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Why Terminology Matters for Successful Rollout of Carbon Dioxide Utilization Technologies

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To realize their full sustainability potential, carbon dioxide utilization technologies (carbon capture and utilization/CCU) presently require policy support. Consequently, they require acceptance among a variety of stakeholders in industry, policy making, and in the public sphere alike. While CO_2 utilization is already a topic of discourse among these stakeholders, there is a lack of common terminology to describe such technologies. On the contrary: The present article shows that terminology in the field of CO_2 utilization technologies is currently used inconsistently, and that different designations such as CCU, CCUS, or CDR convey different meanings and contexts. These ambiguities may cause communication problems with regard to policy making, funding proposals, and especially in public discourse. In order to initiate and accompany a goal-oriented and knowledge-based debate on CO_2 utilization technologies in the future, actors in the field are asked to question their own choices of terminology and to assess its accuracy. Acronyms and technical abbreviations are the chief cause of potential misunderstandings, and so should be avoided whenever possible or else include a brief explanation. Consistent and precise use of terminology will facilitate transparent dialogue concerning CO_2 utilization in the future.

Keywords: carbon dioxide removal (CDR), terminology, glossary, carbon capture and utilization (CCU), carbon capture utilization and storage (CCUS)

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INTRODUCTION

Technologies that capture and utilize carbon dioxide have become widely discussed as means to reduce CO_2 emissions and support industrial transformation and defossilization processes (IPCC, 2018; European Commission, 2019), as well as helping to remove legacy emissions from the air and oceans. These technologies capture CO_2 from different sources, such as industrial point sources or directly from the air, and provide it for use in value-added products, thus aiming to make accessible new sources of carbon while also reducing emissions (North and Styring, 2019). The expected environmental and societal benefits of such technologies depend on a number of variables, and differ fundamentally between the broad range of possible applications (Olfe-Kräutlein, 2020; Ravikumar et al., 2021). Research in accessing CO_2 as a new carbon source was undertaken as early as the 1970s (Aresta, 2010), but it is only in recent years that development has intensified due to increasing pressure to combat climate change and for industrial sectors to meet related emission reduction targets. Today, the first products made with captured CO_2 have already reached the market (Carbon8, 2020; Aircompany, 2021; CarbonCure, 2021; LanzaTech, 2021; Covestro, n.d).

Despite progress in research and implementation of CO_2 utilization technologies, most applications are still in an early development phase. This is partly due to insufficient technical progress. But additionally, applications that are technically feasible face barriers to their upscaling and market implementation, including regulatory barriers, higher economic costs than conventional products, and the high renewable energy demand of most applications (Group of Chief Scientific Advisors, 2018; Olfe-Kraeutlein et al., 2021). Therefore, the support of stakeholders in the political environment as well as among the general public may be a decisive factor for implementing CO_2 utilization technologies (Wilson et al., 2016; Jones et al., 2017).

One factor for acceptance of CO_2 utilization technologies and therefore for social support, is the transfer of information to the public and other relevant stakeholders (Jones et al., 2014; Arning et al., 2017; van Heek et al., 2017), as well as the communication processes that are adopted. This article focusses in particular on the transfer of information and its enabling tools: where a fundamental prerequisite for conducting the necessary dialogues, enabling knowledge-based opinions, and making informed decisions is clarity about the subject of the discourse. A global uniform vocabulary is desirable but hardly feasible; nevertheless, a common and accurate understanding during dialogue on innovative technologies, both in written and spoken forms is of great importance. Ambiguities in terminology can lead to diverse undesirable consequences, such as confusion outside the experts' field, inappropriate contextualization, or underestimating the importance or technological breadth of CO_2 utilization technologies proposed to combat climate change. Moreover, the naming of technologies has a marked influence on the attitudes that people develop toward that technology (Boersma and Gremmen, 2018; Boersma et al., 2019). This will be used to generate opinions in society on what that technology is about, and what risks or benefits it may bear. In particular, based on personal attitudes and beliefs, individuals tend to categorize new technologies among a group of technologies that they are already familiar with (Loken et al., 2008). Via a appropriate name selection, it is possible to avoid inaccurate associations between technologies that do not share benefits or downsides. Moreover, once established, mistaken impressions are not easily corrected and should therefore be prevented (Hall, 2010).

However, the intended meanings of many terms in the fields of CO_2 utilization technologies still varies considerably, and this dissonance can adversely affect both the dialogue and societal debate about the future of such technologies. This article analyze the current terminology used in the research literature today, presents the main terminology differences and inconsistencies, and which of these mainly lead to misunderstandings. Therefore, the authors propose a terminology guideline that may help unify the vocabulary and definitions.

TERMINOLOGY FOR CARBON CAPTURE AND UTILIZATION TECHNOLOGIES

Current Use of Terms for CO_2 Utilization in The Literature

In the scientific and industrial debate, interchangeable terms are used to denominate CO_2 utilization technologies, raising questions about their consistency.

A search in English of the Scopus database (accessed on 2/2/22), revealed the most frequently used long-hand terms are "CO_2 conversion" and "CO_2 reduction" (not to be confused with chemical reduction of carbon), whilst "CCUS" followed by "CCU" are the most common abbreviations. More results are shown in **Table 1**, together with the three main fields of research the results belong to, and the type of document (presentations, discussion papers, scientific literature, etc.). Similarly, the most common expressions and abbreviations for CO_2 utilization technologies used by Palm and Nikoleris (2021) for their CO_2 utilization literature screening are "carbon (dioxide) utilis/zation," "CDU," "CO_2 utilis/zation," "carbon dioxide use/age," "carbon capture (storage) and utilis/zation," "CCU," "CCSU," "CCU&S," "carbon (dioxide/capture and) reuse," "CCR," and "carbon (dioxide) recycling." These analyses demonstrate that in the scientific literature and the corresponding databases there is by no means a uniform terminology but a large array of terms that are used interchangeably and applied without coherent criteria. This easily leads to confusion and omission of results when conducting literature analysis, due to the broad range of search terms required to comprehensively screen online databases.

Inconsistent and Imprecise Use of Terminology as a Source of Misunderstanding

The following examples illustrate how the use of inaccurate or even simply inconsistent terminology in the field of CO_2 utilization can ultimately lead to significant misunderstanding and miscommunication.

CCUS, CCU, and CCS

The term CCUS is particularly prone to misunderstandings, given the broad range of categories it includes. The application of the term Carbon Capture, Utilization, and Storage/CCUS ranges from the description of pure storage processes (i.e., similar or equivalent to CCS) to the description of processes mixing utilization/storage (such as EOR/EGR[1]), to the pure description of utilization processes without specific reference to a storage period (Chalmin, 2020). Thus, in this broad range of cases CCUS can be rather unspecific. Often, however, the joint description of utilization and storage technologies is intended.

In contrast to this and as an example of a fundamentally different interpretation of the term, the German Federal Energy

[1]EOR/EGR – Enhanced oil or gas recovery: In this specific case, it can be claimed that the CO_2 is first used (to enhance oil and gas recovery), but also stored in the underground exhausted reservoirs, where it remains after the extraction procedure.

TABLE 1 | Counts of relevant terminology found in Scopus database (accessed February 2nd, 2022).

Search term used*	Number of documents	Document type					Top 3 subject areas of results
		Articles	Review	Conference paper	Book chapter	Other	
{CCU} and "CO_2"	395	284	50	40	18	3	Environmental Science, Chemical Engineering, Energy
{CCUS} and "CO_2"	654	378	187	53	51	15	Energy, Environmental Science, Engineering
"CDU" and "CO_2"	46	32	0	9	4	1	Energy, Engineering, Environmental Science
"Carbon dioxide utilization"	428	299	44	50	21	14	Chemistry, Chemical Engineering, Energy
"Carbon capture and utilization"	613	458	78	42	27	8	Environmental Science, Energy, Chemical Engineering
"Carbon dioxide reuse"	9	7	0	1	1	0	Engineering, Chemical Engineering, Energy
"Carbon capture and reuse"	9	5	0	2	2	0	Chemical Engineering, Energy, Environmental Science
"Carbon dioxide conversion"	505	402	45	40	11	7	Chemistry, Chemical Engineering, Energy
"Carbon capture and conversion"	34	20	8	1	0	5	Chemical Engineering, Environmental Science, Energy
"Carbon dioxide recycling"	84	55	9	14	2	4	Engineering, Chemical Engineering, Materials Science
"Carbon capture and recycling"	11	5	1	2	0	3	Chemical Engineering, Chemistry, Energy
"CO_2 utilization"	1,430	1,006	158	190	50	26	Chemical Engineering, Energy, Environmental Science
"CO_2 reuse"	50	31	0	14	3	2	Chemical Engineering, Engineering, Energy
"CO_2 conversion"	4,308	3,642	354	218	63	31	Chemical Engineering, Chemistry, Energy
"CO_2 reduction"	12,127	9,292	1,124	1,303	217	191	Chemistry, Chemical Engineering, Energy

Agency (DENA) defines CCUS as a specific denomination for the use of CO_2 in products with a long storage time. Examples include cementitious products or mineralization processes as a whole, thus defining CCUS as a CO_2 utilization process with a "climate-relevant retention time" (DENA, 2021). The definition explicitly excludes mere CCS approaches that do not intend utilization aspects (i.e., underground storage). The definition "CCUS" has also been taken up by the CDU German political party in its 2021 political program, which instead defines CCUS as a technology for solid storage of CO_2 only (CDU, 2021).

The term CCUS is particularly used in North America, where it often indicates EOR/EGR in the context of oil and gas production as the main process of reusing CO_2 (Adu et al., 2018). Although for this specific case the term CCUS fits well from a technical standpoint due to the combination of "using" the CO_2 and storing it, the denomination of EOR/EGR as "CCU/CCUS" is controversial within the expert community. From a sustainability standpoint, the utilization of CO_2 to increase fossil fuel yields is counterproductive to efforts to fundamentally reduce and transition away from the extraction of fossil resources. Nevertheless, recent studies point to the possibility that more CO_2 could be stored with EOR/EGR than the amount released from burning the oil thereby obtained (Núñez-López and Moskal, 2019). In this context, it is worth noting that according to 45Q (a US tax credit for utilizing CO_2), there is greater economic incentive for storing CO_2 rather than reusing it, which might lead to more permanent underground storage in the context of EOR/EGR (Congressional Research Service, 2021).

The use of CCUS in the European context has grown in recent years (e.g., IEA, 2021), although the terms CCU and CCS are still mainly used separately to indicate two different groups of technologies: those that use CO_2 for production processes, and those that have CO_2 storage as their only goal (Bruhn et al., 2016). This approach distinguishes the main goal of such technologies, thereby facilitating and supporting precise dialog management. However, this net separation does not apply to processes where both utilization and storage of CO_2 are involved to different extents, such as cement or plastics production.

Overall, in the context of societal debates (including policymaking and participation of the public to societal-relevant decisions), a lack of common understanding – of what CCUS, CCU, and CCS precisely relate to – make the use of these terms challenging. For this reason, their use is not recommended without clearly explaining the intended meaning, in both societal and technical contexts.

Carbon Dioxide Removal and Recycling

Carbon dioxide removal (or simply carbon removal) refers to any method that "extracts CO_2 from the ambient air by biological, chemical, or physical means" (Global CO_2 Initiative, 2021), providing no specific indication on the following utilization phase. Other glossaries, such as the Carbon Removal Glossary (American University Washington, (n.d)) or the Foresight Transition Glossary (Foresight Transitions, 2020), define CDR as a removal technology for sequestering CO_2 from the atmosphere. In essence, in the first case only the action of removing CO_2 is considered, while in the latter the removal of CO_2 contemplates a much longer timespan and can therefore be grouped with Negative Emission Technologies (NET).

In rare cases, the initialism CDR is also used for carbon dioxide recycling, which creates ambiguity about the use of "recycling" in the context of CO_2 utilization. While national legislation, such the European Union Waste Framework Directive, acknowledge CO_2 as waste or not, the term recycling is hardly applicable to CO_2 utilization technologies. In fact, recycling refers to a process that makes waste material available again for either its original or a different purpose[2]. However, in the present context, CO_2 has not been used previously as an input material, but was instead co-produced in a combustion process or chemical reactions. Therefore, the term "Carbon Dioxide Recycling" can be misleading since it can refer to a different set of associations. This inconsistency would impose a definitional and legal frame of reference that goes beyond a mere specification for CO_2 utilization technologies only. Regardless of the original definition of recycling and as a more effective description, "Carbon Recycling" could be used to address public awareness and confer a positive connotation for technologies that aim to reuse CO_2.

Removing or Reducing Carbon Dioxide

CO_2 utilization technologies aim to use CO_2 to ultimately reduce or eliminate its emission to the atmosphere as well as to remove some legacy emissions. The actual contribution of each technology or product to CO_2 emissions reduction can be defined in absolute or relative terms via LCA (Life Cycle Assessment) and according to the scope of the analysis (for complete guidance, see Zimmermann et al., 2020). This differentiation can be confusing to the public, but it is nevertheless substantial for policy making and requires further reconsideration. A carbon-negative product or technology has negative net carbon emission, meaning that its utilization or production will uptake CO_2 from the atmosphere when taking its entire supply chain into consideration. Instead, when two technologies or products are compared to each other, the denomination as "carbon-reducing" indicates better climate performance (i.e., less overall CO_2 emissions) of one product compared to another, but not necessarily negative overall emissions (Tanzer and Ramirez, 2019). Additionally, to define a product or process as carbon-negative, its entire life cycle needs to be assessed (cradle-to-cradle analysis), as all its stages may be significant in determining the overall emissions. This is not the case for the comparison of products, where assessing a specific stage of the life cycle might be sufficient to identify a relative improvement of the technology, assuming that the other stages are the same (Von der Assen et al., 2013).

TABLE 2 | Classification scheme for climate performance of technologies.

Climate performance	Terms used
Removing and storing atmospheric CO_2 (GHG emissions are lower than the amount of CO_2 fixed)	• Carbon negative • Negative Emission Technology (NET)
Reducing CO_2 emissions (GHG emissions over the entire life cycle are less than in the benchmark process)	• Carbon avoided
Net-zero emissions (GHG emissions are zero over the entire life cycle)	• Carbon neutral
No information on climate performance (GHG emissions over the entire life cycle must be individually assessed)	• Carbon Dioxide Removal (CDR) • Carbon Recycling • Carbon Capture and Utilization (CCU) • Carbon Dioxide Utilization (CDU) • Carbon Capture and Storage (CCS)

In addition to "carbon neutral" and "carbon negative," other definitions exist to describe climate performances, but again no universal technical meaning and effect on climate is associated with these. Often, different terms are used to indicate the same process or climate effect, leading to even greater confusion. In order to provide clarity in this regard, the AssessCCUS glossary (Global CO_2 Initiative, 2021) proposes a classification scheme for the most common terms referring to the climate performance of technologies or products, as reported in **Table 2**. This glossary also proposes solutions to inconsistencies that are highlighted in this article.

Current Efforts to Elaborate on Common Terminology

The problems involved with inconsistent terminology for CO_2 utilization technologies have been recognized by the scientific community and policy makers, and several efforts are underway to develop tools to resolve this predicament (Cremonese et al., 2020).

The International CCU Assessment Harmonization Group established by the Global CO_2 Initiative[3] has developed a glossary for key terms in CO_2 utilization (Global CO_2 Initiative, 2021). After reviewing existing glossaries and the main terminology inconsistencies, suggested solutions were developed, also aiming to avoid redundancy, repetition, and unnecessary complexity. After a validation process involving external stakeholders, the glossary was published in early 2021.

A second comprehensive glossary containing respective terminology is provided in "The CDR Primer" (Wilcox et al., 2021), which aims to communicate the fundamentals of Carbon

[2]KrWG §3 Abs. 25, *§ 3 KrWG - Einzelnorm (gesetze-im-internet.de)*.

[3]For all members of the group, please refer to: https://www.globalco2initiative.org/evaluation/.

Dioxide Removal and its role in addressing climate change. The CDR Primer is edited by authors from the University of Pennsylvania and the non-profit organization CarbonPlan, and includes chapters prepared by a team of international authors.

In Germany, an initiative on the issue of CO_2-utilization terminology is planning to prepare a new document named "DIN SPEC" (as in "specification"). Differently from DIN, EN, or ISO standards developed within technical committees, a specification can be considered a pre-standard as its requirements (such as the level of consensus or inclusion of all interested parties) are less demanding. The development of a DIN SPEC under the direction of the German Institute for Standardization (DIN) is open to any interested party, allowing transparency and ensuring integration of external knowledge. DIN SPECs are generally developed through a series of workshops in a relatively short time (usually <1 year), thereby supporting the timely transfer of research findings to market and society: Early definitions of new products or processes as well as description of interfaces to existing systems enhance acceptance of innovations by industry and end-users. DIN SPEC can also be used to develop initial standardization documents in new contexts not yet covered by existing standardization committees. Nevertheless, the DIN SPEC derives recognized authority from its association with DIN and does not conflict with existing standards. The DIN SPEC represents agreement among its authors and can be considered a first step toward further standardization. Work on the DIN SPEC for CO_2 utilization forms part of the German Federal Funding Scheme CO2WIN and will be published in 2022.

CONCLUSION

This review highlights the current inconsistencies in CO_2 utilization terminology and how these can lead to confusion and uncertainty. These ambiguities may negatively affect understanding of these technologies and introduce communication barriers to policy making, funding, and in public discourse. Terminological ambiguities lead to unclear framings and are thus likely to have a particular impact on the future acceptance of, and political support for, such technologies, affecting. The community involved in advancing such technologies, be it in science, industry, or policy making, has understood the importance of precise terminology and is currently undertaking various efforts to provide precise definitions and ensure easily applicable terminology. The work of the Harmonization Team, resulting in the most recent glossary publication on the assessCCUS website, can be considered the most advanced attempt to produce a universal and international CO_2 utilization terminology in the scientific field.

In order to initiate and accompany a goal-oriented and knowledge-based debate on CO_2 utilization technologies in the future, actors in industry, science, and politics are asked to ponder their own choice of wording and assess its accuracy. Whenever possible, abbreviations that lack further explanations should be avoided, as this approach will most likely lead to potential misunderstanding. Rather, it is advisable to use "CO_2 utilization" or "CO_2 utilization technologies" in full in headings and literature. Should this not be possible, it is advisable to use unambiguous abbreviations (such as CCU) together with sufficient clarification. It is recommended that the term CCUS is avoided in order to support precise dialog management. The term "carbon reducing" or "carbon reduction" must also be used carefully outside the CO_2 utilization community, as it may be confused with the chemical reduction of carbon.

This article also aims to raise awareness that consistent terminology is essential for media representatives seeking to better understand CO_2 utilization technologies. In fact, facilitating accessibility and comprehensibility among non-specialists beyond the field is important for facilitating quicker developments in both regulatory and technical fields. Setting clear and unambiguous framework references for public and policy debates in the future is paramount. Purposeful public debate, that results in acceptance and future ability to act, is based on trust. This should always be taken into account when selecting terminology. Trust can be difficult to achieve yet even easier to lose when inaccurate and inconsistent language is used. Trust arises when arguments are transparent and when the issues at stake are clearly and precisely stated. The efforts to develop consistent glossaries are therefore an important building block toward a constructive and honest public debate on CO_2 utilization technologies and their future role in a more sustainable economy and society.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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