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The Social Acceptance Factors for Insulation Boards Produced With CO_2-Derived Foam

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The negative consequence of increased greenhouse gas emissions have incited research to focus on developing sustainable technologies to reduce the use of fossil raw material. Carbon Capture and Utilization is such a technology. It reuses captured CO_2 as raw material for the production of salable products. Beyond their technical and economic feasibility, the acceptance of these products is vital for the successful roll-out of the technology. The two-step empirical study—a qualitative preliminary study (n = 8 experts, n = 16 laypeople) and a quantitative survey study (N = 643)—described in the present paper focused on the acceptance of insulation boards produced by means of CCU by its potential Dutch and German consumers. The study aimed to quantify the level of public acceptance of the product, to identify perceived (dis)advantages, and to pinpoint the drivers behind the acceptance. In the survey, respondents evaluated cognitive and affective acceptance factors, as well as the acceptance of the use of plastic in the product. The results showed that the respondents had little knowledge on CCU, but that CCU insulation boards were nevertheless accepted rather than rejected, with the benefit perception being the common predictor for the three acceptance measures. Public communication and policy should address the product's (environmental) benefits and foster an increase in the public awareness of the technology.

Keywords: carbon capture and utilization, insulation boards, (social) acceptance, perception, step-wise multiple linear regressions, CO_2-derived products

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1 INTRODUCTION

For several years, humanity has been facing one of its greatest collective challenges: the fight against human-induced climate change. Even in light of the COVID-19 pandemic that spread through the world in 2020, the accompanying issues—i.a., constant health concerns and reduced income—, and its short-term reduction of CO_2-emissions, climate change still ranked in the top five of main national concerns in the eyes of the European citizens (European Commission, 2020). An important driver behind climate change is the increasing amount of atmospheric carbon dioxide (CO_2), which induces the Greenhouse Effect, and consequently causes the Earth's temperature to rise (Volk, 2010). If no measures are taken, global warming is expected to reach 1.5°C between 2030 and 2052 (IPCC, 2018, p. 4). Hence, there is an urgent need to take action, as was highlighted in the Paris Agreement in 2015 (United Nations Climate Change, n.d.)[1].

[1]https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

To mitigate climate change, the amount of CO_2 emissions must be reduced, e.g., by increasing the energy efficiency of buildings and reducing the use of fossil resources for energy generation (IPCC, 2018). However, the transition to the use of renewable resources takes time and a further reduction of emissions is not (yet) possible for energy-intensive industries (e.g., steel and cement industry). That is why technologies like Carbon Capture and Utilization (CCU) are also pursued in countries' policies to reduce emissions, e.g., in the Netherlands (International Energy Agency (IEA), 2020). However, whereas the technical viability and possibilities of CCU have extensively been studied (e.g., Leitner et al., 2018; von der Assen and Bardow, 2014), the research on its social acceptance is lagging behind despite its essential role for the successful roll-out of the technology (Boudet, 2019; Linzenich et al., 2019). In this context, it is important to work on understanding the acceptance of CO_2-derived products by the potential consumers, as well as which factors drive this acceptance (Jones et al., 2017b). Whereas most CO_2-based products still have a low Technology Readiness Level (TRL), and are thus not yet ready for market roll-out, the present paper focuses on a product that should be ready to be sold in 5–10 years time (Zimmermann and Schomäcker, 2017): insulation boards produced by means of CCU (Covestro, n.d.)[2]. The study aimed to gain a better understanding of how the acceptance of this product, and the technology, is formed. The findings could help the development and communication of the product, and guide the design and formulation of the necessary policies.

The present paper first provides background information on CCU and the related work with respect to acceptance research in the field. Subsequently, the empirical approach, the study procedure and the results are reported. The paper closes with a discussion of these results and a conclusion. Special attention is thereby credited to the study's implications for public information and policy issues.

2 RELATED WORK

2.1 Carbon Capture and Utilization

When applying Carbon Capture and Utilization (CCU) emitted CO_2 is captured, if necessary transported and purified, and then reused to produce salable products. Compared to Carbon Capture and Storage (CCS), in which the captured CO_2 is permanently stored, CCU has the economic benefit that the revenue generated by selling the products could offset the initial production costs (Styring and Jansen, 2011; Cuéllar-Franca and Azapagic, 2015). Keeping this economic benefit in mind, Zimmermann and Kant (2017, p. 852) defined CCU as: "A range of technologies that consume CO_2 chemically or non-chemically to provide products or services with the main objective of an economic benefit, ideally with additional environmental and social benefits." The mentioned range of CCU technologies differs for various applications and scenarios—there are several detailed review papers on these technologies, e.g., Mikulčić et al. (2019).

CO_2 can be captured from different sources, e.g., fossil-fueled power plants, and in different ways. The applied capturing method depends on the purity of the CO_2 stream, which, in its turn, also influences whether it should be purified and how it can be reused. The capturing techniques have extensively been studied and are usually divided into three categories: post-conversion capturing, pre-conversion capturing, and oxy-fuel combustion capturing (e.g., Cuéllar-Franca and Azapagic, 2015; Pieri et al., 2018).

After being transported—through pipelines or using ships, trains, or trucks—the CO_2 is either reused directly—e.g., as preservative in the food industry—or it is used as feedstock for the production of commercial products—e.g., chemical compounds like polyols (Mikulčić et al., 2019). Regarding the latter application, the produced chemicals can be used for the production of further products, e.g., polyols can be used in the production of polyurethane (PU) foams, which end up in products like mattresses or insulation boards (Artz et al., 2018; Covestro, n.d.)[2].

2.2 The Acceptance of Sustainable Energy Technologies

For a successful diffusion of CCU, its acceptance should be considered alongside the technical aspects of the technology (Boudet, 2019). Failing projects dealing with sustainable innovations—e.g., regarding CCS (van Os et al., 2014) and wind energy (Wüstenhagen et al., 2007)—have provided valuable insights into the complexity of acceptance in this field. Acceptance is defined as the (active or passive) approval of the development, implementation, and use of technologies (Dethloff, 2004). It is a highly dynamic process in which different stakeholders, including, but not limited to, the general public, continuously re-evaluate and alter their attitude (Wolsink, 2018). Regarding sustainable energy technologies, Huijts et al. (2012) introduced a model to describe how public acceptance in this field is formed. The model addresses the environmental and societal issues of energy consumption and differentiates between a set of influential factors with respect to the technology, the planning procedure, the implementation process, and attitudinal and person-specific characteristics (e.g., perceived benefits and risks, but also cognitive and affective attitudes). Previous studies have shown that a deeper understanding of acceptance issues, and the identification of the drivers behind (non-) acceptance, requires the empirical assessment of technology aspects and benefits and risk perceptions in close relation (e.g., Offermann-van Heek et al., 2018; Arning et al., 2019; Linzenich et al., 2019).

However, studying the public acceptance does not suffice, instead, acceptance research should also include different stakeholders (in line with e.g., Wüstenhagen et al., 2007; Wolsink, 2018; Zaunbrecher and Ziefle, 2016)—i.e., investors, consumers, and local communities—at different points in time. In doing so, acceptance research on CCU should aim to understand its *social acceptance*, which is defined as "the

[2]https://www.covestro.jp/en/company/attitude/myfuturecity/innovative-insulation

extent to which an innovation (e.g., a policy, technology) is endorsed or rejected by key social actors (e.g., politicians, financiers, publics)" (Jones et al., 2017b, p. 2). For studying the social acceptance of CCU, the framework by Wüstenhagen et al. (2007) has been proposed as a starting point (Jones et al., 2017b). According to this framework, social acceptance consists of three interrelated dimensions. The first dimension is socio-political acceptance, which refers to the general acceptance of technologies and policies at a broad level—i.e., by the general public, policy makers, and other key stakeholders. The second dimension is the market acceptance. This specifically refers to the acceptance by consumers and investors. The last dimension is the community acceptance which integrates the local communities that are affected because of their proximity to the technology infrastructure. The social acceptance of CCU often requires longitudinal research within each dimension and between the different dimensions (Wüstenhagen et al., 2007; Jones et al., 2017b).

2.2.1 User Diversity

When considering whether the public is willing to consider innovative and more sustainably produced products, the "user diversity" is a key factor, as the public does not represent a homogeneous mass when responding to technology innovations. Instead individuals may develop heterogeneous acceptance reactions, which depend on individual capabilities and experiences, socio-demographic characteristics—e.g., age, gender—and attitude-related characteristics—e.g., domain-related expertise, technical self-efficacy, and environmental awareness.

Regarding the acceptance of sustainable technologies and products, laypeople are more likely to perceive elevated risk for the environment and their health, which can reduce acceptance (Arning et al., 2018a). In contrast, higher levels of environmental awareness are more likely to be associated with a better acceptance of green technologies, although the direction of action of this relationship has not yet definitively been clarified (e.g., Thøgersen and Noblet, 2012).

To guide a successful roll-out of innovative and sustainable products and technologies, it is important to gain knowledge on the impact of individual factors for the acceptance of these innovations. This knowledge is also meaningful for developers and decision-makers, since it allows them to use this understanding of the individuals' perspectives and requirements in the development process.

2.3 The Social Acceptance of Carbon Capture and Utilization Technologies

Research agendas have increasingly recognized that the technical studies on CCU should be complimented with acceptance studies (Zimmermann and Kant, 2017; Boudet, 2019). This helps to anticipate societal, social, economic, or organisational frictions that could follow the technology's and products' roll-out on the market. It could also circumvent potential public resistance by learning about laypeople's underlying acceptance motives and perceptions for CCU as early in the development process as possible. Potential degrees of freedom in the technical definition can then be used to include public perceptions and requirements. However, even though the first acceptance study on CCU was already published in 2014 (Jones et al., 2014), and some have followed in the years after (e.g., van Heek et al., 2017a; Perdan et al., 2017), the body of literature on the topic still remains limited.

Regarding the socio-political acceptance, several studies provided first insights into the public's reaction to CCU. Laypeople seem to have little knowledge on CCU (e.g., Linzenich et al., 2019; Arning et al., 2019) and the majority of laypeole report to be largely unaware of CCU products (Perdan et al., 2017; Linzenich et al., 2019). However, if the concept, the technology, and the reasons for the technical development are adequately explained, laypeople generally evaluate and accept it positively (e.g., Offermann-van Heek et al., 2018; Offermann-van Heek et al., 2020). Nevertheless, a missing trust in public information and communication, as well as in public authorities, policy, and governance, might hamper the socio-political acceptance (Offermann-van Heek et al., 2018).

As for the community acceptance, a few studies addressed the imagined scenario of a CCU plant being located near the respondents' homes. In the study by Jones et al. (2017a), the participants expected that local resistance could then arise. To a certain extent, this possibility was quantitatively confirmed by Arning et al. (2019) who found that the average positive general acceptance of CCU turned into a slight rejection when the infrastructure was to be located near the respondents' homes. However, besides the worries laymen experience, a more detailed qualitative study by Perdan et al. (2017) also identified perceived benefits for a local CCU infrastructure, e.g., the improvement of local air quality and job creation.

Studies with respect to the market acceptance of CO_2-derived products found that depending on the included product(s), laymen perceive considerable barriers and risks, e.g., for mattresses (e.g., Offermann-van Heek et al., 2018; Arning et al., 2019), fuels (e.g., Engelmann et al., 2020), and drugs (Arning et al., 2018b). Some studies compared different products in order to explore which products, or product types, are preferred by laymen (Jones et al., 2014; van Heek et al., 2017a; Offermann-van Heek et al., 2018). However, since they used different product options, they resulted in inconclusive and partially contradicting results. Moreover, as it is likely that more than one CO_2-derived product will be introduced to the market, it is more valuable to gather knowledge on how these specific products, or product types, are accepted, instead of trying to understand which products are preferred.

Two specific possible CO_2-based products have previously been studied in this way. First, a few studies addressed mattresses produced with polyurethane foam that consists of polyols produced by means of CCU (e.g. van Heek et al., 2017b). The perception was found to play an important role for the acceptance of the product (Arning et al., 2017; Offermann-van Heek et al., 2018). Additionally, health- and safety concerns were identified for plastic CCU products that go beyond the concerns associated with the technology, e.g., the concern of CO_2 escaping from the product, of a decreased product quality, and of the unsustainability of the product's disposal (Arning et al., 2017; Offermann-van Heek et al., 2018). Secondly, a recent study addressed CO_2-derived fuels for road- and air-traffic (e.g., Engelmann et al., 2020). This application of CCU was also generally positively perceived and the willingness to use the fuel was impacted by the respondents' affective acceptance of the product.

Still, there are many more possible CCU products and the acceptance of most production routes thus remains unconsidered (for a review of the possible products see Baena-Moreno et al., 2019).

2.4 Research Questions and Study Design

As part of the social acceptance, the market acceptance is an important dimension to consider since the market acceptance of CCU products is essential to attain the benefits of the technology (Jones et al., 2017b). Therefore, this study contributes to studying the social acceptance of CCU by focusing on the market acceptance of a specific product: insulation boards consisting of polyurethane foam made with polyols that are produced by means of CCU[3]. In doing so, it additionally addresses a part of the socio-political acceptance of CCU, i.e., the acceptance by the general public.

Insulation boards are an especially interesting example of a CCU product, i.a., because of its additional environmental benefits. It is broadly recognized that increasing the energy efficiency of homes and other buildings is necessary to reduce CO_2-emissions (e.g., Fachausschuss "Nachhaltiges Energiesystem 2050" des ForschungsVerbunds Eneuerbare Energien, 2010; IPCC, 2018). Nevertheless, many buildings are still not, or badly, insulated. That is why the estimated global market size for thermal insulation material is projected to reach USD 38.69 billion by 2027 (Visiongain, 2017; as cited in Pavel and Blagoeva, 2018). Additionally, plastic foams are among the most used insulation materials in the EU (Pavel and Blagoeva, 2018). Altogether this shows that a market demand for PU-based insulation material exists, thus making CCU insulation boards a possibly popular CCU product.

The present study is one of the first to address the acceptance of CCU insulation boards. It is also the first quantitative acceptance study on CCU we are aware of that addresses multiple nationalities (Germany and the Netherlands). The study therefore took an explorative approach and aimed to answer the following research questions:

- **RQ_1**: How are CCU insulation boards, as well as CCU as a technology for the production of these insulation boards, perceived?
- **RQ_2**: How are CCU insulation boards accepted by its potential consumers?
- **RQ_3**: What user diversity factors serve as drivers for the acceptance of CCU insulation boards?

3 METHOD

We pursued a two-step empirical procedure. First, we carried out a qualitative interview study in which we identified the key (non) acceptance factors for the product. In order to gain a deeper understanding, we interviewed laypeople, as well as technical and field experts. We thus integrated multiple types of interviewees who sometimes have diverging views (van Heek et al., 2017a). Based on the findings of the interview study we designed a quantitative questionnaire, which was distributed in Germany and the Netherlands.

3.1 The Interview Prestudy

To identify the most relevant acceptance factors for CCU insulation boards a qualitative prestudy was conducted. This helped to gain a better understanding of the product, how it is generally perceived, and what the possible drivers behind its (non)acceptance are. The prestudy consisted of semi-structured interviews with participants from three target groups: 1) five technical experts who encountered CCU (insulation boards) to differing extents in some aspect of their work; 2) three field experts who had work-related familiarity with the insulation market, but not with CCU; and 3) 16 laypeople[4], all of whom were house owners whose occupation was neither related to CCU nor to insulation. The technical experts were selected from the available project partners of the Carbon4PUR consortium[5], the field experts were recruited by contacting a large amount of regional insulation firms of which only three were willing to participate, and the laypeople were house owners stemming from the authors' personal networks. All interviewees volunteered to participate in the interviews and were not compensated for their efforts. **Figure 1** depicts the demographics of the sample and the language in which the interviews were conducted. For the laypeople and field experts, the language of the interview reflects their nationality. The nationality of the technical experts cannot be disclosed to ensure the complete anonymity of the participants.

Before starting, the interviewees were informed that they were free to quit the interview at any time, were encouraged to express their thoughts freely, and were told that none of their answers would be wrong. If permission was granted, the interviews were recorded and transcribed.

A slightly different semi-structured interview guideline was used for each target group. In the interviews with the technical experts we talked about their experience with CCU, their perception of CCU, its climate change mitigation potential, its sustainability, and its usefulness. Additionally we asked the technical experts for their experience with CCU insulation boards, their perceived product-specific benefits and barriers, and the product's possible benefits and barriers for the customer. The interviews with the field experts first covered their experience with the insulation market and the properties of insulation materials. After an explanation on CCU and CCU insulation boards—using the same graphics and similar wording as the explanation provided in the questionnaire, see **Figure 2**—, we then also discussed their perception and acceptance of the product and its possible benefits and barriers for the customer. Finally, in the interviews with the laypeople we first discussed their knowledge on home insulation

[3]In the remainder of the present paper, this product is referred to as CCU insulation boards.

[4]Since one interview was conducted with a couple, we talked to 17 people but only conducted 16 interviews.

[5]https://www.carbon4pur.eu/

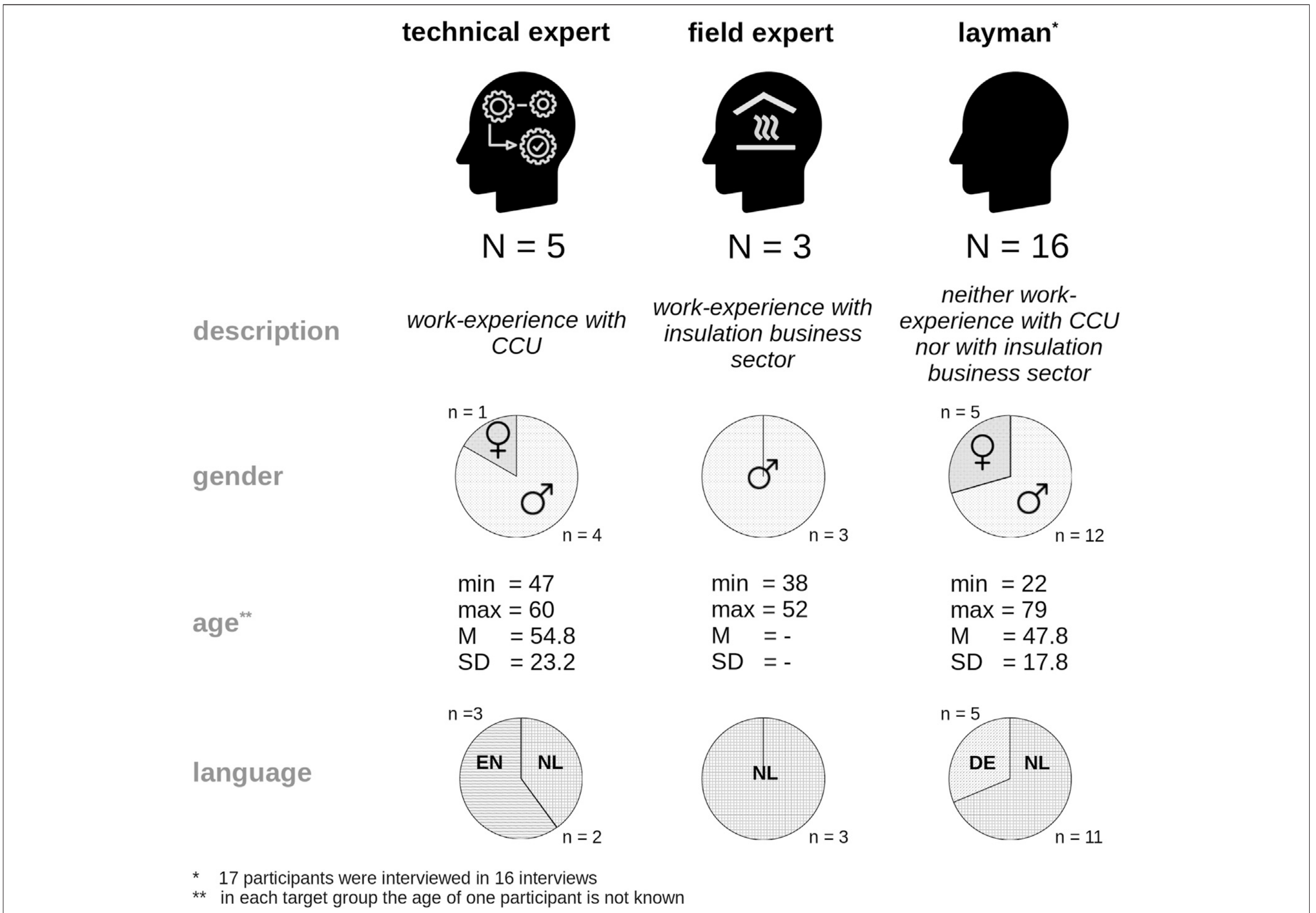

FIGURE 1 | An overview of the available descriptive data on the interviewees sorted by the target groups.

(material) and their perception of the importance of different properties of insulation material. Subsequently, we assessed their familiarity with CCU in general. After receiving the same explanation on CCU (insulation boards) as the field experts received, we asked them for their impression and perception of CCU, their purchase conditions for CCU products, their perception of its climate change mitigation potential, and their intention to use CCU insulation boards.

The subsequent analysis of the interviews provided valuable insights into the perception of CCU and CCU insulation boards. Regarding the *perceived benefits*, most of the laypeople would consider CCU insulation boards because of the environmental benefits. Almost all laymen mentioned the technology's benefit of removing CO_2 from the atmosphere, and about a third mentioned the advantage of needing less fossil resources, as represented by the following quote[6]:

> Well, on the one hand I think that removing the CO2 out of the air [is a benefit], which is a hot item at this moment. On the other hand, I believe the fact that one needs less fossil fuels [is a benefit], yes, which we will eventually run out of anyway so if you use those less that also has its benefits. So those two components, I think those are most important. (male, 51, layman)

It was also mentioned that CCU could help politics deal with the climate crisis. Other, less often, mentioned benefits included less reliance on foreign countries for fossil resources, a possible price benefit if CO_2 is a cheaper feedstock than fossil resources are, and the possibility to annul unpopular restrictions caused by the climate crisis[7]. Several more benefits were mentioned by the technical experts: CCU can have an economic benefit for companies because of the reuse of their waste stream and resulting reduced costs, it can create job opportunities, and it

[6]In the present paper, all quotations have been translated to English if necessary.

[7]It is important to note that this statement was a result of the Dutch interviews that were conducted when protests by the farmers were a frequently covered topic in the Netherlands. Although their protests addressed the proposed rules to limit the agricultural nitrogen emissions, the participants in the interviews mentioned them in relation to CO_2.

Please read the following explanation carefully
Carbon Capture and Utilization (abbreviated: CCU) is the name for a set of techniques that capture carbon dioxide (CO_2) from the air, for example, from steel-factory emissions, and use this as feedstock for salable products. In this way, carbon dioxide can, for example, be reused to produce chemicals like methanol and urea, but also to produce certain types of plastics that can be used in products like building materials and mattresses.
In Figure 1 you can see an abstract representation of how insulation boards are normally produced. Normally, fossil fuels, like oil, are used as the raw material for the plastics that are used in insulation boards.
Figure 2 shows that for the production of insulation material through *Carbon Capture and Utilization* (abbreviated: CCU), the captured CO_2 combined with a **smaller amount** of fossil fuels are the raw materials for the production of the used plastic.
During the last two question blocks, the insulation boards that are produced through *Carbon Capture and Utilization* are called **CCU-insulation boards**.

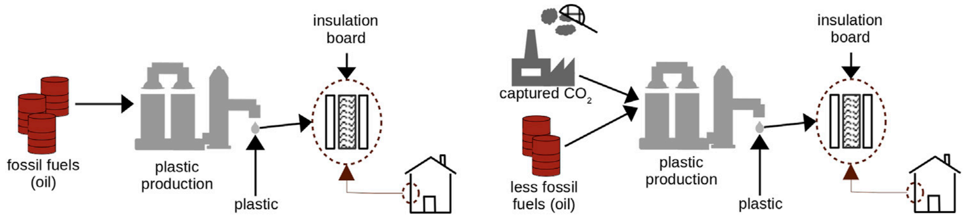

Figure 1: production of "normal" insulation boards **Figure 2: production of CCU-insulation boards**

FIGURE 2 | The English translation of the explanation on CCU that was provided in the questionnaire.

might generally raise people's awareness of how a by-product can be reused.

When it comes to the *perceived barriers*, the most frequently mentioned concern was the use of plastic in CCU insulation boards. This resulted in questions about the product's sustainability, as represented by the following quote:

> Which concerns? That they are still producing a lot of plastic even though they are forbidding plastic everywhere and they still produce plastic. (male, 74, layman)

For the two laymen who indicated they would not consider using the product in their home, the use of plastic was provided as the reason. Further, it was noted that CCU should not become an excuse for factories to keep on emitting CO_2 instead of trying to reduce their emissions. Neither should investments in CCU delay investments in entirely sustainable technologies. Moreover, some laypeople expressed unease because they expected CO_2 could leak from the product and be dangerous for people:

> [. . .] in relation to the environment, CO2 has something negative. [. . .] and now you are taking it out of the atmosphere and using it in products, for example, for the insulation of your house, but it has obviously not been researched yet what the possible effects could be and if the CO2 could also escape from the products again. I would want to know that. Because it might have health risks. (male, 52, laymen)

Further concerns regarded the energy-intensiveness of CCU, the possibility that the new production process produces harmful by-products, and that it will not be enrolled on a large enough scale to be beneficial. Moreover, also regarding the product's sustainability, doubts about its disposal were expressed.

When it comes to *materials' properties*, most participants (laypeople and experts) indicated that *price* is a decisive factor when choosing an insulation material. Other properties that were frequently mentioned as being important for the choice were that the product causes *no health risks*, its *fire safety*, and its *insulation value*. Interestingly, the laymen without insulation experience all indicated they would consider *health risks* and *fire safety* whereas both factors were not considered by roughly half of the laymen who insulated before. None of the laymen came up with the insulation material's composition or production method as something they would consider. Furthermore, ease of installation and lifespan were also more frequently regarded as being important than as not being important. Regarding the latter, the participants mentioned they would not want the insulation material to have to be replaced frequently.

On the basis of the interviews, we identified three categories that are relevant for the market acceptance and adoption of CCU insulation boards: the perceived benefits, and barriers, of CCU and CCU insulation boards, and the properties of the insulation material. While the interview study succeeded to confirm previous findings of studies on the acceptance of CCU for CCU insulation boards as a product example, it also provided new insights: i.e., the association of the use of plastic with the acceptance of CCU insulation boards.

3.2 The Questionnaire

Using the results of the prestudy, as well as knowledge gathered from previous studies on the acceptance of CCU (products) (e.g., Arning et al., 2018a), an online questionnaire was designed as a measuring instrument. In line with the target groups of the study, the questionnaire was available in Dutch and in German. Prior to running the survey, the questionnaire was checked for technical correctness by CCU experts, and for comprehensibility and wording by German and Dutch native speakers. Furthermore, the ethical acceptability of the study's aims and procedures was checked and approved by the ethical board of the Faculty of Humanities at RWTH Aachen University.

Before starting, the respondents received several screening questions: experience with house ownership, experience with insulation, nationality, and age. The screening enabled the collection of similar amounts of Dutch and German respondents and ensured that there would be a high enough share of house owners and respondents with retrofit experience in the sample. Additionally, respondents who were too young to participate (age < 18 years) could be redirected.

The screening was followed by a brief introduction on the topic of the study. The respondents were also reminded of their rights and informed on how the collected data would be dealt with (especially with regard to the requirements of data privacy, closely in line with the data privacy standards of the DSVGO (Schwartz, 2019)).

Upon starting with the main part of the questionnaire, demographic information was collected (gender, education, occupation), followed by the measurement of several further user diversity factors using multiple-item measurements.

First, *self efficacy*—which refers to how well people can handle difficulties in everyday life—was included using the instrument by Beierlein et al. (2014). To provide a second self efficacy perspective, *technical self efficacy*—which refers to how confident people feel when using new technologies—was then measured using four items of the instrument by Beier (1999). These user diversity factors were followed by two environment-related factors. The first was a personal indication of how environmentally aware the respondents behaved, *environmental behavior*. To measure this, four items were developed based on items used by the European Commission (2019), p. 42–52) (inspired by Linzenich et al., 2019). As the second environmental aspect, *environmental concern* was measured using several items from the revised NEP scale by Dunlap et al. (2000), as well as an item on the disbelief that an individual can make a difference in the fight against climate change and other ecological problems (inspired by the scale on self efficacy regarding environmental action by Heath and Gifford, 2006).

In the next part of the questionnaire, the respondents received an abstract explanation on CCU and CCU insulation boards, as depicted in **Figure 2**. The instruction text was kept neutral and was checked for clearness and comprehensibility by technical experts. The respondents were subsequently requested to share their perception of CCU insulation boards. To do so, ten statements on the benefits of the product, as well as eleven statements on its barriers, were extracted from the prestudy (described in subsection 3.1).

TABLE 1 | Cronbach's α and descriptive statistics for the retained and computed factors.

		# of items	α	*M*	*SD*
1	self efficacy	3	0.92	3.72	0.83
2	technical self efficacy	4	0.88	3.02	1.18
3	environmental behavior	4	0.86	3.57	0.98
4	environmental concern	4	0.78	3.81	0.80
5	climate change belief/responsibility	2	0.70	3.13	1.28
6	barriers	11	0.90	2.34	0.84
7	benefits	10	0.94	3.30	0.86
8	cognitive acceptance	3	0.94	3.13	0.98
9	affective acceptance	7	0.92	3.46	0.94
10	acceptance of the use of plastic	4	0.89	2.90	1.02

Finally, the respondents evaluated their acceptance of CCU insulation boards. The market acceptance of CCU insulation boards by the consumers should ultimately be an indicator for their decision to adopt the product. Such a decision is likely affected by a combination of cognitive and affective evaluations of the product (Finucane et al., 2000). To measure the acceptance we therefore included whether the potential consumers would tolerate or consider using the product, as well as their feelings towards it. First, we used several items on the respondents (cognitive) favourable reception of the product, i.e., their willingness to use, tolerate, and recommend it. Secondly, using a six-point semantic differential (Osgood, 1964), the respondents indicated their affective evaluation of CCU insulation boards. The used adjective pairs were thereby inspired by the instrument used by Linzenich et al. (2019). Additionally, five items addressed the acceptance of the use of plastic in CCU insulation boards. These were based on the analysis of the qualitative prestudy.

All items can be found in the **Supplementary Material**. In the scope of the present paper, the items of all multiple-item measurements were randomized and evaluated using a six-point Likert scale. Except for the questions on the benefits and barriers of CCU insulation boards—which were randomized among each other—the respondents received all questions in the same order. As a final note, the questionnaire only covered the use of CO_2, although CCU also reuses captured CO. This choice was made to minimize the complexity of the topic in the eyes of the participants (laypeople). Additionally, for similar reasons, the polyurethane foam used in the end product was referred to as plastic.

3.3 Data Preparation

3.3.1 Data Cleaning

After collecting responses with the help of the paid services of a market research company, the data was cleaned to ensure the quality of the final dataset used for analysis. In total, $N = 2{,}847$ responses were collected. In the quality check, incomplete cases were first removed. Subsequently, we removed the speeders. Respondents were marked as speeders if the time they took to complete the questionnaire was less than 65% of the median

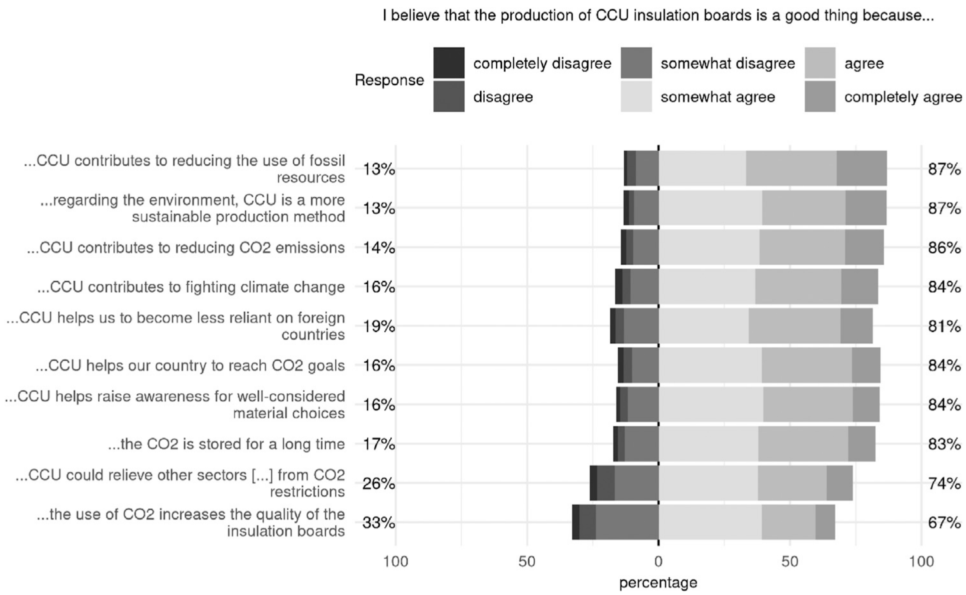

FIGURE 3 | A visual representation of the shares of the given answers to the statements on the benefits of CCU insulation boards (N = 643).

duration. A difference was thereby made between respondents who never owned a house before, house owners without insulation experience, and house owners with insulation experience, since these three groups received a different amount of questions, e.g., questions asking for details on their house ownership and retrofit experience. Finally, the remaining cases were manually checked for unrealistic answering patterns and some more responses were removed on these grounds. This procedure resulted in a final dataset of N = 643 complete responses with sufficient data quality to be included in the statistical analysis.

3.3.2 Data (re)coding and Construct Building

Since Germany and the Netherlands have different educational systems, the question on the highest achieved level of education differed in both versions of the questionnaire. We therefore first computed an education construct by sorting the respondents in a group with a high level of education and one with a low level of education using the ISCED scale as a guideline (Eurostat Statistics Explained, n.d.)[8]. Since the Dutch question did not differentiate between different levels of secondary education, we chose to view both the ISCED low and medium group as low. The grouping can be found in the **Supplementary Material**.

We then (re)coded the data so that for all multiple-item measurements, the most negative answer was coded as 0, and the most positive as 5. The middle of the scales thus lay at 2.5. The (re)coded data was used to conduct an exploratory factor analysis using principal axis factoring as the extraction method and Oblimin rotation as the rotation method. The sampling adequacy, as indicated by the Kaiser-Meyer-Olkin Measure (KMO), was marvellous (KMO = 0.93). All individual items were adequate for the analysis (with KMO values for the individual items >0.7, well above the minimum of 0.5 (Kaiser and Rice, 1974, as cited in Field, 2018, p. 1014). Factors were extracted on the basis of Kaiser's criterion (eigenvalue > 1) which was possible since the average communalities were >0.6 (Field, 2018, p. 1030).

Before computing the constructs, we tested their reliability using Cronbach's α. Only factors with α > 0.7 were computed by taking the mean of the included variables. In that way, we identified and computed ten constructs. In **Table 1** the descriptive statistics, as well as the value for Cronbach's α, are depicted for these constructs. Additionally, which items were included in the constructs, as well as their factor loadings and descriptive statistics, can be found in the **Supplementary Material**.

3.4 The Sample

The sample consisted out of n = 331 (51%) German respondents and n = 312 (49%) Dutch respondents. Of these respondents, 57% were male and 43% female and the ages ranged between 18 and 87 years, with an average of M = 55.8 (SD = 14.5). There were more respondents who completed a low level of education (60%) than ones who completed a high level of education (40%). Although, the majority of the sample was employed when taking the questionnaire (52%), a relatively large part of the respondents were retired (37%). The remaining respondents were either unemployed (9%) or students (2%). In addition, most respondents were house owners (71%). About half of the house owners had experience with retrofitting (34% of the entire sample) and the other half did not (37% of the entire sample).

[8]https://ec.europa.eu/eurostat/statistics-explained/index.php/International_Standard_Classification_of_Education_(ISCED)#Implementation_of_ISCED_2011_.28levels_of_education.29

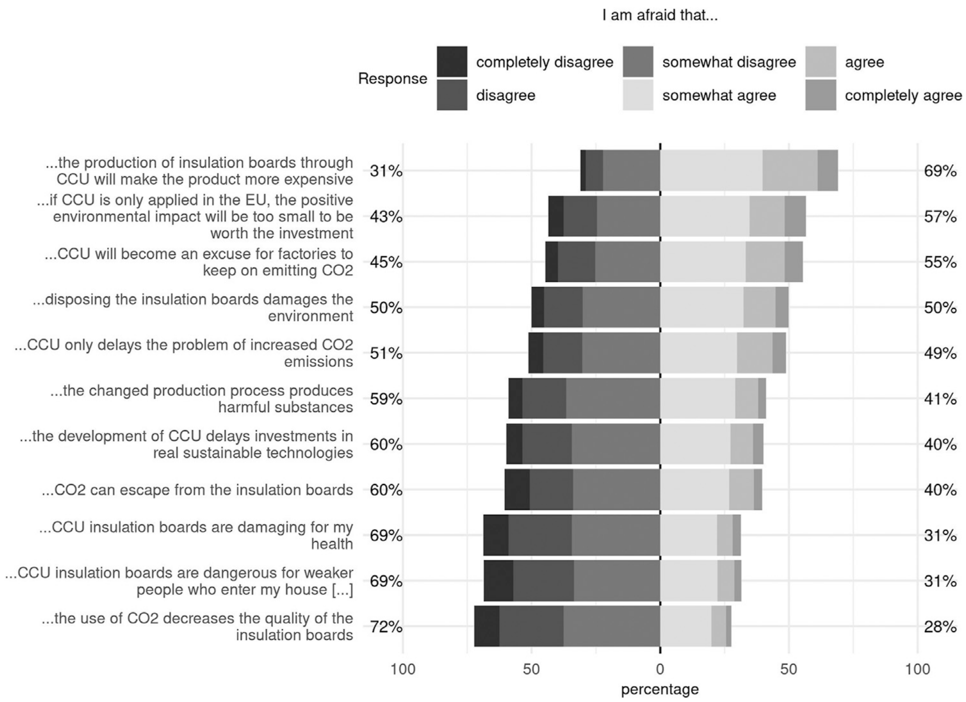

FIGURE 4 | A visual representation of the shares of the given answers to the statements on the barriers of CCU insulation boards (*N* = 643).

Finally, before receiving the explanation, on average, the respondents felt badly informed about CCU (*M* = 0.65, *SD* = 1.20). The sample's average scores for further (user diversity) factors included in the analysis are depicted in **Table 1**.

3.5 Statistical Approach

After the data preparation, we analyzed the gathered data using both descriptive (means, standard deviations, frequencies, and percentages) and inference statistics. The level of significance was set at 5%.

We ran step-wise multiple linear regressions using bidirectional elimination to identify which factors predict the acceptance of CCU insulation boards. For the identified models, we reported the adjusted R^2 and the F-statistic and significance level. Additionally, for each of the predictors, we reported the following coefficients: the unstandardized beta (*B*), the standard error for the unstandardized beta (*SEB*), the standardized beta (β), the t-test statistic (t), and the probability value (*p*). The β value thereby indicates the strength and direction of the predictor's relationship with the dependent variable. We also calculated the Variance Inflation Factor (*VIF*) and Tolerance statistic (*T*) as regression diagnostics. This showed us that none of the regression models were effected by multicollinearity, since all $VIF < 10$ and $T > 0.01$ (Bowerman and O'Connel, 1990, as cited in Field, 2018, p 534).

To take a closer look at the model predictors, we additionally calculated Pearson correlations, independent samples t-test, or one-way independent ANOVAs with the Bonferroni post-hoc test, depending on the data type. For the independent samples t-tests and ANOVAs we calculated *r* as the effect size. Additionally, we conducted several one-way t-tests to calculate whether variable means significantly differed from the midpoint of the scale. For these one-way t-tests, Cohen's *d* was calculated as effect size. The effect sizes, as well as the correlation coefficients, can be interpreted using the benchmarks provided by Cohen (1988, 1992) (as cited in Field, 2018, p. 178–180): ± 0.1 (small effect), ± 0.3 (medium effect), ± 0.5 (large effect).

4 RESULTS

This section starts with the descriptive analysis of the perception of CCU insulation boards using the evaluation of the statements on its benefits and barriers. Subsequently, the descriptive analysis of the different aspects of the acceptance of the product is outlined. Finally, the linear regressions and subsequent tests that were used to gain an understanding on how the acceptance is formed are described.

4.1 The Perception of CCU Insulation Boards

For the analysis of the perception of CCU insulation boards we referred to the single benefit and barrier statements. Since the mean evaluations of these statements—which can be found in the **Supplementary Material**—can be misleading, we looked at the shares of agreeing and disagreeing attitudes. In **Figures 3**, **4** the share of given answers have been depicted for the benefit and barrier statements, respectively.

We see that for all benefits, more than two thirds of the respondents agreed to the statement and that most statements were evaluated similarly. CCU technology's contribution to reducing the use of fossil fuels was the best evaluated benefit. Of the 87% of the respondents who tended to agree to the statement, 19% even completely agreed. This was closely followed by CCU being perceived as a more sustainable production method. That CCU could relieve other sectors from CO_2 restrictions and that the quality of the insulation boards are increased by the use of CO_2 were evaluated slightly less positively than the other statements. For these statements, some more respondents tended to disagree, although the largest part still agreed.

For the barriers we see a more divers evaluation. The least perceived barrier referred to the decreased quality of the insulation boards caused by the use of CO_2. A large part of the respondents also disagreed to the two barrier statements that questioned whether the product would be safe for people's health. Whether CO_2 can escape from the insulation boards, whether the development of CCU delays investments in real sustainable technologies, and whether the new production process produces harmful substances were rejected more hesitantly, with (about) 60% tending to disagree to the statements. Regarding the sustainability of CCU and CCU insulation boards, the respondents' opinions seemed to be divided. With a (near) 50:50 distribution of agreeing and disagreeing attitudes on whether CCU only delays the problem of increased CO_2 emissions and whether disposing CCU insulation boards damages the environment. Moreover, some more respondents tended to agree than disagree that CCU will become an excuse for factories to keep on emitting CO_2 and that if it is only applied in the EU, the positive environmental impact will be too small to be worth the investment. Finally, most respondents tended to fear that the production of insulation boards through CCU will make the product more expensive.

4.2 The Acceptance of CCU Insulation Boards

We measured three acceptance related constructs: *cognitive acceptance*, *affective acceptance*, and *acceptance of the use of plastic*. The *cognitive acceptance* thereby consists of items related to the direct (cognitive) willingness to use/tolerate the product. On average, the respondents accepted the use of CCU insulation boards rather than rejecting it ($M = 3.13$, $SD = 0.98$). The sample's mean cognitive acceptance was significantly higher than 2.5, the midpoint of the scale ($t(642) = 16.4$, $p < 0.001$, $d = 0.65$).

The construct for the *affective acceptance* included the evaluation of seven adjective pairs which were presented as a semantic differential. It thus measured the feelings the respondents had towards CCU insulation boards. On average, the respondents had positive feelings about the product rather than negative ones ($M = 3.46$, $SD = 0.94$). The sample's mean affective acceptance was significantly higher than the midpoint of the scale ($t(642) = 25.9$, $p < 0.001$, $d = 1.02$). As **Figure 5** shows, the product was perceived as being acceptable, useful, and sensible. To a lesser extent, the respondents also believed in its sustainability, harmlessness, eco-friendliness, and that it is (health)risk free.

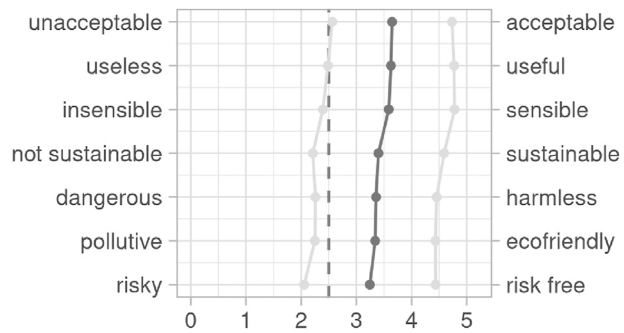

FIGURE 5 | The affective evaluation of CCU insulation boards ($N = 643$). The dark line indicates the mean evaluation and the lighter lines the standard deviation to both sides.

Finally, the *acceptance of the use of plastic* included statements that measured whether the respondents would accept/mind the use of plastic in CCU insulation boards. The use of plastic was accepted rather than rejected ($M = 2.90$, $SD = 1.02$) and the sample's mean significantly differed from the midpoint of the scale ($t(642) = 9.95$, $p < 0.001$, $d = 0.39$). The fact that CCU insulation boards are a building material was barely seen as a reason for why the use of plastic would not be minded ($M = 2.74$, $SD = 1.18$). In comparison, the fact that CCU is a more sustainable production method ($M = 2.92$, $SD = 1.13$) and that CCU insulation boards have a long lifespan ($M = 2.93$, $SD = 1.16$) were slightly better evaluated as excuses for the use of plastic. Finally, the respondents also somewhat felt like they would choose an insulation material which contains plastic if it has the best properties (e.g., insulation value, price and fire safety) ($M = 3.01$, $SD = 1.19$).

4.3 The Impact of User Diversity Factors

To analyze which perceptions and user diversity factors contribute most to the formation of an acceptance judgement for CCU insulation boards, step-wise multiple linear regressions were calculated. We thereby started by using the cognitive acceptance as the dependent variable, since a cognitive acceptance would be a prerequisite for the product to be successful. This resulted in a model that explained 57% of the variance for the evaluation of the cognitive acceptance ($F(3, 639) = 289.6$, $p < 0.001$). The model is depicted in **Table 2**. The cognitive acceptance was best predicted by the affective acceptance, followed by the acceptance of the use of plastic, and finally the benefit perception (excluded variables: *barriers, environmental concern, environmental behavior, climate change belief/responsibility, technical self efficacy, self efficacy, age, gender, education, experience, nationality*).

The subsequently calculated Pearson correlations also show that the higher the affective acceptance ($r = 0.70$, $p < 0.001$), the acceptance of the use of plastic ($r = 0.53$, $p < 0.001$), and/or benefit perception ($r = 0.57$, $p < 0.001$), the higher is the cognitive acceptance of CCU insulation boards.

In a next step, we looked at how these three predicting factors for the cognitive acceptance could be predicted. First, for the

TABLE 2 | Step-wise multiple linear regression model for the cognitive acceptance of CCU insulation boards: Adjusted R^2 = 0.57 (N = 643)

	B	*SEB*	*β*	*T*	*VIF*	*t*	*p*
constant	−0.033	0.11				−0.29	<0.77
affective acceptance	0.49	0.036	0.46	0.58	1.74	13.7	<0.001
acceptance of the use of plastic	0.22	0.029	0.23	0.76	1.31	7.74	<0.001
benefits	0.26	0.036	0.22	0.66	1.53	7.04	<0.001

TABLE 3 | Step-wise multiple linear regression model for affective acceptance of CCU insulation boards: Adjusted R^2 = 0.63 (N = 643)

	B	*SEB*	*β*	*T*	*VIF*	*t*	*p*
constant	1.80	0.15				12.3	<0.001
cognitive acceptance	0.38	0.03	0.39	0.51	1.95	11.7	<0.001
barriers	−0.31	0.029	−0.28	0.84	1.19	−10.5	<0.001
benefits	0.27	0.032	0.25	0.66	1.50	8.45	<0.001
acceptance of the use of plastic	0.093	0.027	0.10	0.70	1.41	3.50	<0.001
nationality	−0.12	0.046	−0.062	0.98	1.02	−2.55	0.011
experience	0.073	0.029	0.055	0.99	1.01	2.54	0.011

TABLE 4 | Step-wise multiple linear regression model for the acceptance of the use of plastic in CCU insulation boards: Adjusted R^2 = 0.36 (N = 643)

	B	*SEB*	*β*	*T*	*VIF*	*t*	*p*
constant	2.14	0.27				7.8	<0.001
cognitive acceptance	0.36	0.048	0.34	0.46	2.18	7.39	<0.001
climate change belief/responsibility	−0.16	0.028	−0.20	0.82	1.23	−5.69	<0.001
affective acceptance	0.20	0.055	0.19	0.38	2.62	3.71	<0.001
environmental behavior	−0.11	0.037	−0.11	0.79	1.27	−3.07	0.002
benefits	0.12	0.049	0.11	0.56	1.80	2.50	0.013
barriers	−0.11	0.046	−0.094	0.68	1.46	−2.48	0.013
age	−0.006	0.002	−0.079	0.98	1.02	−2.50	0.013

TABLE 5 | Step-wise multiple linear regression model for the benefit perception for CCU insulation boards: Adjusted R^2 = 0.45 (N = 643)

	B	*SEB*	*β*	*T*	*VIF*	*t*	*p*
constant	−0.23	0.22				−1.04	0.30
affective acceptance	0.32	0.042	0.35	0.41	2.46	7.65	<0.001
cognitive acceptance	0.24	0.038	0.28	0.45	2.23	6.44	<0.001
environmental behavior	0.14	0.032	0.16	0.64	1.55	4.35	<0.001
barriers	0.12	0.036	0.11	0.69	1.44	3.28	0.001
nationality	0.19	0.055	0.11	0.84	1.19	3.43	<0.001
climate change belief/responsibility	0.064	0.023	0.096	0.74	1.25	2.85	0.005
acceptance of the use of plastic	0.079	0.031	0.094	0.64	1.56	2.57	0.010
environmental concern	0.097	0.039	0.090	0.63	1.57	2.46	0.014

affective acceptance we found a model that explained 63% of the variance ($F(6, 636) = 180.7$, $p < 0.001$). The model consisted of six predictors and is depicted in **Table 3**. The cognitive acceptance best predicted the affective acceptance, followed by the barrier perception, the benefit perception, and the acceptance of the use of plastic. Finally, nationality and experience with house ownership/insulation played a small part in predicting the affective acceptance as well (Excluded variables: *environmental concern, environmental behavior, climate change belief/responsibility, technical self efficacy, self efficacy, age, gender, education*). The higher the cognitive acceptance, benefit perception ($r = 0.58$, $p < 0.001$), and the acceptance of the use of plastic ($r = 0.48$, $p < 0.001$), and the lower the barrier perception ($r = -0.52$, $p < 0.001$), the higher the affective acceptance. Regarding nationality, compared to the Dutch respondents ($M = 3.32$, $SD = 0.92$), the German respondents ($M = 3.59$, $SD = 0.94$) scored slightly and significantly higher ($t(641) = 3.77$, $p < 0.001$, $r = 0.15$). The affective acceptance also significantly differed for the experience with house ownership/insulation (no houseowners: $M = 3.30$, $SD = 0.98$; houseowners without experience: $M = 3.48$, $SD = 0.92$; houseowners with experience: $M = 3.57$, $SD = 0.92$; $F(2, 640) = 4.02$, $p = 0.018$,

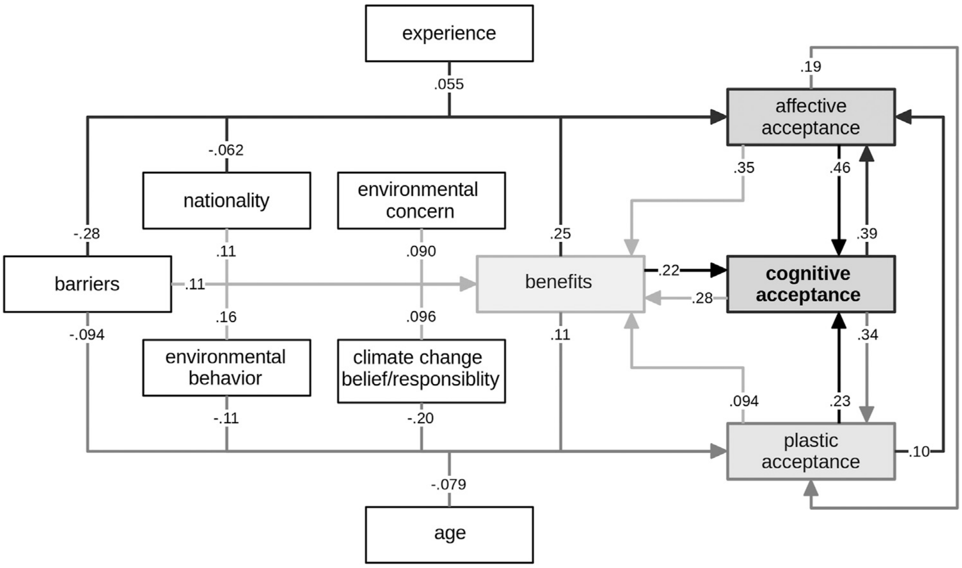

FIGURE 6 | The visualization of the combined results of the step-wise multiple linear regressions for the complete dataset (*N* = 643). The values on the arrows indicate the standardized beta coefficient of the respective relationship, as can also be found in **Table 2**–**5**

$r = 0.11$). The Bonferroni post-hoc test thereby showed that only the respondents who were not houseowners and the houseowners with insulation experience significantly differed ($p = 0.015$).

Next, for the acceptance of the use of plastic, we found a model with seven predictors that explained 36% of the variance ($F(7, 635) = 53.7$, $p < 0.001$). The model is depicted in **Table 4**. The acceptance of the use of plastic in CCU insulation boards was best predicted by the cognitive acceptance, followed by the climate change belief/responsibility, affective acceptance, environmental behavior, and the perception of the benefits. Moreover, the perception of the barriers and age also had a small effect (Excluded variables: *environmental concern, technical self efficacy, self efficacy, nationality, gender, education*). The higher the climate change belief/responsibility ($r = -0.13$, $p = 0.001$), environmental behavior ($r = -0.032$, $p = 0.53$), barrier perception ($r = -0.38$, $p < 0.001$), and age ($r = -0.079$, $p = 0.046$), the lower the acceptance of the use of plastic. Moreover, the higher the cognitive acceptance, affective acceptance, and perception of the benefits ($r = 0.35$, $p < 0.001$), the higher the acceptance of the use of plastic.

Finally, we found a model with eight predictors that explained 45% of the variance of the perception of the benefits ($F(8, 634) = 67.7$, $p < 0.001$). The model is depicted in **Table 5**. The benefit perception was best predicted by the affective acceptance, followed by the cognitive acceptance, environmental behavior, the barrier perception, and nationality. To a lesser extent, it was also predicted by the respondents' climate change belief/responsibility, acceptance of the use of plastic, and environmental concern (Excluded variables: *technical self efficacy, self efficacy, age, gender, education*). The higher the respondents' affective acceptance, cognitive acceptance, environmental behavior ($r = 0.33$, $p < 0.001$), climate change belief/responsibility ($r = 0.22$, $p < 0.001$), acceptance of the use of plastic, and environmental concern ($r = 0.24$, $p < 0.001$), the higher their benefit perception. The direction of the relationship between the benefit and barrier perception is positive as well in the model, although the correlation between both variables is negative ($p = -0.22$, $p < 0.001$). Finally, regarding nationality, the German respondents had a slightly higher benefit perception ($M = 3.35$, $SD = 0.86$) than the Dutch ones ($M = 3.25$, $SD = 0.86$). However, this difference between both nationalities was not significant ($t(641) = 1.60$, $p = 0.11$, $r = 0.063$).

In **Figure 6** the combined results of the regression analyses have been visualized.

5 DISCUSSION

Carbon Capture and Utilization (CCU) is an approach to capture and subsequently reuse CO_2. The social acceptance of the technology and resulting products is a prerequisite for its successful roll-out. The present study contributed to studying the social acceptance of CCU by focusing on the market acceptance—and socio-political acceptance by the general public—of one example of a CCU end-product: insulation boards (Wüstenhagen et al., 2007; Covestro, n.d.)[2].

The study applied a mixed-method procedure by first conducting a qualitative pre-study in which technical experts, field experts and laypeople were interviewed, and subsequently using these results to design an online questionnaire. We collected 643 responses from German and Dutch participants, which were used to analyze the perception and acceptance of CCU insulation boards. The study resulted in a better understanding of the drivers behind the acceptance. This knowledge can be used to tailor public information and communication concepts and to inform communal and policy strategies for the support of CCU products.

5.1 The Acceptance of CCU Insulation Boards

Overall, CCU insulation boards were accepted fairly well (RQ_2). In the present study, acceptance was assessed using three components: cognitive acceptance, affective acceptance, and the acceptance of the use of plastic in the product.

The respondents' cognitive acceptance refers to their indicated willingness to consider using the product. This is likely one part of people's ultimate decision to adopt a product (Finucane et al., 2000) and therefore important to consider early on. On average, the respondents' cognitively accepted rather than rejected CCU insulation boards, but they did not score particularly high, which corresponds to the pattern of findings in other studies on CCU products (Arning et al., 2018a). In view of the fact that CCU insulation boards are not yet available on the market and therefore no further diffusion-promoting aspects are effective—e.g., possibility of testing, observability of benefits (Rogers, 1983)—, it can, at this point in time, be assumed that there is a positive willingness to accept this CO_2-based product. However, it must be remembered that the respondents' level of knowledge about CCU and was very low. Although technical information on CCU and CCU insulation boards was provided in the study to ensure the assessment of valid acceptance evaluations (de Best-Waldhober et al., 2009), it should be recognized that this is an initial acceptance reaction. Its characteristics and stability should be further studied in the course of the market roll-out of CCU products.

The respondents' affective acceptance refers to their feelings about CCU insulation boards and is the other likely part of people's decision to adopt a product (Finucane et al., 2000). To measure these feelings, a semantic differential with several opposing adjective pairs was used. This showed that overall, the feelings CCU insulation boards evoked were positive. It was particularly perceived as an acceptable, useful, and sensible product. Compared to the findings of Linzenich et al. (2019), who investigated the affective acceptance of CCU technology infrastructure in comparison to CCS infrastructure, it is noticeable that the affective acceptance of CCU insulation boards as a product option is significantly more positive. This suggests that the product level is more accessible to the public when introducing sustainable technologies and is more positively valued due to the perception of personal benefits. When introducing and communicating sustainable technology infrastructures, attention should therefore also be directed to the product level, as higher affective acceptance levels can be assumed here.

Finally, the acceptance of the use of plastic was so far not considered in any other study on the CCU technology- or product acceptance. Instead, this acceptance-relevant aspect was retrieved from the results of the preliminary interview study in which several participants questioned the lower sustainability of CCU insulation boards because of the use of plastic in the product. In recent years, an increasingly critical attitude towards plastic (Filho et al., 2021), especially towards plastic pollution (Soares et al., 2021), as well as a turn towards more natural (building) materials (e.g., Takano et al., 2014) can be observed. In fact, public rejection of plastic products may act as a serious barrier to the market success of CCU-based plastic production in the future. On the other hand, (more) sustainably produced plastic products might offer a solution to possible acceptance problems for plastic-containing building material. Here, further studies are necessary that, in addition to the acceptance parameter, also include other techno-economic and ecological criteria related to the entire life cycle of the product (von der Assen and Bardow, 2014).

The successful adoption of CCU insulation boards does not only require the acceptance of the application of the CCU technology, but also the acceptance of a polyurethane-containing material for insulation in general. Although the respondents' evaluation of this aspect of acceptance was somewhat lower than their evaluation of cognitive and affective acceptance, they still accepted the use of plastic rather than rejecting it. Based on the evaluation of the different statements on the use of plastic, it is likely that the acceptance of the use of plastic is highest, when the product has better material properties (like insulation value, price, and fire safety) than other, more sustainable, materials. However, future research is necessary to validate this assumption. Such studies should aim to understand the trade-offs consumers make when choosing a building material (or other product), by using a choice-based conjoint analysis which, besides sustainability, includes material properties like price and lifespan. This would help to get a more realistic idea of people's decision making when choosing a building material, and thus also of the importance of sustainability compared to traditional quality criteria. However, it does not suffice to only consider end users. Instead, the experience and attitudes of intermediaries—e.g., craftspeople, architects, builders, tradesmen, DIY stores and energy consultants—towards sustainable and "green" products seem to be of utter importance (Kundurpi et al., 2021; Vidmar, 2021; Zaunbrecher et al., 2021). A recent study by Zaunbrecher et al. (2021) explored the role of intermediaries when it comes to consumers' retrofitting decisions. The study showed that intermediaries can positively influence sustainability and energy efficiency measures given that these "change agents" are informed about CCU-based materials (cognitive component) and are open to innovations in the building sector. In order to foster the successful roll-out of environmentally friendly and sustainable insulation materials, future studies should therefore aim to collect the attitudes towards risks and innovations of this important group of stakeholders.

5.2 Acceptance Drivers for, and Perception of, CCU Insulation Boards

To gain a more detailed understanding of the acceptance of CCU insulation boards, we also looked at the drivers behind the acceptance. Using step-wise multiple linear regressions, we calculated the predictors for the cognitive acceptance—since this embodies the willingness to use CCU insulation boards—and its three predictors: affective acceptance, acceptance of the use of plastic, and benefit perception.

Besides the three acceptance measures predicting each other, we found that the benefit and barrier perception, as well as several environment-related factors played a substantial role for social acceptance (R_3). These findings are in line with previous acceptance studies on CCU(-products) (e.g., Arning et al., 2019; Offermann-van Heek et al., 2020). Regarding the benefit and barrier perception, we also evaluated the single statements (R_1). All benefits were generally positively perceived, with the best perceived benefits being the reduce of the use of fossil fuels in the production of the insulation boards and the application of a more sustainable production method. For the barriers we found a more diverse evaluation. The respondents were generally unconcerned about a reduced product-quality or potential health risks. This is good news as in previous studies with other CCU products (e.g., mattresses Offermann-van Heek et al., 2018; Arning et al., 2018b) health risk perceptions were a significant barrier for using CCU products. However, respondents did have doubts relating the product's sustainability and environmental friendliness. Additionally, they felt like CCU insulation boards would be more expensive.

For the benefit and barrier perception we found that although they correlated negatively, their regression relationship was positive. Since environmental behavior was a more important predictor for the benefit perception than the barrier perception was, this might indicate that respondents with a specific level of environmental behavior both saw more benefits and barriers. Since the benefits and barriers most respondents agreed to were of an environmental nature, this could indicate that environmentally aware consumers are unsure of their perception of the product. However, further research including cluster analysis would be necessary to validate this.

Finally it is noteworthy that although the acceptance of the use of plastic played a role in predicting the other three tested variables, it was never the most important predictor. Instead for the prediction of the cognitive acceptance, the affective acceptance was more important, and for the prediction of the affective acceptance, the cognitive acceptance, as well as the benefit and barrier perception were more important (R_3). Hence, if CCU insulation boards evoke positive feelings and are positively perceived, this is likely more important for most consumers' decision whether to adopt CCU insulation boards than the use of plastic in the material. Ones again this underlines the importance of a positive perception of the product for its acceptance.

5.3 Limitations and Future Research Desiderata

Beyond the insights into the social acceptance of CCU insulation boards provided by the present study, there are still a number of methodological limitations and further research issues that need to be pursued in future studies. A first (methodological) limitation lies in the use of Likert scales without a neutral middle. Since the respondents were required to make a choice, they might have over- or underestimated predefined benefits or barriers they would not have come up with themselves (Arning et al., 2019). However, since the used items were based on the preliminary study, we still assume that they were valid and relevant in the context of CCU and CCU insulation boards. Additionally, the respondents had a low subjective prior knowledge on CCU. We can therefore not exclude that the respondents experienced a generally difficulty in answering the questions. The necessity to make a choice might have resulted in so-called "pseudo-opinions". Such opinions are weak and easily change if people receive new or different information and are therefore not directly representative for their actual behavior. However, since future early consumers of CCU insulation boards will probably also have little prior knowledge on CCU, "pseudo-opinions" caused by a deficiency in knowledge are still important to understand what initial reactions will likely be like and will thus be valuable for the product's initial communication (Bishop et al., 1980; Daamen et al., 2006; Arning et al., 2019). In that regard we can also not exclude that the provided explanation on CCU (insulation boards) affected the respondents' attitude towards the product and technology. Even though the explanation was formulated neutrally and was checked for correctness by technical experts, providing different forms and kinds of information might yield different results. Future studies should investigate the thematic framing and the role of instructions in greater detail. Here it could be examined if, and if so to which extent, varying instructions and information shape the participants' evaluation. This would yield valuable insights on how to effectively develop public communication and information for CCU products.

Moreover, the aforementioned broader public's low level of knowledge on the CCU technology, confirming results of recent studies (e.g., Arning et al., 2019; Offermann-van Heek et al., 2020), is not only a methodological issue regarding the validity of the acceptance measurements. Instead, it also raises the question of how public educational strategies can be launched to raise awareness for technological innovations in the energy sector and to increase the knowledge on the domain in relevant stakeholder groups. Only when end-users, intermediaries or even policy makers are well informed and innovations are broadly communicated, will they be able to make informed decisions (Beierle, 2002; Swofford and Slattery, 2010; Østergård et al., 2017). Methodologically, one could question why laypeople should be informed about the production details of CO_2-based products at all—arguing that they often do not possess the domain knowledge to evaluate technical details from an acceptance perspective. However, previous acceptance research has shown that trust in the industry producing such novel products using technologies is a critical issue (Offermann-van Heek et al., 2018). Whenever consumers feel that innovations are introduced to the market without transparency, doubts about the correctness of the information might be triggered (De Best-Waldhober and Daamen, 2006; Offermann-van Heek et al., 2018). It might then be suspected that the innovation is merely a marketing ploy used by companies to make money, e.g., greenwashing (Offermann-van Heek et al., 2018). That is why it is of crucial importance to learn from the public to identify possible misconceptions to be able to address them early in the roll-out process.

Another limitation regards the focus of the social acceptance perspective. In this study we only studied a small part of the social acceptance of CCU and CCU insulation boards (Wüstenhagen et al., 2007). The present study which focused on the market acceptance—and a part of the socio-political acceptance—of one example of a CCU product does therefore not suffice to draw conclusions on the likelihood of the technology's and product's success. Firstly, only the acceptance of a few CCU products has been studied so far (e.g., van Heek et al., 2017b; Engelmann et al., 2020). For that reason, we cannot draw conclusions on the impact of specific CCU products on acceptance. It remains unclear whether the acceptance differs between and across products that are used in people's close personal spheres—e.g., clothes, mattresses, shoes, or cosmetics—compared to more externally used products—e.g., insulation material. We can also not draw conclusions on the specificity of the CCU technology, i.e., whether the acceptance of the CCU technology differs from that of other energy technologies (Linzenich et al., 2021). The body of literature on the acceptance of specific CCU products, and stakeholders, should thus be expanded by future research.

Finally, future research should extend the current study by including more and still other individual acceptance drivers, like personal innovativeness (Arning et al., 2018a) and trust (Offermann-van Heek et al., 2018). Moreover it would be interesting to more closely compare different nationalities. The results indicated that for the Dutch and German respondents, a difference in their acceptance exists—the German respondents were a bit more positive regarding CCU insulation boards compared to the Dutch respondents. However, nationality is a carrier variable, meaning that these results are not caused by the respondents having a different nationality as such, but rather by other attitudinal and behavioral factors as well as socioeconomic settings that differ for different nationalities. Uncovering these factors would result in valuable information for the communication of the product across countries.

6 CONCLUSION

The role of social acceptance with respect to technology innovations in general, and CCU technology and resulting products in particular is of critical importance. Given the potential of CCU technology for mitigating climate change by capturing and using it as a feedstock for commercial products it is a major goal that different stakeholders understand and value CCU-based technologies and products. However, to reach a broad social acceptance for any innovation (process), the trias of information, communication, and education, are of outstanding importance. There is thus an urgent need to gain knowledge and information on, as well as experience with, the CCU technology and resulting products.

The covered study contributed to research in this field by using interviews and a subsequent questionnaire to study the market acceptance of a specific CCU product: insulation boards made with polyurethane foam based on polyols produced by means of CCU. Valuable insights regarding the further development and roll-out of the CCU technology and related products can be extracted from the results of the study. Besides the well-known affect of the perception of the novel product, we found that environmental criteria are critical for the roll-out of CCU insulation boards as well. The public information and communication thus need to highlight these environmental aspects, both regarding the perceived benefits and barriers.

The respondents' low level of knowledge on the CCU technology, which was also found in other empirical studies (e.g., Arning et al., 2018a; Linzenich et al., 2021), is alarming. Educational efforts should therefore be directed at increasing the public's knowledge about CCU and its potential, in order to allow people to make informed decision on their support, thereby fostering responsible climate and energy saving actions. Such educational efforts address secondary and higher education, as well as the general public (Pisarski and Ashworth, 2013; Zaunbrecher and Ziefle, 2016). Since experts and laypeople might have different information needs, the knowledge gaps for the respective groups need to be identified and addressed accordingly using effective and honest communication (Achterberg et al., 2010; Brunsting et al., 2013).

Another aspect of public education is the raising of trust in the information(Offermann-van Heek et al., 2018). Beyond the information itself, trust in the information requires the communication of both benefits and barriers, as well as the consequences a novel product or technology might bring forth. The perception of CCU insulation boards, as well as their affective evaluation, were found to be important drivers behind its acceptance. The perception of the product, as well as further drivers behind its acceptance, thereby suggest that it is likely beneficial to highlight the environmental friendliness and sustainability of the product.

Furthermore, a bi-directional communication on eye-level between all stakeholders involved is needed to integrate the public and listen to their arguments and information needs, including their claims for how and when in the product development process people need to be informed (Pisarski and Ashworth, 2013; Zaunbrecher and Ziefle, 2016; Kluge et al., 2021). If community audiences are integrated in discussions in early stages of technical development, technical designers may profit from insights won by listening to the public. Vice versa laypeople's interest and their engagement in energy-related projects is increased. This enables the public to form a base for informed decision making and allows them to be a part of a responsible energy transition.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because ; The raw data supporting the conclusions of this article can be made available on request by the authors, after consultation with and approval by the project consortium Carbon4PUR. Requests to access the datasets should be directed to ziefle@comm.rwth-aachen.de.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ethics Committee (Division 7.3) "Empirical Human Sciences" at the Faculty of Humanities at RWTH Aachen University. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors actively contributed to the conceptualization and preparation of the first draft of the manuscript. LS and KA were responsible for the methodology and conduction of the described study. LS did the data curation, validation of the data, formal analysis, and visualization. LS and MZ were responsible for editing. MZ was responsible for the funding acquisition.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2021.717975/full#supplementary-material

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