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ScienceDirect

Energy Procedia 114 (2017) 7212 – 7223

Energy Procedia

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

Differences between laypersons and experts in perceptions and acceptance of CO_2-utilization for plastics production

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Abstract

Carbon capture and storage (CCS) and carbon dioxide utilization (CDU) are increasingly discussed by actors from industry, politics, and science as option to mitigate climate change. Apart from reducing emissions, using CDU CO_2 can substitute fossil resources during the production of new plastic products, e.g., mattresses of polyurethane foam. To date, there has been virtually no systematic research on public perceptions concerning CDU for manufacturing plastics, i.e., whether future users accept such products. Thus, this qualitative interview study examined CDU acceptance regarding different plastic products and analyzed laypersons' perceptions and needs in comparison with attitudes and perspectives of scientific experts.

Peer-review under responsibility of the organizing committee of GHGT-13.

Keywords: utilization of CO_2; CDU; technology acceptance; interview study; lay people vs. experts; CO_2 polymers

1. Introduction

Climate change, characterized by global warming, poses one of the major problems and challenges worldwide and is predominantly caused by an excessive amount of emitted greenhouse gases [1]. An estimation of the Global Carbon Project anticipates that 36 billion metric tons of CO_2 emissions from fossil fuel burning and cement production were emitted into the atmosphere worldwide in 2014 [2]. Due to an increasing amount of emissions in the last decades, it is now tried to combat climate change and protect the environment by reducing CO_2 emissions with a variety of technological approaches and innovations. As the largest percentage of CO_2 emissions is caused by energy generation in power plants using fossil fuels such as lignite and hard coal, natural gas and oil [3], energy

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Peer-review under responsibility of the organizing committee of GHGT-13.
doi:10.1016/j.egypro.2017.03.1829

generation by renewable energy sources is particularly funded and constantly evolved [4]. Despite all previously used reduction measures, it is a current problem that still a large number of highly CO_2 producing and fossil resources consuming technologies exists. CCS and consecutively CDU are promising approaches to reduce CO_2 emissions and the use of fossil resources. The utilization of CO_2 enables manufacture of diverse materials with varying CO_2 proportions, which can be used for consumer products as well as for technical applications: the range of applications extends from technical products, e.g., where CO_2 replaced previously used chemicals as refrigerants [5,6], to everyday products such as mattresses which are made of plastic foams (polyurethane) using CO_2 as chemical feedstock [7]. As most of today's used and conventionally produced plastic products are completely based on mineral oil, it is of major importance that a portion of this scarce resource with CO_2 can be replaced [7]. Thus, with this procedure, fossil resources and CO_2 emissions can be reduced at the same time by using CO_2 as raw material. Since plastic products based on CO_2 are currently already produced in the testing stage and will be produced in series by 2016 [8,9], it is questionable how the success of these technically promising products can be estimated. Since purely technical, environmental or economic benefits do not guarantee success of innovative products and technologies, the question arises, how do potential customers perceive these products? Future users' acceptance is a decisive factor for demand and consequently success of new and innovative products [10]. Therefore, it is important to learn which extent future users will accept products made by innovative and in case of CO_2, quite negatively associated materials. Previous research on CO_2 utilization is often limited to the concept of the technology itself and focuses on technical aspects of manufactured products. Future users' needs, perceptions, and desires are mostly not considered so far. To the best of our knowledge, there has been no empirical acceptance study focusing on the acceptance and perception of specific plastic products manufactured by CO_2 utilization. Thus, in this study the acceptance of different CO_2 products was investigated and relevant acceptance factors for future users were identified using a qualitative empirical approach. An interview study with experts and laypersons revealed perceptions and motives associated with CDU products and examined perceived benefits and barriers as well as the willingness to buy and use products, which are partly made of CO_2.

2. CDU and Public Acceptance

Since the acceptance of Carbon Dioxide Capture and Storage (CCS) has been broadly explored already, in this study CO_2-utilization (CDU) is focused. Thus, initially different approaches of CO_2-utilization and especially the use of CO_2 for plastic product manufacture are described. Subsequently, the theory on technology acceptance and the research questions as well as aims of the study are presented.

2.1. Carbon Dioxide Capture and Utilization

In recent years, CCS was discussed around the world as an option to reduce CO_2 emissions, to store after deposition, and to relieve the environment this way [3]. As there are currently numerous large-scale industrial CCS plants in the US, Canada, Asia, and partly in Europe and, correspondingly, large amounts of stored CO_2 [11], it is increasingly questionable whether these quantities of CO_2 can be reasonable used instead of only stored. There are several different ways of CO_2-utlization and using CO_2 for the production of different products, with distinction between physical and chemical utilization and the preparation of inorganic materials. The options of chemical utilization of CO_2 are very promising, because of a high potential in terms of usable material volume and enabling a long-term and partly permanent storage of CO_2 [3]. CO_2 is currently used for the production of urea, methanol, cyclic carbonates, and salicylic acid: for instance the production of urea using CO_2 and ammonia at high pressure and high temperature is the quantitatively most significant use of CO_2 with approximately 106 million tons of CO_2 per year and is applied as agricultural fertilizer [12]. In contrast to these CDU options, which are already implemented by existing technologies, there is a high number of technical innovations on the threshold of technological implementation which are tested and partly implemented in pilot projects (e.g., [12], [8]). In particular, the production of carbonates and polycarbonates from CO_2 allows access to very high demand and sales volumes in the field of chemical and plastics sectors [13]. Due to a virtually unlimited availability of CO_2, associated economic and ecological savings of fossil resources, and a variety of applications of possible plastic products, this type of CO_2-utilization is extremely promising [3]. Through a direct copolymerization of epoxides with CO_2, so-called aliphatic polycarbonates can be prepared, for example [14], which in turn serve as starting material for a variety of plastic products. Similarly, the production of other plastic substances such as polyol, polypropylene and polyurethane out of CO_2 is possible. In this process, CO_2 serves as a basis and by splitting the carbon block (C1) it provides plastic raw materials, from which building materials, insulations as well as household articles can be produced [3]. A study on life-cycle-assessment of CO_2-utilization for polyurethane concluded that by means of CO_2-utilization a reduction in the global emissions budget could not be reached, but significant amounts of fossil resources (mostly oil) and resulting CO_2 emissions (during production) can be saved compared to the manufacture of conventional products [15]. In summary, from the technical perspective, CO_2-utilization for plastic products has ecological and economic advantages: on the one hand, the environment can be relieved by savings of emissions as well as fossil resources and, on the other hand, costs of expensive fossil resources can be saved.

2.2. Technology acceptance and risk perception

Besides environmental and ecological benefits of a technology, it is important to what extent future users accept products made of such innovative and, in the case of CO_2 partly negatively perceived materials [16]. The consideration of future users' acceptance is necessary to be able to assess the technology's and products' potential success and to give product manufacturers indications and recommendations, even before final products reach the market [17]. With regard to CCS, many acceptance studies have been conducted worldwide and results showed that acceptance of CCS strongly varied by country or region and in particular the storage of CO_2 was perceived and considered critically [16], [18,19,20,21]. Therefore the question arises what will happen if CO_2, which previously was "only" stored, now is used for the manufacture of all-day plastic products? Do future users desire such products at all? These questions remain unanswered, as there are no acceptance studies pertaining to specific CDU products so far. Previous studies concerning the public acceptance of CDU [22,23] focused on the technology level and not on specific consumer CDU products: both studies revealed a rather positive perception of the CDU technology and discovered poor knowledge about the technology as well as a lack of awareness about CDU. Jones et al. [23] conducted a focus group study, highlighted perceived risks and benefits of CO_2-utilization in general and distinguished between personal, societal, and environmental acceptance-relevant factors. It has to be considered whether these results can be transferred to the product level of CDU acceptance, because an understanding of determinants that affect acceptance is essential for a successful adoption of innovative products and technologies [24]. Addressing previously nearly unexplored research areas (like CDU product acceptance), it is not possible or recommendable to resort to existing acceptance models: indeed, the Technology Acceptance Model (TAM) is a well-established theoretical approach to explain and predict the adoption of technologies [25], provides a basis for many other acceptance models and has been adapted for many contexts, e.g., [26]. However, previous acceptance models cannot be simply transferred and adapted to the context of CO_2-utilization, mainly because previous models do refer to another type of technology, mostly, information and communication technology in the working context where acceptance is formed by two key factors: ease of use and perceived usefulness of a technology or application. For the context here, in which other acceptance determinants might play a role, such as risk perception, perceived benefits and barriers of the CCU products, existing acceptance models are not appropriate. Thus, there are no suitable theoretical models that could be adapted to the context of CDU product acceptance. Hence, in this new and comparably uncharted research area, a qualitative approach is necessary and forms the cornerstone to examine perceptions with regard to CO_2 in general and to specific products made by CO_2-utilization. Only this way it is possible to be respond to future users' needs, ideas as well as fears and the perceived benefits, perceived barriers as well as examine use intentions.

2.3. Research questions and aim of this study

To the best of our knowledge, no acceptance-related research exists so far, which investigates the acceptance of CO_2-utilization with respect to the manufacture of specific plastic products. Thus, the aim of this study was, first, to explore acceptance-relevant criteria (i.e., perceived benefits and barriers as well as conditionals of use) that people refer to evaluate plastic products produced by CO_2-utilization as compared to conventional plastic products. These findings provide a valuable starting point for follow-up studies and the quantification of acceptance-relevant criteria.

Second, the study was supposed to gain an understanding of public perceptions concerning different CDU product types, technical applications as well as consumer products, since product-specific aspects (e.g., personal benefit of the product, products' closeness to body) were assumed to be relevant. Further, we wanted to uncover and compare laypersons' as well as experts' perceptions, attitudes, and assessments in order to gain deeper insights into the acceptance of CO_2-utilization. Finally, we aimed at understanding future customers' communication and information needs concerning CDU products to provide communication recommendations to product manufacturers.

3. Method and Materials

This chapter presents the empirical approach of the study. First, the characteristics of partly standardized interviews are explained. Then, the interview guidelines are presented in detail. Finally, data analysis and participants of the study are described.

3.1. Semi-standardized interviews

The qualitative interview study was carried out in April 2015 and in total, twelve participants were interviewed with semi-standardized interviews in their private living environment (laypersons) and at their workplace (experts). In general, qualitative methods are often used in communication science to analyze new and previously unexplored contexts [27]. Semi-standardized interviews are usually applied in early stages of investigations, if it is not possible to resort to quantitative methods, because many fundamental aspects have not been clarified yet and it is not possible to formulate research questions due to a lack of knowledge [28]. The interview method of this study was in particular focused on perceptions and attitudes of the respondents, such as personally perceived benefits as well as barriers and fears. With regard to the topic of CO_2-utilization for the manufacture of plastic products, the use of a qualitative methodical approach was chosen, because, so far, detailed acceptance studies have been carried out only for CCS but not for CO_2-utilization and specific from CO_2 produced plastic products. The interview method of this study in particular focused on perceptions and attitudes of the respondents towards CCU products, such as personally perceived benefits as well as potential barriers and fears. Thus, the exploratory approach provided insights into opinions, perceptions, fears, and ideas according to CO_2-utilization and concrete CO_2-products both on the laypersons' as well as the experts' perspectives. The interviews were carried out rotationally, between lay people and experts, in order to be able to utilize the knowledge of experts in the following laypersons' interviews and to be able to confront experts with reported conceptions and perceptions of laypersons. The participants could respond freely and openly and there was always the opportunity to be responsive to individual suggestions and ideas that eventually found no attention in the interview guideline.

3.2. Interview guideline and data analysis

The construction of both interview guidelines was carried out in three steps [27,28]: first, priorities of the interviews were determined based on an extensive literature research. These priorities were formulated in superordinate main issues and subordinated issues. Finally, an approximate order of thematic sections was set. However, it had not to be strictly adhered to in order to do justice to spontaneous comments and ideas of the respondents. All questions were provided openly, whereby a higher complexity and aspects can be obtained that have found no attention so far. Thus, the interviewer is able to inquire more accurately and to adapt the interview individually and spontaneously.

The interview guideline for the *laypersons'* interviews consisted of several thematic sections. First, the participants were asked to deliver demographic information about their age, gender, and professional activity. In a next step, participants should draw or write down their ideas and associations with a) CO_2, b) CO_2 savings, and c) CO_2 emissions successively. Further, participants were asked for their self-reported knowledge and previous expertise with CCS & CDU. Then, basic information about CO_2-utilization for manufacturing plastic products (CO_2-polymers) was delivered. Care was taken to present information as objectively as possible. In contrast to qualitative approaches dealing with perceptions of CCS [18], we provided information before the actual questions of the interviews started. It was necessary that the broad lines of CO_2-utilization for plastic products were understood by the participants in order to enable an evaluation of different types of CO_2 manufactured products and their perceived benefits and barriers. The first thematic issue was related to perceived benefits of CO_2-utilization for plastic products. If necessary, it was inquired which global, ecological, economic, social, or personal benefits were associated with the technology. In contrast, perceived barriers were subsequently discussed in the areas of safety in production, safety of consumer products, ecological effects on the environment, and effects on human health. The penultimate section included a comparison of four different plastic products, all of which can be made of CO_2-polymers: technical coatings, building isolation, mattresses and t-shirts. Here, we asked for participants' general opinion on each product, perceived benefits and barriers according to the specific product, and the willingness to buy and use each product. Finally, the interviewees should summarize within a conclusion which product they prefer and reject most and what kind of information they would like to receive together with the products. The last question of all laypersons' interviews pertained to whether CO_2, if it is used for the manufacture of plastic products, is perceived as rather "harmful" or rather "green" and why. The interviews with laypersons took on average approximately 30 minutes.

The *experts'* interviews were individually adapted to the experts' education and scientific discipline in order to gain as precise information as possible and took on average also approximately 30 minutes. After querying demographic data and present associations with CO_2, the subject and background of the study was introduced. Knowledge and expertise with CCS and CDU was discussed and in particular the areas of technical and ecological background as well as potential and efficiency of CO_2-utilization were focused. Further, possible benefits in terms of environmental, economic, and social aspects as well as potential barriers of CO_2-utilization were discussed. Afterwards, the experts were asked to assess the different applications – if possible and depending on respective disciplines. Further, the experts were prompted to empathize with the laity and to speculate about their fears, perceptions, and usage intentions. Finally, the experts were asked to assess CO_2-utilization as a way to combat climate change.

Following the interviews, the recorded audio files were transcribed literally and analyzed by means of the qualitative content analysis [29]. For data analysis, a deductive system of categories was derived from current literature and iteratively supplemented with inductive categories after analyzing the data material. To avoid subjective effects on the categorization, all authors coded the quotations independently and only indisputable quotations were included in the categories.

3.3. Participants

A sample of six laypersons and six technical experts was recruited from personal surroundings and scientific institutes of the university. Twelve adults volunteered to take part in the interviews and were not gratified for their efforts. The mean age in the layperson group was 41 (range: 22-79) with four males and two females. All laypersons did not know the terms CCS or CDU and were not familiar with the technologies (especially not with CO_2-utilization). The mean age of the group of technical experts was 32 with five males and one female. All experts knew the terms CCS as well as CDU and partly had profound knowledge about CO_2-utilization. To cover a broad range of possible applications, the technical experts were recruited from various disciplines, i.e., architecture (2), heat- and mass-transfer (1), mechanical engineering (2) and chemical engineering (1).

4. Results

The following section presents the results of the interviews. The findings are structured inspired by the order of topics in the interview guideline. Thematically connected results are reported compendiously.

4.1. General perception of CO_2 and CDU

First, it is interesting even though not really surprising that laypersons and experts clearly differed in their associations concerning CO_2 (Fig. 1). Laypersons predominately associated negative aspects with CO_2: primarily, all lay participants mentioned or drew emissions caused by motor vehicles, aircrafts, ships, power plants, or even cows. Furthermore, CO_2 was mostly described as pollutant for human health and the environment. Half of the lay participants associated with CO_2 not only harmfulness but also toxicity. In addition to negative aspects, a majority of the lay participants reflected also about the necessity to reduce CO_2 emissions. However, unlike the laypersons, the experts associated mostly objective and neutral aspects with CO_2. All experts described CO_2 initially as component of life, e.g., as part of exhaled air, as central component of photosynthesis, and as molecular compound. Further, the necessity of reducing CO_2 emissions was mentioned by all scientific experts. The architects among the experts thought about CO_2 emissions due to cement production.

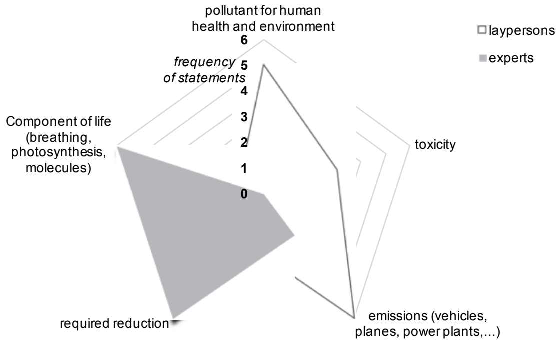

Fig. 1: Associations with “CO_2” by experts and laypersons.

Asked for ideas and associations with CO_2 savings and CO_2 emissions, the answers of laypersons and experts were more similar (Fig. 2).

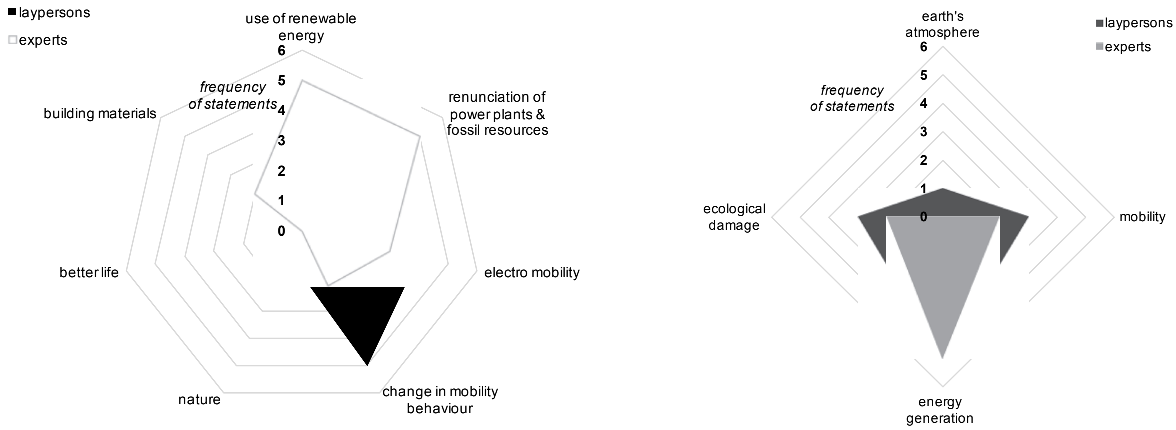

Fig. 2: Associations with “CO_2 savings” (left side) and “CO_2 emissions” (right side) by experts and laypersons.

For both laypersons and experts, using renewable energies and a renunciation of power plants and fossil resources are very important strategies for CO_2 savings. Similarly, an increasing use of electric vehicles as well as change in the mobility behavior, e.g., using smaller vehicles or using public transport, are desired by both groups. The architects among the experts emphasized that a large amount of CO_2 emissions accumulates in the production of building materials and thus, the development of innovative building materials would contribute considerably to CO_2 savings. A few laypersons desired a better life and nature in conjunction with CO_2 savings. According to associations with CO_2 emissions, all experts exclusively emphasized emissions due to energy consumption, i.e., power plants and use of fossil resources, as well as due to mobility, e.g., vehicles and aircrafts. These aspects were also accentuated by almost all laypersons. The laypersons additionally associated CO_2 emissions with ecological damage, i.e., climate change and global warming as well as changes within the earth’s atmosphere. Asking for a final assessment of CO_2 related to CDU, the perceptions turned out to be very different among the laypersons: while especially younger participants ascribed a "green" character to the utilization of CO_2, for older participants CO_2, maintained a pollutant which is not desired for the manufacture of products. The experts emphasized that CDU for plastic products could only have a minor role in combating climate change but it could have a large ecological and economic potential for saving fossil resources.

4.2. Perceived benefits of CO_2-utilization

Perceived benefits were discussed in the categories environmental, economic, and personal benefits (Fig. 3).

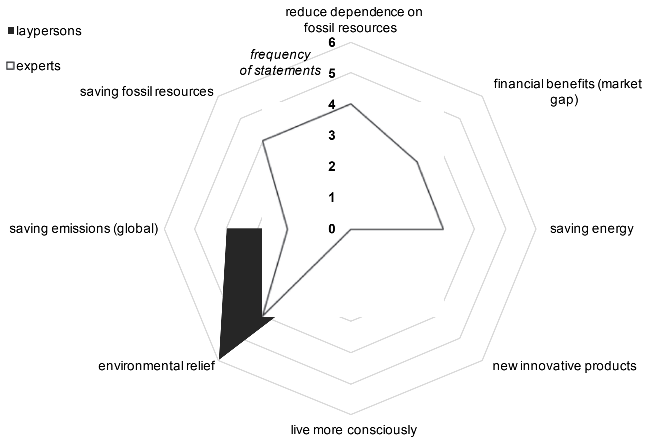

Fig. 3: Perceived benefits of CO_2-utilization by experts and laypersons.

Likewise, laypersons as well as experts considered environmental benefits as major advantage. Both groups desired and expected an *environmental relief* by using CO_2 as feedstock for plastic product manufacture. However, the kind of desired and expected environmental benefits differed considerably. For the laypersons, this was expressed by the expectation of highest possible savings of global CO_2 emissions (namely 30%-50%), as CO_2 was bound as a pollutant and extracted from the environment. This can be demonstrated by the following statement:

> *"… But - if CO_2 is removed from the environment, then even a small percentage is already good – because this way the environment is relieved. Of course, the more the better!" (female, 54, layperson)*

In contrast, a majority of scientific experts named an expectation of significant savings to the global CO_2 emission budget to be unrealistic.

> *"I mean - how many billion tons of CO_2 are existing? These are so large amounts - there are estimates that a maximum of 1% of emissions can be converted into products under the most favorable of all conditions. For example, if you would provide the enterity of Germany with gasoline based on CO_2…"(male, 33, expert)*

Instead, in the experts' perspective, environmental benefits were located in savings of limitedly available resources, if fossil resources such as oil and gas are partly replaced by CO_2 as feedstock for the production of plastics. In addition, experts formulated the environmental and economic benefits of a lower dependence on these fossil resources. Similarly, *economic benefits* were also discussed by half of experts in terms of saving energy and exploiting a market gap by new, innovative, and "green" products. In contrast, economic benefits were only mentioned by one single layperson. Personal benefits in terms of an opportunity to use new, innovative products and to live more (environmentally) conscious were also only discussed by a single layperson.

4.3. Perceived barriers of CO_2-utilization

Perceived barriers of CO_2-utilization were discussed in the categories <u>*health*</u> concerns, <u>*environmental*</u> concerns, and <u>*safety*</u> concerns (see Fig. 4). While almost all experts emphasized to have no safety concerns due to sufficient product inspections in Germany, the majority of laypersons raised safety concerns, primarily regarding to environmental and health related misgivings. With respect to health concerns, nearly all scientific experts mentioned no such concerns, because the CO_2 was not expected to occur in products as gas and CO_2 was perceived as harmless compared to other commonly used chemical substances.

"You have to remember, it is no longer real CO_2 in it - it is trapped in a polyol structure and thus, it is no longer gaseous – it can not be set free (…) the material the customer comes in contact with is ultimately the same as before (in conventional products). Only the carbon atom comes from CO_2." (male, 31, expert)

In contrast, a majority of laypersons (4 of 6) expressed concerns about potential leakage of CO_2 from products and a majority (4 of 6) also feared a harmfulness of CO_2 in products for their own health. Specifically, it was feared that allergies, changes in ambient air, circulatory system problems, and respiratory problems up to suffocation might be caused by the leaking of CO_2. This can be taken from the following exemplary quotes:

"CO_2 is harmful to human health! I do not want to come in contact with products manufactured by CO_2." (female, 79, layperson)

"I ask myself how a CO_2-product will change the air, if I store it in my apartment. Is it able to cause allergies? ..." (male, 60, layperson)

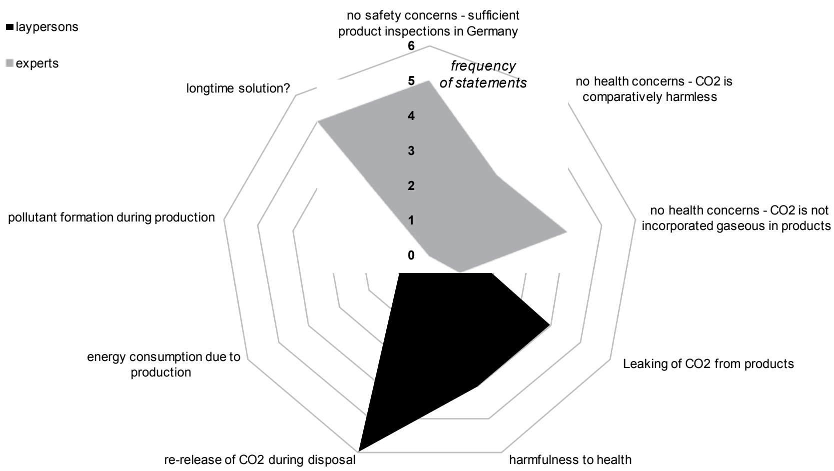

Fig. 4: Perceived barriers of CO_2-utilization by experts and laypersons.

Regarding *environmental* concerns, all laypersons feared a *re-release of CO_2 during the disposal* of products, when they are no longer needed. This aspect was not discussed at all by the scientific experts, because in their perspective the feedstock of CO_2-products is the same as for conventional products and thus, the disposal conditions and resulting emissions are the same as for conventional products. Additionally, a few laypersons feared a high energy consumption due to the production and pollutant formation during the production. Some laypersons doubted that utilization of CO_2 for plastic products is a sustainable longtime solution.

"The use of CO_2 for plastic product manufacture is no long-term and sustainable solution – the real issue is

only delayed. For example, what happens if the products are no longer needed? Then, emissions accumulate again...” (male, 30, layperson)

“These are nice ideas, but a solution of the real problem? It is not… – I guess… I do not think that we will stop climate change this way…” (male, 60, layperson)

In contrast, sustainability was the most criticized aspect by the experts. It was mentioned that the utilization of CO_2 for products is only like fighting the symptoms and not the real cause or problem.

“It may be a tiny little contribution, but it will not help combat climate change directly. Other measures must be tackled, such as reconstruction of the electricity sector, less CO_2 production – it has to be started with the polluters!” (male, 31, expert)

Particular criticism was given to the limited durability of all products and the assumption that this way climate change will only be further delayed and not actively fought. At this point the engineers among the experts emphasized that CDU can act as part of a whole strategy and can help to relieve the environment by saving fossil resources and emissions.

4.4. Evaluation of diverse CO_2-products and applications

Similar to benefits and barriers, the four products or applications (*technical coating, building isolation, mattress, t-shirt*) were also evaluated differently by experts and laypersons. The experts evaluated all products as basically positive, wherein a manufacture of products with a high CO_2 proportion and therefore higher potential to save fossil resources was particularly desired. In contrast, the laypersons rated the four products and applications strongly diverse: all participants assigned the highest potential to *building isolation*, because they assumed a high CO_2 proportion and lower energy costs as a result of high energy savings due to the isolation. Thus, all lay participants identified the building isolation as the best product. A *t-shirt* produced by CO_2 was evaluated worst, because the laypersons suspected a low CO_2 proportion and a high production effort. Additionally, the closeness to one’s own body and associated perceived health complaints were criticized especially by older participants.

The application of *technical coating* was rated as rather neutral by the laypersons, because they claimed to not come into contact with this application. Finally, the evaluation of a *mattress* produced with CO_2 was especially diverse between older and younger lay participants: while younger participants had only slight reservations and mostly would like to buy as well as use such a mattress, it was rejected by older participants due to doubts about the product and possible effects on human health.

“No, I can not imagine that. As a product on which I lie with my own body? – No, I would not accept it – under any circumstances. It’s too close to the body!” (female, 79, layperson)

“I would fear exhalations of CO_2, because you will get sick of it!” (male, 70, layperson)

The laypersons’ different and not consistent or holistic assessments of CDU products show that it is important to explore various product-related aspects and their trade-offs as well as other CDU product alternatives (e.g., fuels, preservatives, medicines) in greater depth (see 5.).

4.5. Desired CO_2-product information

A last interesting aspect refers to the information which should be given when purchasing a CO_2-product. At this point, the data made by laypersons and scientific experts differed distinctly as well. Laypersons would like to get detailed information about the product and its lifecycle: e.g., product’s CO_2 proportion, its general composition, ecological balance during manufacture, potential advantages and disadvantages of the product and its manufacture, disposal conditions. Half of the laypersons suggested providing the CDU products with energy efficiency symbols.

"I would prefer an understandable and simply illustrated labeling and information on components of the product, whether it benefits the environment and is efficient - perhaps with using an energy efficiency symbol, that is easy to understand!" (male, 60, layperson)

In contrast, the experts agreed unanimously that CO_2 generally must not be declared as a component of a product, because the exact composition of conventional products is also assumed to be unknown.

"… but maybe it's better to just not say anything: because no consumer knows what's exactly inside in a conventional mattress. I do not even know what actually is in this phone either, it's just some kind of plastic." (male, 33, expert)

In case that an identification of a CO_2-containing product should take place, the experts also estimated that a symbol of efficiency or eco-label (with a note on where further product information can be found) would be appropriate. There was general agreement both among the laypersons as well as the experts, that a communication and marketing strategy with regard to products made from CO_2 has to be well designed due to the comparatively negative perception of CO_2.

5. Discussion & Conclusion

The aim of this study was to explore laypersons' and experts' perceptions regarding benefits and barriers of CO_2-utilization for specific plastic products. Further, the study was supposed to investigate the influence of different product types on acceptance of products manufactured by CO_2-utilization. Finally, we wanted to explore differences and similarities of experts' and laypersons' associations as well as perception regarding CO_2-utilization and specific products. Overall, participants' general perception of CO_2-utilization was positive (similar to previous CDU acceptance studies [22,23]) as long as personal and direct contact with products was not intended. Direct, i.e., bodily contact with products made from CO_2 was especially rejected by older lay interviewees. In a first step, written, drawn, and narrated associations with CO_2 showed that laypersons' mental models of CO_2 hold strongly negative connotations. In part, CO_2 is no longer thought of as part of the natural life cycle, because it is only viewed as pollutant. However, it is assumed by lay participants that this will most likely due to current, strongly negative reporting about CO_2 emissions in press, television, and on the internet. In contrast, scientific experts associated CO_2 with mostly objective and factual aspects, presumably because they deal with the chemical element and substance CO_2 in their everyday work. Interestingly, experts could not understand at all why CO_2 was perceived as strongly negative by laypersons. This shows even more the importance of a well-designed (and focusing on future users) strategy for information and marketing with respect to by CO_2-utilization produced products.

Compared with previous research results [23], *environmental* benefits and barriers were discussed intensely by the lay participants of this study, while personal benefits, societal factors, or technical issues were only marginally mentioned. For both groups, the *major benefit* of CO_2-utilization for plastic products was an *environmental* relief. However, ideas about the type of relief differed considerably. Laypersons imagined environmental relief as significant savings of CO_2 emissions in terms of the global emissions budget. This was rated to be unrealistic by experts, because according to their job, they have precise ideas, on the one hand, about annual amounts of arising CO_2 emissions and, on the other hand, about maximum amounts of annually used plastic products. Similar to existing studies [15], the majority of experts considered that, by utilization of CO_2, a significant amount of fossil resources (about 20%) can be saved compared to the production of conventional products. Hence, communication and information strategies should focus on benefits and advantages in terms of fossil resource savings. As the laypersons suggested, the products' advantages could be communicated by using easily understandable and simply illustrated energy efficiency labels such as, for example, an adapted version of the European Union energy label[30].

Possible *disadvantages and hazards* of CO_2-utilization for plastics manufacture were evaluated very differently. The experts predominately considered that neither health nor environmental hazards exist, because the basic substance is identical to the base substance of conventional products. In their opinion, no CO_2 can leak and no additional emissions will be released during disposal than during disposal of conventional products. Even if the experts are of course right from a technical point of view, the laypersons' even irrational viewpoint is still of great importance. Laypersons assumed that CO_2 could be released from the products and this, in turn, could be a potential hazard to their health and the environment. This negative perception persisted, even as it was emphasized by the interviewer that the products contain no gaseous CO_2. Apparently, laypersons' affective responses as fears and strong suspicions for health hazards are strong and mostly hidden drivers for acceptance and should be directly addressed in future communication strategies. Information and communication strategies should explain understandably and detailed how CO_2 is used for the manufacture of plastic products. This applies in particular to products, which are close to the body, e.g., mattresses and clothes. It has to be communicated quite clearly if potential risks due to CO_2 persist or not. This is essential for the credibility of public communication and, on the long run, essential for the acceptance of the products. Doubts about the sustainability of CDU and CDU products represent another important barrier (for laypersons and experts) that should also be addressed in future research. As some experts suggested, it would maybe be useful to emphasize and communicate that CDU and CDU products could be part of a holistic energy policy strategy to combat climate change instead of considering CDU as merely a short-term technology.

The study also revealed that laypersons do overestimate single characteristics of CCU products (technical aspects as well as the closeness to one's own body) but are not able to see the whole picture. Therefore, future research should focus on different CDU product alternatives and investigate the acceptance depending on various product-related aspects (e.g., closeness to body, technical characteristics, product prices). For instance, if information about production costs etc. is available, it will be very interesting and helpful for product manufacturers (as well as marketing and energy policy strategies) to know, whether future users are willing to pay even higher or only lower product prices for CDU products in comparison with conventional products.

This study revealed enlightening insights into users' requirements in the context of CO_2-utilization for plastic products in general and specific products in particular. It represents a first approach in both scope and methodology and forms a cornerstone for following quantitative studies. However, one limitation is the specificity of the participant groups examined here. Our lay interview participants all had no knowledge about CDU, most probably related to a lack of public awareness (as the utilization of CO_2 for plastics production is not part of the public debate in Germany). This corresponds to prior studies regarding CO_2-utilization acceptance, in which a very low level of knowledge and information was also found [22,23],[31] and it is assumed that these factors restricted participants' ability to comment more detailed on perceived benefits and barriers also in this study. Therefore, transfer of knowledge and information concerning CDU and CO_2-products should particularly be focused in subsequent studies. With regard to the selection of interviewed experts, need for improvement exists inasmuch that only scientific experts were chosen. In further studies, it would be helpful to consult field experts, such as people from economy, industry, and policy, in order to cover a broader range of insights into acceptance of CO_2-utilization as well as technical conditions. Stills the findings will serve as a base for consecutive quantitative studies. For example, a choice-based conjoint study would be helpful to determine users' preferences, relative importance and tradeoffs concerning different characteristics of CO_2-products, perceived benefits in terms of environmental relief and perceived barriers in terms of health and environmental concerns. Results of these tradeoffs could serve as further advices and recommendations for industrial manufacturers and respectively marketing. In addition, the results of this study showed that user diversity in particular in terms of age as well as knowledge about CCS and CDU (laypersons vs. experts) affected CDU product acceptance. Thus, we will analyze effects of user diversity (e.g., age, gender, knowledge, risk perception, environmental consciousness) on the acceptance of different specific CDU products in future quantitative studies. Finally, it is also highly probable that country-specificly and cultured attitudes influence CDU product acceptance (just as it varied country-specific in the case of CCS [16], [18,19,20,21]) and therefore, a country- and culture-specific comparison of CDU product acceptance should also be addressed in further research.

Acknowledgements

The authors thank all participants – laypersons as well as experts - for their patience and openness to share opinions on a novel technology. Furthermore, the authors want to thank Chantal Lidynia for research assistance. This work has been funded by the European Institute of Technology & Innovation (EIT) within the EnCO2re flagship programme from Climate-KIC.

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