-related risk perceptions was not carried out so far, even though risk perception of innovative technologies and its products is a critical factor for the success or failure of a technology and its products on the market [12].

Therefore, *risk perception* has become a decisive factor in recent years for technology acceptance research as well as for the successful design and rollout of large-scale technologies. Risk perception refers to the subjective assessment of

the probability and the outcomes of negative events such as natural hazards or environmental threats [13]. Accordingly, risk perception research tries to explain, predict, and influence perceptions of and attitudes toward technologies and related risks [14]. Regarding CDU, risk perception in the public is highly relevant, because it might lead to the perception of dread, which can evoke feelings of fear [15]. For many other technologies, such as mobile communication technology [16], [17], nuclear technology [18], [19], nanotechnology [20], [21], and even CCS [9], risk perception has been thoroughly researched, but little is known yet about the perception of risks in the context of CDU. The knowledge about perceived risks related to CDU is especially important considering the fact that the majority of the public usually has only limited domain knowledge and is therefore not fully able to evaluate the technical potential of innovative technologies and products. In contrast, prevailing misconceptions and inappropriate cognitive models form users' perceptions of novel technologies and products, leading to a conservative and reluctant or even negative prevailing mood [22].

Hence, the present study aimed for a) an empirically based conceptualization and quantification of CDU risk perception, b) an evaluation of its relationship with CDU product acceptance, and c) a user-specific analysis approach, which accounted for the effects of individual differences in CDU risk perception. Methodologically, a two level empirical approach was pursued. First, for conceptualizing "risk perception of CDU", qualitative focus group discussions were run, where the sub-dimensions of CDU-product-associated risks were determined. Second, a quantitative online survey was carried out to quantify the impact of single CDU risk sub-dimensions on general CDU risk perception and to relate CDU risk perceptions to CDU product acceptance. Third, the impact of user factors on CDU product risk perception and acceptance was analyzed.

3. Methodology

3.1. The prestudy

In order to get insights into determinants of CDU risk perceptions, a prestudy was conducted. Due to the limited knowledge about risk perceptions associated with CDU, a qualitative empirical approach (focus group discussions) was pursued. The extracted risk categories served as a conceptual basis for the development of the questionnaire and its items. Focus group participants were potential future consumers of CDU products with low previous knowledge about CDU (laypeople, aged between 21-56 years). According to the semi-standardized interview-guideline, participants talked about their personal opinion regarding CDU, perceived risks, and acceptance-relevant factors, on the one hand, related to the CDU technology in general and, on the other hand, regarding a specific CDU product, a mattress made of CDU-foam. The interviews were audio- and video-recorded, transcribed, and analysed by means of a qualitative content analysis [23]. This led to an inductive category system of risks related to the CDU technology and a CDU-mattress, which were perceived by laypeople in the context of CDU technology and products: environmental risks, health risks, product feature and quality risks, and sustainability risks.

- *Environmental risks*: perceived risks related to the disposal of CDU-mattress (e.g., release of CDU, additional environmental pollution due to characteristics of the CDU-foam in the mattress)

  A common example of comments referring to the category of health risks was:

  "So, what happens if the mattress is disposed? Perhaps the plastic foam contains toxic additives that are more harmful to the environment in the end?"
  (male participant, 27 years)

- *Health risks*: perceived health risks and fears (e.g., health effects such as allergies, breathing difficulties due to leaking CO_2 from the CDU mattress)

  A typical comment in the focus group - referring to health risks - was:

"I' am afraid, that CO_2 – which is toxic, isn't it? – might leak from the mattress when I am sleeping. This won't let me sleep safe and sound."
(female participant, 53 years)

- *Product feature and quality risks* (e.g., reduced ergonomic sleeping comfort, reduced durability of the CDU mattress)

  An example for comments - referred to product feature and quality risks - was:
  "For me it is very important that the mattress is as comfortable as a normal mattress, with various ergonomic comfort zones – because I really have problems with my back."
  (female participant, 34 years)

- *Sustainability risks* (e.g., low sustainability of the CDU technology, delaying investments in other green technologies, a false pretence to continue burning fossil energy sources)

  A typical comment in the focus group - referred to sustainability risks - was:
  "They only want to continue to operate their coal plants. This CDU-technologies impedes the change, I mean, the development of other green technologies."
  (male participant, 24 years)

At this point, it is important to consider, that some of the perceived risks do not have any objective or scientific basis but are based on laypersons' misinformation or missing technical or chemical knowledge. Even though objectively wrong, these perceptions stem from the mental models and assumptions of laypeople about the CDU technology and affect their acceptance of this technology.

3.2. The Questionnaire

Based on the CDU risk categories, which were extracted in the prestudy, the questionnaire was developed, which was structured as follows: a) information text about the technical process of CDU and introduction of a mattress as a potential CDU product; b) demographic information and assessment of user factors (environmentally aware behaviour, subjective (i.e., self-rated) level of information about CDU, technical self-efficacy [24]; c) general acceptance of CO_2 mattresses, the willingness to buy and use a CO_2-mattress; and finally, d) risk perception of CDU mattresses in general (ratings of perceived risk and threat of CCU products in general) and with regard to its sub-dimensions (risks regarding the environment, health, product features, and sustainability). Questionnaire data was collected online in January - February 2016.

3.3. The Sample

A total of n = 232 participants volunteered to answer the questionnaire, which was distributed in social networks forums. Since only complete data sets were used for statistical analyses, a sample of n = 154 remained. Participants (53% males, 47% females) were on average 30.8 years old (SD = 11.3, range: 18-78 years). The sample was highly educated with 60 % holding a university degree, further 24% had "Abitur" (German university entrance diploma). The majority (72%) lived in the city center, 22% in smaller towns, and 6% in rural areas. Almost 40% reported to work in a technical profession. The sample reported to behave environmentally aware (M = 4.1, SD = 0.9, min = 1, max = 6) and to have a positive technical self-efficacy (M = 4.3, SD = 1.1, **Error! Reference source not found.**). The CDU-knowledge level in the sample was very low (M = 2.1, SD = 1.3, min = 1, max = 6): 46% reported to feel uninformed about CDU, only 1% perceived themselves as very well informed.

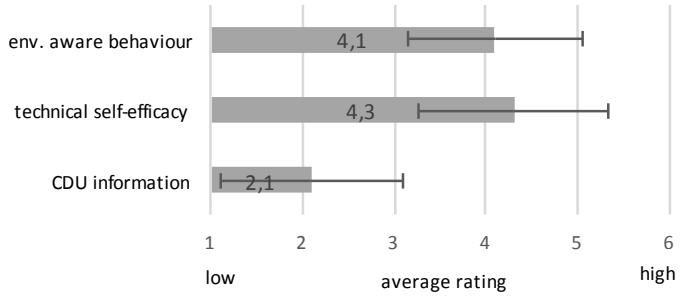

Figure 1: User factors (environmentally aware behaviour, technical self-efficacy, and level of CDU information) in the sample.

3.4. Statistical analysis

To ensure measurement quality, item analyses were calculated prior to further descriptive and inference analyses (Table 1). Cronbach's alpha > 0.7 indicated a satisfying internal consistency of the scales. Data was analyzed with correlational and linear regression analyses. The level of significance was set at 5%. To analyze the impact of user factors on CDU risk perception and acceptance by contrasting participants with high and low values on the respective attitude scale, a median-split was conducted for technical self-efficacy (MD = 4.38), environmentally aware behavior (MD = 4.21) and subjective level of information (MD = 2.0).

Table 1: Item analysis for the scales used in the study (Cronbach's alpha).

Construct	Number of items	Cronbachs's alpha
Technical self-efficacy	8	0.82
Environmentally aware behaviour	7	0.83
Subjective level of information	1	-
Environmental risks	3	0.73
Health risks	4	0.92
Product feature and quality risks	3	0.77
Sustainability risks	4	0.79
CDU risk perception	3	0.76
CDU mattress acceptance	5	0.89

4. Results

4.1. General CDU product acceptance and risk perception

Findings revealed a positive perception of the mattress as CDU product example (M = 4.4, SD = 0.8), although existing CDU knowledge in the sample was rather low (M = 2.1, SD = 1.3). Asked for their willingness to buy and use a CDU mattress, 23% belonged to the group of rejecters (with 9% strong rejecters), 24% reported a slightly positive purchase- and use intention, and 53% approved to buy and use a CDU mattress (with 35% strong approvers).

General CDU risk perception was comparably low (M = 2.8, SD = 1.0), 29% approved to perceive risks associated with CDU products (mattress) and 4% reported high CDU product risk perception (indicated by values > 5). This indicates, that most respondents did not feel threatened by CDU product risks.

Regarding the sub-dimensions of risk perception, product quality risks were evaluated the highest (M = 4.2, SD = 1.0), followed by sustainability risks (M = 3.6, SD = 1.0), and environmental risks (M = 3.3, SD = 1.0), which were not perceived as threatening. Perceived health risks caused by CDU mattress usage were rejected (M = 2.8, SD = 1.0), i.e., participants did not believe that the CDU-mattress caused any health risks.

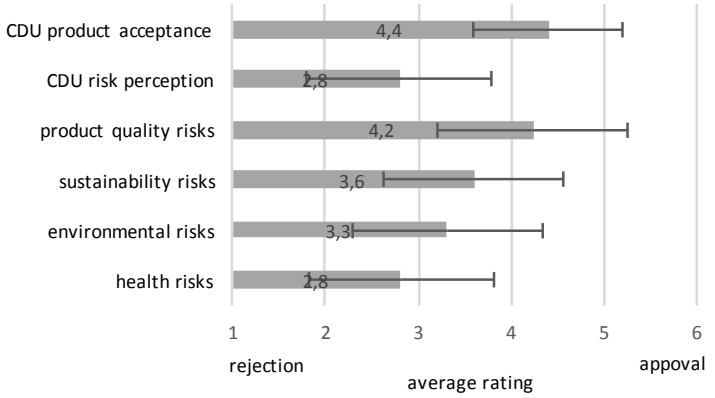

Figure 2: CDU product acceptance and risk perception ratings.

4.2. CDU risk perception

General CDU risk perception ratings were related to the ratings of the risk sub-dimensions as predictors in stepwise linear regression analyses in order to find out, which risk component affected the perception of CDU risks the most. *Health risks* (ß = 0.47, t = 7.4; $p < 0.000$) and *environmental risks* (ß = 0.41, t = 6.5; $p < 0.000$) explained $R^2 = 62\%$ of variance in general CDU risk perception ratings. Sustainability and product quality risks were excluded from the regression model, i.e., they were no significant predictors of CDU risk perception. The findings of the regression analysis indicate, that health and environmental risks are the main constituent factors in CDU risk perception.

To investigate the relationship between CDU risk perception and CDU product acceptance, bivariate correlations were conducted. The higher the risk perception of CDU, the lower was the acceptance of the mattress as a CDU product example ($r = -.35$; $p < 0.000$). A regression analysis on CDU product acceptance as criterion with the risk sub-dimensions and the general CDU risk perception as predictors explained $R^2 = 32\%$ of variance in general CDU product acceptance ratings, with product quality risks (ß = .45, t = 6.6; $p < 0.000$) and general risk perception (ß = -.29, t = 4.3; $p < 0.000$) as relevant predictors.

However, the reported findings apply for the complete sample, where inter-individual differences between respondents are not considered. Therefore, the impact of user diversity on CDU risk perception was analyzed in a next step.

4.3. Impact of user factors on CDU risk perception and acceptance

To investigate the impact of user factors on CDU risk perception, correlational analyses between risk perception ratings and user factors (sociodemographic factors, technical self-efficacy, environmentally aware behavior, level of CDU information) were calculated in a first step.

Interestingly, age and education did not have any effects on CDU risk perception and acceptance ratings. The only exception was found for a slightly lower perception of product quality risks with increasing age ($r = -.17$; $p < 0.05$). Regarding *gender* as user factor, female respondents reported a higher CDU risk perception in general ($r = -.23$; $p < 0.01$) as well as higher risk perceptions on the sub-dimensions (Table 2). CDU product acceptance was not affected by gender.

Looking at attitudinal factors, people with high levels in *environmentally aware behaviour* reported higher environmental ($r = .16$; $p < 0.05$) and sustainability risks ($r = .24$; $p < 0.01$). Further associations with general CDU risk perception or CDU product acceptance did not exist for environmentally aware behaviour. Regarding the *level of information*, more informed respondents reported to perceive lower CDU risks in general ($r = -.19$; $p < 0.05$) as well as lower health ($r = -.21$; $p < 0.05$) and environmental risks ($r = -.19$; $p < 0.01$).

Table 2: Bivariate correlations of user factors and CDU risk and acceptance ratings.

	health risks	environmental risks	product quality risks	sustainability risks	CDU risk perception	CDU product acceptance
gender (1 = male, 2 = female)	.29**	.23**	-0.05	.18*	.23**	-0.03
age	-0.06	-0.03	-.17*	-0.12	-0.06	0.02
education	-0.08	-0.56	-0.02	0.04	-0.05	-0.07
level of information	-.21**	-.19*	0.07	-0.04	-.19*	-0.00
technical self-efficacy	-.32**	-.28**	.25**	-0.14	-.36**	.24**
env. aware behaviour	0.08	.16*	-0.15	.24**	0.06	0.08

Looking at attitudinal factors, people with high levels in *environmentally aware behavior* reported higher environmental ($r = .16$; $p < 0.05$) and sustainability risks ($r = .24$; $p < 0.01$). Further associations with general CDU risk perception or CDU product acceptance did not exist for environmentally aware behavior. Regarding *level of information*, more informed respondents reported lower CDU risks in general ($r = -.19$; $p < 0.05$) as well as lower health ($r = -.21$; $p < 0.05$) and environmental risks ($r = -.19$; $p < 0.01$). The other risk sub-dimensions or CDU product acceptance were not related to the level of information. *Technical self-efficacy* showed the highest correlations with most of the CDU risk perception constructs: Except for sustainability risks, lower levels of technical self-efficacy were associated with higher ratings for general CDU risk perception ($r = -.36$; $p < 0.01$) and the respective sub-dimensions, i.e., health risks ($r = -.32$; $p < 0.01$) and environmental risks ($r = -.28$; $p < 0.01$). Interestingly higher levels of technical self-efficiency were related to a higher perception of product quality risks ($r = .25$; $p < 0.05$) and a higher acceptance of the mattress as a CDU product example ($r = .24$; $p < 0.01$).

To sum up, gender, level of information, and technical self-efficacy were identified as relevant user factors in the context of CDU risk perception.

Focusing on interrelations between the three relevant user factors, bivariate correlations revealed, that level of information ($r = -.17$; $p < 0.05$) and technical self-efficacy ($r = .42$; $p < 0.000$) were lower in females. Environmentally aware behavior was higher in women ($r = .33$; $p < 0.000$). Level of information and environmentally aware behavior as well as technical self-efficacy were not related, but lower levels of technical self-efficacy were related to higher levels of environmentally aware behavior ($r = -.2$; $p < 0.05$).

To find out, if constituent factors of risk perception differed according to relevant user factors, stepwise regression analyses were applied for gender (male vs. female) and technical self-efficacy (high vs. low technical self-efficacy).

For *male* respondents, product quality risks ($ß = .42$, $t = 4.5$; $p < 0.000$) and environmental risks ($ß = -.35$, $t = -3.79$; $p < 0.000$) explained $R^2 = 35\%$ of variance in general CDU risk perception ratings. Sustainability and health risks were excluded from the regression model, i.e. they were no significant predictors of CDU risk perception in male respondents. For *female* participants, product quality risks ($ß = .46$, $t = 7.2$; $p < 0.000$) and health risks ($ß = -.24$, $t = -3.79$; $p < 0.05$) explained $R^2 = 29\%$ of variance in general CDU risk perception ratings. The sub-dimensions "sustainability risk" and "environment risk" were excluded from the regression model.

Regarding the set of bivariate regressions for the two levels (high vs. low) of technical self-efficacy, we found for *low technical self-efficacy*, that health risks ($ß = .52$, $t = 5.8$; $p < 0.000$) and environmental risks ($ß = .38$, $t = 4.25$; $p < 0.000$) explained $R^2 = 63\%$ of variance in general CDU risk perception ratings. Sustainability and product quality risks were not relevant predictors in the regression model. For respondents with *high technical self-efficiency*, environmental risks ($ß = .49$, $t = 5.1$; $p < 0.000$) and health risks ($ß = .35$, $t = 3.7$; $p < 0.000$) explained $R^2 = 56\%$ of variance in general CDU risk perception ratings. Here, sustainability and product quality risks were no significant predictors of CDU risk perception in respondents with high levels of technical self-efficacy.

Summing up, the results indicate, that the determinants of CDU risk perception are not identical in specific user groups, but contribute in varying extent to the general CDU risk perception.

5. Discussion

CDU is a promising approach to fight greenhouse gas emissions and – to an even bigger extent – to reduce fossil resource dependency in the production of plastics and synthetic materials. Since innovative large-scale technologies are often perceived critically by the public, which might even lead to the complete rejection and open protests against the technology, the present study focused on risk perception and acceptance of a CDU foam mattress as an CDU consumer product example. The study yielded a first conceptualization of CDU-product-risk perception and the contribution of its single sub-dimensions to general CDU risk perception and to CDU acceptance, as well as an integration of individual differences (user factors) into the analysis of CDU risk perception. Based on these findings, recommendations are derived for a successful rollout of the CDU technology and its products as well as for effective accompanying communication strategies.

5.1. Risk perceptions of CDU

In general, we found a comparably positive perception and acceptance of the CDU technology and its products (mattress), with low levels of perceived risks associated with the CDU technology. For the total sample, we were able to explain major amounts of general CDU risk perception by four underlying risk determinants: health risks, environmental risks, sustainability risks and product quality risks. Knowing about the sub-determinants of risk perception is highly valuable, because it allows a more detailed understanding, why people feel threatened by a technology. Contrary to findings of risk perception research in other technology branches (e.g., nuclear -, nano- or gene technology [18], [21]), health-related and environmental fears were rather low in the sample, i.e. people did not feel threatened in their health conditions and were unconcerned regarding environmental damage caused by the CDU technology. Instead, the objection of a reduced sustainability of CDU technology in comparison to other green technologies and – most important – the perception of potential product quality risks in a CDU foam mattress (e.g., reduced ergonomic sleeping comfort or a reduced durability of the mattress) were perceived as higher risks. However, the assumption that perceived health and environmental risks can be taken from the CDU research agenda is premature. Consistently with risk perception research, perceived health and environmental risks contributed the most to general CDU risk perception. As mentioned before, the relevance of *health risks* in perceived risk perception is not surprising, since the debate about modern technologies usually centers on risks, which includes known risks as well as potential or yet unknown risks. Even though perceived risks might not be based on an objective scientific proof, the level of subjectively perceived risks of a new technology or product is an important early indicator of people's alertness to its potential hazards [25].

The significance of *environmental risks* is somewhat more surprising, because environmental risks were found to elicit lower fear levels compared to health risks [26]. One explanation for this is that environmental risks (and their communication) are judged as farther away in time and space and are more difficult to imagine and visualize, which leads to a lower involvement and urgency in people [27]. However, in the present study, environmental risks (such as environmental damage caused by the disposal of the mattress) were relevant for risk perception and therefore should be considered in CDU product scenario development and in marketing or communication activities.

The perception of *sustainability risks* of the CDU technology is also acceptance-relevant, since it doubts the usefulness of the technology in general [28]. The core argument of this risk subcomponent is the assumption that CDU is the wrong approach to reach climate protection targets. In the focus-group discussions, technically experienced participants often related the amount of CO_2-savings in CDU to the amount of global CO_2-emissions, with the resulting impression that CCU was too inefficient to be worth the efforts and investments. In this context, participants mentioned that the CDU technology was labeled as "green technology" by the industry. They assumed that CDU was a pretext to continue the operation of coal power stations one the one hand, and to hamper the research and investments in renewable energies on the other hand. Accordingly, CDU technology communication activities need to clarify the sustainability objection, e.g., by emphasizing the potential of reducing fossil resources and by developing scenarios of CDU system implementation, where the complete lifecycle of CDU products (starting from energy costs for the deposition of CO_2 to the issue of disposal) is considered.

Regarding *product quality risks*, the statements in the focus group and respondent ratings indicate that potential customers hold high quality standards when considering to use CDU products. Although not explicitly investigated, but

derived from the focus group sessions, participants do not acknowledge the "green" background of CDU products per se. Instead, they set the same expectations compared to conventional products. Referring to pricing questions, the focus group findings indicate that potential customers are not willing to pay higher prices for a "green CDU" product. On the contrary, they expect to benefit from savings in the production process (fossile ressources). Future research will have to investigate the trade-off between product features, the impact of CDU as climate-friendly technology, and pricing issues in more detail.

Finally, the relationship between risk perception and acceptance in the context of CDU technology and products was rather weak in our study. Only a small part (32%) of acceptance variance was explained by risk perception. This indicates that a) risk perception and acceptance are two distinct factors, and b) that CDU product acceptance comprises more determinants than risk perception. Considering the acceptance decision as a cost-benefit-analysis, the "benefit"-part of the equation is missing. Hence, for a holistic model of CDU acceptance, the benefits and positive affects related to the CDU technology should be empirically integrated as well (as considered in the technology acceptance framework for sustainable energy acceptance by [29]).

5.2. The impact of user factors on CDU risk perception

The inclusion of user factors revealed individual differences in CDU risk perception patterns. Interestingly, CDU perception was independent of age and education. Environmentally aware behavior was also not associated with CDU risk perception – with one exception: people with a "green lifestyle" doubted the sustainability of CDU, i.e., its contribution to climate protection goals. This finding corresponds to [11], where people with a stronger environmental worldview were also found to be a less favorable of CDU. We assume that these people either doubt the ecological benefit of CDU or that they judge it as too low compared to other sustainable technologies. Further qualitative studies will be necessary to uncover the underlying motive patterns, which contribute to a rejecting attitude.

Relevant factors, which lead to differing CDU risk perceptions are gender, technical self-efficacy, and level of information. At first sight, female potential consumers appear to feel more threatened by the CDU technology and products. However, this can also be attributed to a higher sensitivity for health-related issues in women and gender-specific reporting-effects [30]. Moreover, gender is only a carrier-variable without explanatory power. Therefore, other attitudinal variables, which are associated with gender, provide more insights into individual differences in risk perception. This applies to technical self-efficacy, which is usually lower in women (e.g., [31]). People with lower levels of technical self-efficacy often have a poor technical understanding and – accordingly - perceive higher risks with regard to technical topics due to inadequate mental models (e.g., leaking CO_2 from the mattress while sleeping) [11], [32]. One strategy might be to convey knowledge about technical details of CDU. However, risk communication research has shown that providing information to laypeople is a highly sensitive issue. Poorly designed risk communication may even provoke negative emotional responses, either due to the risk under consideration, or to certain elements of the communication, such as frightening images [11]. Enhancing trust in CDU technology and products might be another efficient way (e.g., by establishing a health and environmental quality seal) to react to higher risk perceptions in lay people with a low technical self-efficacy.

A final note refers to the level of information in the sample. People described themselves as not informed about CDU. Interestingly, the level of information was not related to gender or technical self-efficacy. Apparently, the CDU technology, its technical background, application potential, and contribution to climate protection targets are comparably unknown to the public. Thus, future research has to identify appropriate CDU communication strategies for lay people to raise the awareness and knowledge about CDU and to appropriately address risk perceptions.

5.3. Methodological considerations and future research

The present study yielded some initial, but valuable insights into risk perceptions of the CDU technology; however, since little research has been conducted yet in the field of CDU perception, some limitations remain and further research questions emerge.

We analyzed a convenience sample of participants, that was self-selected and highly educated, which limits the transferability of our findings. Hence, our study should be replicated in a larger and more representative sample, which would also allow to identify risk profiles among potential CDU consumers.

Since the present study had a strong focus on the mattress as CDU product example, future research should be extended to the acceptance of other CDU products (e.g., cosmetics, fuel, production material) and to the CCU production technology in general (e.g., the influence of different CO_2 sources on acceptance).

One final note refers to the low level of awareness of the technology in the sample and the risk of assessing weak or "pseudo" opinions regarding CDU. In the focus groups we noticed a high interest in the topic and a desire for more information. Hence, future research should be directed on the tailored, target-group specific design of information about CDU (e.g., technical and economic feasibility of CDU, sustainability and "greenwashing" issues, mental models of CO_2, etc.).

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