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A synthetic review of the trust-participation nexus: Towards a relational concept of trust in energy system transformations to net zero

Abstract

Trust is crucial to achieving sustainability transformations and net zero. Much research has focused on building trust in policies, technologies and behavioural changes related to sustainability. It has been argued that building trust is strongly linked to processes of communication, deliberation and participation. In this article, we reconsider this relationship through analysing how studies of two decarbonisation technologies - carbon capture and storage (CCS) and wind energy - conceptualise trust and approach the relation between trust and participation. In a systematic review of 97 journal articles, we investigate how trust has been defined and conceptualised and how the relationship between participation processes and trust building has been established. Our findings show that trust has mainly been approached through a narrow theoretical lens, primarily as a key factor for gaining acceptance for specific technology projects. In this dominant instrumental framing participation serves as a means to gain trust or overcome distrust. How trust emerges, transforms or erodes, therefore, remains unclear beyond rationalistic assumptions on the role of actors, information provision or participation processes. Drawing on our literature analysis, we propose a new theoretical framework for trust and its relation to participation. This 'networks of trust' approach linked with an ecologies of participation perspective is based on sociological theory and relational perspectives in science and technology studies, enabling a broader understanding of the trust-participation nexus that goes beyond narrow acceptance-based approaches.

Keywords: Trust, Participation, Relational, Carbon capture and storage, Wind energy, Decarbonisation, Sustainability transformations.

1. Introduction

"Perhaps an appropriate final observation in this context is to note the intrinsic futility of trying instrumentally to engender public trust in science, whether by 'public engagement', dialogue, or any other means." [1 p. 219]

Achieving net-zero greenhouse gas emissions by 2050 will involve fundamental transformations on many different levels. One of these transformations concerns the production and consumption of energy for which both societal changes and technological innovations will be necessary. In this article we focus on one aspect that is crucial for this – trust. We turn to the question of trust in large energy infrastructure projects that has been a point of ample scientific discussion. Whereas earlier research attributed the lack of acceptance of such projects to public misunderstandings and a lack of public knowledge associated with an assumed 'deficit model' [e.g. 2–4], more recent contributions have emphasised 'democratic deficits' and stressed the importance of public engagement for trust building [e.g. 5–7]. The central assumption is that organised public outreach will help to overcome public mistrust in science, technology development, and governance.

As indicated by the introductory quote, a simple assertion of trust building through public engagement has been criticised as misleading for several reasons. First, trust and participation involve complex sets of practices that occur in heterogeneous social, cultural, political and technological settings. Trust has been conceptualised in various ways [e.g. 8,9] and it can be directed at many different things – for instance trust in institutions, actors, knowledge or technologies. Likewise, participation has been shown to be highly diverse, ranging from formal invited deliberative processes, consultations, and behaviour change initiatives, through to citizen-led forms of activism, protest, community action, digital engagement, and so on [10,11]. The assumption that participation will generate trust is questionable in light of this heterogeneity. Second, the actors – for instance scientists, companies or 'the public' – and technologies involved in these processes do not exist in pre-given forms but are co-produced and stabilised in socio-material constellations [e.g. 12,13]. Particular participation efforts enact particular publics, stakeholders and experts and thereby add another layer of complexity that makes assumptions on a causal connection to trust building unlikely. Third, in reinventions and reiterations of the 'deficit model' [1] it is assumed that a lack of trust shall be compensated by more public participation. Instead of overcoming public knowledge deficits, here the emphasis becomes one of "fixing technology with society" as public participation is seen as a remedy "for any wayward tendencies of technological development" and a warrant of social acceptance [14 p. 203]. Thus, this 'new' deficit model inherits the flaws of previous ones since it aims to control public responses with monocausal assumptions [1]. For these three reasons, it is unlikely that the nexus between trust and participation can be understood through an instrumental framing that simplistically assumes that participation will lead to trust and can thus be used as a trust building strategy.

Following this line of thought, we suggest it is necessary to study how trust and participation have been connected in previous research and to ascertain if such narrow instrumental framings do indeed dominate. *For this purpose, we analyse how studies on decarbonisation*

technologies conceptualise trust and approach the relation of trust and participation. We conducted a systematic review of trust related research for two decarbonisation technologies – carbon capture and storage (CCS) and wind power. We chose these technologies since a lack of trust by publics and stakeholders has been documented as a challenge in past deployment efforts [e.g. 15,16] and ways to overcome this have been studied. At the same time, these technologies differ regarding their climate policy relevance and deployment history. Wind power is considered an established technology that is deployed on large scales in many countries and features prominently in climate policy programs [e.g. 17–19]. Despite the high expectations of its relevance for climate change mitigation and plans for a speedy roll out, CCS remains an emerging technology with only a few plants operating on an industrial level [e.g. 20–22].

Additionally, and highly relevant for public perception and trust, wind energy and CCS differ in their environmental impacts, visibility, and role in decarbonisation. While environmental issues such as bird and bat fatalities, visual impacts or noise are concerns discussed for wind farms [e.g. 23], the capture and geological storage of CO_2 has been controversial amongst others because of fear of leakages, induced seismicity and delaying decarbonisation [e.g. 24–27]. While wind farms themselves produce renewable energy, CCS is intended to capture, store and thus retain hard-to-abate emissions from industries [e.g. 28] or contribute to carbon dioxide removal (bioenergy with CCS – BECCS or direct air capture with CCS – DACCS) [e.g. 29,30]. Finally, CCS and wind energy can differ in how they are socially organised, with CCS mainly associated with large-scale infrastructure projects led but governments and companies, whereas wind energy can take this form but also exists at smaller scales in projects initiated and governed by local communities [31,32]. We are interested to see whether these technological differences, varying impacts, contrasting perceived risks, and alternative forms of social organisation between wind power and CCS lead to differing relations between trust and participation around these technologies.

Surprisingly, we do not find this to be the case, at least in how existing literatures deal with these relationships. Our systematic review shows that trust has mainly been understood instrumentally as something to heighten acceptance for technology deployment – for both CCS and wind energy. Public participation is marked as an important factor to increase or build trust in a linear way. It is, however, predominantly addressed in a "residual realist perspective" [12 p. 200,33 p. 11] – meaning that engagement is assumed to occur in discrete events, based on pre-given meanings of 'participation' and 'the public', and where pre-defined objectives can be achieved if the right kind of participation is offered. The study of trust is often limited by instrumental assumptions and a narrow focus on a small number of factors (for instance trust in a communicator or a particular interest group). We therefore find that many existing studies decontextualise relationships between trust and participation from the situations in which they play out in the co-production of decarbonisation technologies and society in particular settings.

Building on this literature analysis, we propose a new theoretical framework for the trust-participation nexus based on sociological theory [e.g. 34,35] and relational perspectives in science and technology studies (STS) [e.g. 36]. We suggest that an approach based on *networks of trust* enables the study of trust relations in different '*ecologies of participation*'

[12]. Our theoretical contribution moves beyond the existing literature by connecting a multidimensional approach to trust with emerging developments in STS approaches to participation. This reconceptualisation allows us to study the role of trust in energy system transformations towards net-zero in a comprehensive way and supports policy makers and scientists in acknowledging heterogeneous participation practices and in framing new ones.

The article is structured as follows. The next section describes the methods and data for the systematic literature review. The third section outlines the key findings from our review of wind energy and CCS literature. In particular, it focuses on the definitions of trust, its relationships to participation, and the limitations associated with the prevailing conceptualisations. Based on this, we introduce a *networks of trust* approach (section 4) for the study of the trust-participation nexus (section 5) in energy system transformations towards net-zero. In conclusion, we reflect on the implications of our study for further research and future public engagement and trust building efforts.

2. Methods

To obtain a comprehensive sample of social scientific literature, we searched the Web of Knowledge database for trust research on CCS and wind energy. Table 1 presents the keywords and operators we used. The Web of Knowledge database was selected because it represents widely used, international repositories of peer-reviewed publications [37]. Only peer-reviewed journal articles were considered. This introduces a selection bias to our analysis since other means of scientific knowledge diffusion, like books or reports, are not included in the review process [38]. We addressed this potential bias by carefully checking the references used in our literature corpus and found that peer-reviewed journal articles were dominant in the reference lists. The literature was collected in September 2021. Table 1 provides an overview of the search and selection process and the final sample of articles.

Table 1: Search and selection process for systematic literature review (Topic search: Title, abstract, keywords, keyword plus)

Topics	Search terms	Web of Knowledge Results
Wind energy production	Trust AND wind energy	122
	Trust AND wind farm	44
	Trust AND wind turbine	35
Carbon capture and storage	Trust AND carbon capture and storage	45
	Trust AND CCS	69
Total references	315	
After merging duplicates	213	
Selection 1: Connection to topic based on titles and abstracts	109	
Selection 2: Content differentiation based on introductory and final sections		
	Trust & wind energy production	Trust & carbon capture and storage

N. of articles	54	43

We conducted a systematic review to ensure a transparent literature selection. Following literature review guidelines and other systematic reviews [e.g. 39–41], the selection of papers was done in two steps. First, all duplicates were merged and all papers with no connection to the topic of this review were eliminated based on titles and abstracts. In a second step, the introductory and final sections of the remaining 109 papers were analysed to differentiate the publications further and sort them according to technology and relation to trust. This process resulted in 54 articles on trust and wind energy as well as 43 papers on trust and CCS.

In order to analyse the concepts of trust and their relation to participation (if any) in the texts, we conducted a qualitative content analysis of these article samples. Following Schreier [42], we deduced three broad categories from our research question to collect text passages on definitions of trust, the functions of trust and the relation of trust and participation. For these categories, we inductively defined additional subcodes during the coding process based on the article content (see Appendix).

3. Understandings of trust – results of the systematic review

We present the results of the systematic review in four steps. First, we outline how trust has been defined in the analysed literature. Second, we note whose trust is studied and what that trust is directed at (e.g. technologies, information, responsible agents). Third, we explore the functions that are associated with trust. Fourth, we summarise trust-building approaches and the conceptualisation of the link between trust and participation.

A core finding of the review is that although trust plays an important role in most of the articles we analysed, it is only defined in about 30 per cent of the papers on wind energy and CCS respectively. It is repeatedly acknowledged that there is little scholarly agreement on how to conceptualise and define trust [e.g. 43–45,building upon 46,47,or 48]. Nevertheless, we see a surprising alignment of trust concepts in the analysed articles. This is most evident in the CCS literature that defines trust following two theoretical strands. The first builds on Rousseau et al. [49]and Earle [50] by understanding trust as accepting "vulnerability based upon positive expectations of the intentions" [49 p. 395] of others, thereby arguing for an asymmetrical relation of trust based on dependence on others. The second draws authors like Earl or Siegrist [e.g. 51,52] and follows the assumption that people's trust in organisations responsible for technology management and use affects their risk and technology perception [53] and distinguishes between competence and integrity based trust [e.g. 54–56]. Competence based trust is understood as trust in the experience and expertise of the organisation, while integrity based trust stems from the perception of organisational honesty, openness and concern.

We find more variety of trust concepts and references in the wind power research – for instance, framing trust as "long-term relationship between actors" [57 p. 149] or "a feeling or belief that someone will act in your interest" [58 p. 1391, building on 48]. Still, most definitions (14 out of 17 that provide a trust definition) centre on positive expectations of intentions of

others and the distinction between competence and integrity based trust, drawing on Earl, Siegrist or Greenberg [e.g. 51,52,47].

Following these definitions, the research on trust regarding wind power and CCS is focused on the trust of publics in e.g. project developers, government agencies and authorities, energy companies, NGOs or scientists. In short, trust in actors and institutions relevant for the development, management and operation of the energy infrastructures in question. Related to this is a strand of research studying trust in information, mostly meaning trust in the providers and communicators of such information [e.g. 59,60]. Trust in other aspects, such as the siting process [61] or the technologies themselves [62–64] rarely comes into view. Some publications argue that there is little knowledge amongst publics on these issues and therefore their perception is moderated by trust in actors [43,54,65].

While papers repeatedly note that trust is a general element of reducing complexity [in reference to 34], the main function of trust is seen in gaining public acceptance [66–74]. Especially in projects with high uncertainty and complex, hard to comprehend technologies, trust is seen as a vital element for gaining greater rates of project approval. Often this is considered a mediating effect since trust positively influences the perception of planning process and fairness, risks and benefits or a willingness to pay and thereby strengthens project support [54,58,64,75–81]. This linear relation between trust and acceptance is critically discussed [82] and enriched with complexities [43,45], nevertheless it remains the dominant rationale. Arguments that place trust as the basis for collaboration or co-production of renewable energy governance or technology deployment are less frequent [83–87].

Whereas trust building is less often addressed than the question of whether there is trust in actors or not, we find discussions of multiple influences on the emergence of trust – many of which are interlinked and coincide with common suggestions for technology communication [for an overview e.g. ,88]. There is general agreement on the instability of trust and that it is easy to lose and hard to recover [45,58,87,89,90]. Transparency, fairness and procedural justice in the processes of technology deployment are seen as prerequisites for upholding and gaining trust for wind power and CCS projects. Often, they are connected to public engagement strategies of varying scopes. Suggestions for efforts reach from (complete, balanced, honest) information provision and consultations [69,83] to collaboration, dialogue and meaningful participation in decision-making [e.g. 91,92]. For the most part, participation is seen as an enabler of trust. Fewer arguments place trust as an enabler of participation [e.g. 85].

In an instrumental rationale, the connection between participation and trust is seen on a level of causal relation: institutionalised participation practices focused on lay-publics will lead to trust, which will again lead (directly or indirectly) to energy project support and acceptance [e.g. 66,90]. As we already established, the last part of this equation is shared by many publications in our sample. The instrumental link of participation activities and trust, however, is discussed critically by some. “Alibi participation designs” [70 p. 255] and agenda driven approaches to participation can do little to engender trust and can trigger distrust [93]. Thus, it is stressed that trust building is influenced by the participation setting [94]. The need to open up for meaningful public contributions and for re-distributions of power and authority

in decision making processes are noted [45,84,95], but more in-depth conceptualisations of participation are rare [96,97].

Most notable for such increased conceptual complexity is the contribution by Dwyer and Bidwell [6 p. 168] who explore the participation trust link theoretically and empirically by introducing a "chains of trust" approach. They consider trust as a "belief that individuals or institutions are able and obliged to act in the interest of the public" (ibid.). This belief, in turn, influences and is influenced by the perception of legitimacy, credibility, and competence of key actors. Participation is understood as a two-way interaction with information exchanged between publics and process leaders. There should be no predetermined outcomes, the opportunity to offer input and that input should be valued enough to affect decisions. They specifically ask: "How is trust built during an engagement process?" and propose a model showing the "flow" of trust from trust in process leaders, to trust in process and outcomes and finally acceptance of the outcome [6 p. 168]. For the example of offshore wind farms, they argue that building this chain relies much on informal practices, for instance, engagement in advance of the formal process, having trusted liaisons, providing opportunities for meaningful input and creating a sense of ownership.

In summarising the results of this systematic review, we find that trust is often not defined. Where it is defined it is in a rather narrow sense focused on a few factors, like trust in actors or information. This narrowing down translates into a strong emphasis of the studies on trust in actors and stakeholders. The dominant function of trust is seen to be creating project support. In this instrumental framing, building trust is reduced to a tool for gaining public acceptance for specific technology projects. Even though there is some reflection and critique on instrumental uses of participation, papers that link trust and participation still (implicitly or explicitly) assume an increase of trust and project support by the 'right kind' - mostly meaning non-instrumental, dialogue orientated formats - of participation. Therefore, these understandings of participation remain in a "residual realist perspective" [12 p. 200]. Taking this into consideration, the systematic review opens up two new avenues for work on participation and trust: (i) defining trust in a relational way; and (ii) reconfiguring the relations between trust and participation.

4. Networks of trust – towards a relational theory of trust

In this section, we turn to the first task and propose a relational theory of trust. Rather than thinking of 'chains of trust' that are understood as a sequential process or in emphasising single entities to trust in, we go beyond perspectives in the above review and introduce *networks of trust* to address the interrelations, contexts and prerequisites of trusting in actors, technology, knowledge or processes.

The approach we want to outline is inspired by the contribution of Engdahl and Lidskog [36] who characterise trust as anticipatory, asymmetrical, emotional and relational. While the anticipatory and asymmetrical nature of trust has been noted in some of the CCS and wind energy articles we analysed, the emotional and relational dimensions need to be added and expanded. The relevance of emotions for trust has been outlined multiple times [e.g. 98] but

this aspect is almost missing from the reviewed literature. Likewise, relational accounts of trust, meaning analytical approaches that study interconnections of influences on trust instead of focusing on the effects of individual factors [e.g. 9], are only partially represented in our sample. Our goal is to develop the relational perspective further in order to link it to participation efforts in decarbonisation projects.

Drawing on Simmel, Engdahl and Lidskog we establish trust as **anticipatory** because it necessitates the suspension of the unknown. In reference to the imperfect knowledge that can be acquired concerning the future, Simmel [35 p. 177] places trust close to religious beliefs when framing it as "both more and less than knowledge". In this sense, trust deviates from certainty as trust-givers act as if they know more than they really do amidst the unlimited possibilities of the future [34,99]. Trust, thus, can be considered as a "positive expectation regarding the future" – an interpretation based on uncertain and incomplete information, specific settings and previous experiences [cf. 36 p. 708].

But why is it necessary to take this 'leap of faith'? Trusting in others, technologies, nature or other aspects of the world allows one to achieve outcomes that would be otherwise impossible. In other words, trust enables collaboration and the incorporation of various entities into courses of action. It is, therefore, crucial for all kinds of societal interaction.

> "Without general trust that people have in each other, society itself would disintegrate, for very few relationships are based entirely upon what is known with certainty about another person […]." [35 p. 177]

These benefits of trust are accompanied by costs that represent the **asymmetry** ingrained in the act of trusting [36]. It involves the acceptance of dependency upon others (humans and non-humans) despite not having secure information on what they are going to do or how they are going to perform next. In the case of CCS, we can envision trust in the secure geological storage of CO2. This positive expectation regarding the future is necessary to achieve an otherwise impossible outcome (i.e. hindering CO2 to enter the atmosphere by storing it in geological formations) but it comes with the acceptance of dependence on, among other things, operators of CO2 storage facilities, caprocks, pipelines, and monitoring technology. The same would apply to methods for carbon dioxide removal – like afforestation, where trust comes with accepting dependency on weather conditions (drought, fires), forest management, plant and place selection.

Engdahl/Lidskog [36] add an **emotional** dimension to trust. Building on Mead [e.g. 100] and Barbalet [98,99] they perceive emotions not pejoratively as an irrational distraction, but argue that emotions are relevant for value judgements and meaning making in social life. As "unreflective values" emotions guide the processes of information-seeking and evaluation and are therefore highly relevant for risk assessment and problem solving [36 p. 710, see also 101]. The emotional impact on trust concerns the confidence of trust-givers in others and the outer world as well as the confidence in their own judgement of others and the outer world. This "double confidence" [99 p. 375] is framed as an emotional experience – featuring feelings of positive expectation of the future and safe dependency – making emotions an integral part of situation evaluations and the formation of expectations regarding the future. Thus, Engdahl/Lidskog [36 p. 712] characterise trust as "an emotional attitude, a feeling that affects

our judgements and makes us perceive the world (others as well as ourselves) in a specific way". Consequently and most important for the following relational characterisation of trust, the context in which trust is given includes subjectively asserted qualities of the trust taker (the person or thing that is trusted) and the trust giver (the one who trusts).

Finally, trust is characterised as **relational**. Following Wynne [e.g. 4], Engdahl/Lidskog [36] introduce multiple influences affecting trust, including past experiences, social meanings, social relations, and potential threats to the identities of citizens. Similarly and based on their empirical study of trust in data driven systems, Steedman et al. [9 p. 825] propose to think of "complex ecologies of trust", which are made up of multiple factors "including, experience, perception, understanding and feelings as they relate to organisations, services, people or practices". Our argument is that if we wish to look at what underlies and motivates trust, we need to unfold this relational dimension further. We introduce the figure of *networks of trust* in which trust emerges, is stabilised, transformed, dissolved, re-emerges or fades away. Understood as something that is not fixed but fleeting, temporal and in need of re-enactment, trust is conditional and differs regarding how enduring it is amidst these changes (e.g. differences in the endurance of trust concerning technologies or family). It might turn into mistrust, accentuating doubt and uncertainty, or even distrust, meaning the absence of trust [8]. Asking how trust is stabilised means asking how heterogeneous entities and socio-material settings enable, foster, discourage or hinder trust.

Take for instance Latour's account of a laptop malfunction [102]. Trust in such an everyday technology relies on experience with the device, usage habits and practice in a socio-technical constituted situation that many of us have integrated into our working and private life. In this case, trust can be stabilised so much that it turns into certainty for the individual user (in consequence there is a continuum between trust and certainty, rather than a clear-cut division). Leaning on Luhmann [34], trust in the laptop reduces complexity and allows for more complex interactions since one does not plan for malfunctions under every circumstance. However, a failure occurs in Latour's laptop and it will not connect to the internet. All of a sudden, confidence is lost; trust in the technology emerges as a question. Will I be able to access my emails? Does the backup copy cloud system hold and operate? Can the laptop be relied upon for future work? Can I assess this with my technical expertise? The case of Latour's laptop ends happily and after the device briefly emerged in all its technical and non-technical complexity, it re-enters the state of a trusted working companion after some time for reassurance. Technical support, sound counsel and technical performance re-stabilise the relation of trust or rather re-constitute this relation. The laptop disappears again in daily habits.

We could go on and explore how policies for the digitalisation of work in the (social) sciences, the interaction of software and hardware, internet dependent working environments and much more co-produce the relation on a larger scale and make such a performance of trust possible (and necessary), but this shall suffice to illustrate the mixed-bag of socio-technical constellations that enable the continuous performance of trust in an everyday technology. We see that it is not trust in one entity per se – for instance, the laptop, the technical staff, Microsoft or one's own technical proficiency – but a network of human and non-human associations that make trust possible as an "assemblage" [e.g. 103 p. 91]. We do (or do not)

trust these different entities but this singular trust cannot be understood on its own. They become relevant in multiple, intersecting *networks of trust*.

While most aspects concerning trust in larger, less personal technologies are already present in this example, we need to introduce another thought to capture the political and cultural dimensions of trust before returning to our decarbonisation technology examples. As noted for the laptop, trust is co-produced. This co-production of trust in a technology or any other human or thing also includes the political and cultural contexts for trusting and the norms and beliefs that accompany it [104]. Such contexts impact how an issue or technology is constructed, framed and understood and, therefore, need to be considered for the building and fading of trust. Jasanoff calls upon a comparative study of biotechnology and genetically modified crops in Britain, Germany and the United States [105] to exemplify how "an entire technology […] was defined to harmonise with underlying visions of the state and its rights and obligations vis-à-vis citizens" [104 p. 8]. Drawing upon studies of media representations of CCS in different countries it becomes clear that CCS in Finland [106] and in Germany [27] are constructed differently, for instance, according to the national and European climate policies and discourses, storage capacities, energy consumption and production patterns, and that these conceptions of CCS change over time. Rather than being a given entity, CCS is constituted in "historically situated real social practices" [107], hence the understandings of what CCS is are not (easily) interchangeable across contexts. In this sense, a multitude of networks of trust can or cannot be established related to CCS in different contexts. In short, one cannot assume a priori that CCS means the same in Germany as it does in Finland, and trust in CCS in both countries may mean something completely different.

These theoretical considerations have strong implications for the empirical study of trust in CCS or wind energy. With a networks of trust approach the investigation of trust in actors, policies, information or technologies appears truncated if it leaves aside the rich "hinterland" of socio-material constellations [108 p. 28]. Rather than developing trust building efforts that aim at 'the public' or stakeholders, it is necessary to explore the heterogeneous arrangements that underlie trust. Taking the example of CCS, we would have to study how, for instance, national climate policy, divergent understandings of CCS, perceptions of (ir)responsible companies, governmental agents and scientists, its presentation as a technical solution for climate change mitigation (especially in comparison to other options), the monitoring of CO_2 storage sites, and the application of CCS (be it for achieving negative emissions through coupling bioenergy or direct air capture with CCS or for enhanced oil recovery) factor into *networks of trust* and constitute them on different governance levels. The same is true for wind turbines and wind energy production. What wind energy means in a certain context is constituted as much through turbine type, placement, and local environmental settings as through energy grid infrastructure, feed-in regulations and tariffs or energy policy. Therefore, understanding trust in wind turbines requires context specific assessments of influencing factors [for details on the wind energy landscapes see 109]. Of course, this list is not all encompassing and many more relevant influences could be named, but it shows the length to which empirical trust research on large decarbonisation infrastructures would have to go based on the proposed theoretical framework.

In this section, we have defined trust as positive expectation regarding the future (this technology will work, this knowledge will stay true, this human being will not betray me, and so on). We have shown that trust is an interpretation that is anticipatory, necessarily includes the acceptance of dependency in an unknowable setting (asymmetry), has an emotional dimension, and is constituted in heterogeneous, intertwined socio-material networks. Now we turn to the second question and ask: how does participation as one 'node', so to speak, factor into these networks?

5. Relations of trust and participation

Our systematic review finds that where participation and trust are linked in academic studies, participation is conceptualised as an enabler of trust. Participatory practices are believed to increase trust in technological projects and therefore their acceptance [e.g. 66,90]. Rather than attesting to a 'knowledge deficit' as the source for opposition to technological projects the articles turn towards a deficit of participation [1]. In an instrumental framing, it is assumed that making up for this engagement deficit through increased efforts at participation will also (re-)establish or increase trust. It is noted that the contexts of participation, like proper options for dialogue instead of one-way communication or early, honest and open engagement, are important to enable meaningful participation and to actually achieve an increase of trust [e.g. 6,70,84,93]. However, under this perspective, participation and trust appear as fixable and controllable given the right configurations of 'the public', communicators and participation formats. These approaches, therefore, adopt what has been called a "residual realist perspective" on participation, which assumes a pre-existing external public composed of autonomous individuals, narrowly defined formats of participation that occur in discrete events, and linear cause-effect understandings of the impacts of participation, for example between the performance of participation and the (re)gaining of trust [e.g. 110 p. 353].

Based on our *networks of trust* approach, participation can hardly be a single 'silver bullet' in a network of entities affecting trust in a specific situation. The argument that is brought forth here is that participation is not a fixed entity that might solve a lack of trust. Instead, the connection of trust and participation cannot be pre-determined and to understand it participation needs to be studied in its heterogeneity. Drawing on a "relational co-productionist" [e.g. 110] perspective on participation, we assume that publics are multiple socio-material collectives constructed through participatory practices and not predating them. These practices themselves are highly diverse and, for decarbonisation technologies, "always co-produced – i.e. entangled with, shaped by, and shaping other collective practices and the energy system in which they are situated." [12 p. 201]. Participation does not have a linear impact but stirs multiple 'intermediaries' [103] and affects that cannot be predetermined. Lastly and most importantly, participation does not happen as a single event but is part of ecologies of diverse, interrelating participatory collectives and practices [12].

Taking this into consideration, the relationship between participation and trust presents itself as an open question that requires empirical investigation. Simple and linear linkages can only cover a few of the possible connections between these practices. Looking beyond

institutionalised participation efforts there is a need to study the dynamics of trust in different *ecologies of participation.* Instead of focusing on discrete participation events, research needs to recognise, attend to and map the diversities of, and interrelations between, "socio-material collectives of participation and public involvement that make up wider spaces such as systems, issues and constitutions" [110 p. 358]. This includes a multitude of collective participatory practices, like "public opinion surveys, deliberative process, behaviour change initiatives, digital democracy, citizen science, protests, activism, community energy, and everyday social practices which consume energy" [12 p. 308], in which subjects, objects and models of participation are performed and constructed. Additionally, wider spaces of participation have to be considered, meaning spaces "within which multiple participatory practices connect and interrelate" [12 p. 308]. These are, in turn, situated in the regulations, policies, social practices, socio-technical imaginaries or forms of public reason established in a political culture and relevant to the issue at stake. This approach recognises diverse forms of participation that are commonly excluded in a residual realist perspective, but which have important effects on relations of trust.

Combining the *networks of trust* and *ecologies of participation* frameworks, we argue that trust emerges, transforms and erodes differently in relation to participatory practices. To illustrate this and the implications for trust research, we now apply our theoretical considerations to CCS and wind energy. In a residual realist model, trust is the result of a participation process done right and the list of suggestions for an ideal public engagement process is long. For instance, early, honest, complete information provided by a competent source, a participation setting that enables dialogue, collaboration and leaves room for a meaningful impact of public and stakeholder needs and concerns would increase trust in a carbon storage or wind turbine project and positively affect its public acceptance. In a relational co-productionist perspective, we need to ask how subjects, objects and models of participation are performed, how they frame applications of CCS or wind energy in one setting, and how diverse participatory collectives are interrelated and contest or support these frames.

When we turn to the example of the capture and storage of residual emissions from a steel mill, we might think of a formalised participation setting with stakeholder information and exchange and study how trust is affected by this intervention. In this perspective, with its scope and frame focused on the feasibility of one application of CCS in one setting and with one participation approach, we miss a considerable amount of participation activities on various levels. Other interest groups or initiatives might engage with the problem of residual emissions differently, for instance, questioning if emissions from a steel mill are hard-to-abate and essential, if steel could be replaced by alternatives or if other routes for decarbonisation (like hydrogen) would be possible. The existence of these groups and the discussions surrounding it affect the trust that might be gained by the formalised participation setting.

We see this also for wind turbine deployment, albeit with different discussions and influences. Formalised participation efforts might aim to provide information on bird casualty rates or noise emissions from the turbines and thus, seek to address some of the most common concerns related to this technology. Again, such a formalised practice risks rendering invisible other modes of participation that might connect to the regional expansion of renewable

energy in varying ways and affect trust in a new wind power installation. Examples for such activities are initiatives that focus on energy grid stability or the overburden of energy lines that are not being enhanced quickly enough. Other efforts in regional energy transitions that might bring economic counter-arguments to a new wind turbine to the table would be forgotten as well as initiatives with a strong focus on energy savings.

As participation multiplies in both examples instrumental efforts to engender trust in publics or stakeholders seem futile since only minor aspects within this wider ecology could be controlled. This does not mean that all (formalised) participation efforts are in vain, but considering them an instrumental enabler of trust would overestimate their role in wider networks of trust.

With this new scope of research on the participation-trust nexus a broader set of actors, interests and non-human entities need to be taken into account, in a more thorough and reflexive analysis. Rather than following instrumental assumptions, the study of *networks of trust* in different *ecologies of participation* allows us to assess the role of trust in energy system transformations towards net zero in a more comprehensive and multi-dimensional way. Thus, this framework can support scientists, policymakers and wider society in acknowledging heterogeneous participation practices, avoiding the harmful and futile attempts to control trust with any measures of participation, and framing public engagement efforts directed at taking responsibility for one's own trustworthiness.

6. Discussion and conclusion

In this paper, we set out to analyse how studies on decarbonisation technologies conceptualised trust and approach the relation of trust and participation. To do so, we conducted a systematic review for trust related research on wind energy and CCS. Surprisingly, given their distinct socio-material configurations, we find few significant differences between studies of these two technologies. Instead, an instrumental perspective on trust and participation is common in articles on CCS and wind energy. The theoretical lenses applied in the reviewed literature can explain this alignment. They emphasise overarching individual factors for trust – like trust in actors, institutions or provided information. While these are relevant, a sole focus on them remains generic and thereby neglects the heterogeneous influences specific for the two decarbonisation technologies.

Upon finding mostly narrow approaches to both participation and trust in the literature, we offer a new theoretical orientation rooted in a relational co-productionist understanding by establishing a link between *networks of trust* and *ecologies of participation.* The most important features and conceptual consequences of this theoretical readjustment are summarised in Table 2*,* which contrasts instrumental and relational approaches to the study of trust.

Table 2: Contrasting instrumental and relational understandings of trust

	Instrumental understanding of trust	**Relational understanding of trust**

Theory	Assumed causal connections for trust building and gaining trust	Emphasises heterogeneous relations that create, change or stabilise trust
Functions of trust	Providing acceptance and support for decarbonisation projects	Reduction of complexity, enabling goal attainment through forming (social) relations
Who trusts? (subjects of trust)	Publics/stakeholders as individual actors	*Networks of trust* where objects and subjects of trust and the methods of trust-building are co-produced and distributed
Who is trusted? (objects of trust)	Trust in individual actors, singular entities or practices	
Trust building	Occurs in organised and planned practices with particular methods and tools	Occurs through diverse, non-linear practices that cannot be controlled
Participation	Participation as a key means of trust building – assumed linear causal relationship between participation and trust	Participation as one relevant aspect in networks of trust, emerging in '*ecologies of participation*'

An instrumental understanding of trust assumes a causal relationship between trust-building measures and the actual gain of trust. Publics or stakeholders, which are perceived as groups of individual actors, are the subjects of trust, meaning those who trust in someone or something. Trust-building is understood as an organised and planned practice with defined (and refinable) methods and instruments [e.g. 66,90]. It aims to build trust in individual actors, individual institutions or practices related to the decarbonisation project (e.g. technologies, communication measures, company representatives) [e.g. 54,59,60,65]. In this perspective, the trust gained acts as an acceptance and support provider for decarbonisation projects. Participation is seen as key to building trust. Although it is noted that agenda driven approaches to participation will do little to engender trust [e.g. 93] its conceptualisation remains residual realist. In a linear conception of time, trust appears as a condition that can be generated and fixed for an occasion (e.g. energy project approval or deployment phase).

A relational understanding of trust emphasises the heterogeneous interconnections and complex intermingling that creates, changes or stabilises trust in a specific setting. Understood as positive expectation regarding the future, trust reduces complexity since not all eventualities need to be considered and it allows one to achieve otherwise impossible outcomes at the cost of accepting dependency on actors, technology, natural phenomena, and so on. However, trust is not a fixed condition but is continuously performed and thus, changes over time, being stabilised or losing stability in networks of socio-material associations. The objects and subjects of trust are not pre-given but co-produced in these networks. The same holds true for trust-building practices, which are not always planned and organized, but often involve unsystematic and non-linear approaches whose outcomes cannot be fully controlled. Participation can be a relevant node in *networks of trust*, but it is not considered as an instrumental and organised enabler of trust. The relation of trust and

participation becomes a question in multiple *ecologies of participation*, likely to affect trust in different ways.

Based on our proposed reconceptualisation, research on trust in large energy infrastructure projects related to net zero becomes much more challenging as seemingly causal connections dissolve and influences multiply. Future studies should reflect on frequently reproduced assumptions on who the subjects and objects of trust are (who needs trust, of whom, in what?), study the rich contexts of trusting and question if and how trust can be built. Especially, the conventional relationship between participation and trust that has been revealed by our systematic review needs to be reassessed and examined in heterogeneous contexts and practices of public engagement with decarbonisation technologies. This does not mean that participatory approaches to decarbonisation technology implementation are doomed to fail, but simplistic attempts to control trust and engender it at a particular point in time for a particular project or goal through participation appear futile from a *networks of trust* perspective.

From a practical point of view and as policy implication it is important to let go of instrumental attempts to control trust or the search for trust building recipes and focus on "the only thing which one can expect to control, and to take responsibility for […] is *one's own trustworthiness"* [1 p. 220]. The literature already suggests ways how this can be achieved. Wynne argues that the closest that institutions might get to 'guaranteeing' public trust is to cultivate their own trustworthiness by "being openly self-aware and questioning […] about their own imaginations and assumptions of science (which would include a lack of control) and of publics". This includes being brave enough to concede power in decision-making and being open to alternative framings of decarbonisation problems and solutions. It also requires those who seek to engender trust, to trust in the assessment of others instead of aiming to guide, limit or control it.

The implication for participatory practices is that instead of instrumentally predetermined engagements there is a need to seek out, acknowledge and encourage participation in the terms of heterogeneous publics and stakeholders. This means that there cannot be a standard procedure in diverse contexts, but that a context specific (co-)design of participation is required. Opening up decarbonisation technology assessments for pluralistic appraisal that involves a multitude of perspectives [111], practising "technologies of humility" [13 p. 227] – including reflections on blind spots and articulations of uncertainty or non-knowledge [112] – and encouraging deliberative mapping [113] and experimentation [114] have been offered to enable non-instrumental participation. These suggestions resonate with Chilvers and Kearnes' [110] suggested virtues of good participation from a relational co-productionist viewpoint: "Reflexivity, humility, diversity, responsibility, responsiveness, experimental" and can be complemented by their collection of approaches for reflexive, responsible and ecologised participatory practices [110 p. 356-363].

Based on the analysis and arguments presented in this article, we see two important avenues for future decarbonisation technology research related to trust. A first line of inquiry turns towards the empirical research on trust in diverse *ecologies of participation* in energy system transformation towards net zero. Much like different forms of participation induce different

visions of energy futures [11], it needs to be explored if and how diverse forms of participation are linked to different experiences and qualities of trust (and vice versa). There is a need for cross-regional or cross-country comparisons to contrast institutional, regulatory, political, cultural and environmental factors that strongly factor in the configuration of larger participatory contexts. One limitation of the systematic literature review in our study is the focus on two large decarbonisation technologies. Issues of public support and trust have been much discussed for these types of large-scale technologies, and increased attention to more everyday energy practices or technologies, such as heating [115], laundry [116] or ventilation routines [117], could benefit from the application of relational perspectives on trust and participation. Furthermore, our search strategy is limited by the selection biases in the Web of Knowledge database with its main focus on journals and less on other types of publications relevant to social scientific research (e.g. books, reports) [38]. We tried to counter this bias by carefully checking the references in our literature corpus for relevant literature beyond peer-reviewed journal articles. Nevertheless, some topics might be overlooked if they frequently appeared in books or reports.

The second research avenue aims at questions on the trust-participation nexus that received little attention so far. Can there be too much 'opening up' of development, deployment or decision-making processes? Could this limit trust in the expertise of those 'opening up' the process or could a strong emphasis on non-instrumental participation lead to the prolonged deployment or introduction of energy related practices, technologies or regulations (e.g. the wilful obstruction of energy innovations by interest groups through participation)? Are there different endurances of trust? Since trust has predominantly been treated as a condition of a specific time and event, it remains unclear how long trust lasts and what factors influence its durability at a systemic level. Taking the example of CCS, we have to consider different temporalities related to the capture, transport and storage of CO_2 as the last part needs to be trusted for hundreds of years. Finally, how are trust and trust building affected by power relations? This would be especially interesting in cases in which power differences are so prominent that all participation must appear as an alibi since the ability to make decisions seemingly or actually rest with one group of actors. With the presented reconceptualisation of trust and its connection to participation, this article hopes to provoke discussions on these issues and stimulate further research.

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Appendix: Code overview

Code	Code description	Example
1. Definitions of trust	This code is used for text segments that define trust. This may mean that the authors themselves introduce a definition of trust or that they refer to already existing definitions as a basis for the text.	"Trust is a difficult concept to define, but in this context, we consider trust to be a belief that individuals or institutions are able and obliged to act in the interest of the public [35]." (Dwyer/Bidwell 2019: 168)
1.1 Trust in what	This code is used for text sections that indicate what trust is directed towards. For instance: trust in actors, trust in institutions, trust in technologies, trust in processes or trust in information.	"With technologies such as CCS where public knowledge is low, the public's willingness, or lack thereof, to accept uncertainty is often linked to the trust that they have in the organisations, institutions and individuals that are developing and promoting the technology." (Howell_et_al_2014: 497)
1.2 Dynamics of trust	This code is used for text segments that outline how trust changes over time. This can refer to statements on the emergence, transformation or erosion of trust. It also applies to text segments that position trust as something stable and negate changes over time.	"The public can lose interest and patience due to low levels of shared power, which can further damage the public's trust in authorities and intensify the original conflicts." (Liu et al. 2018: 2)
1.2.1 Trust building	This code is used for text segments that state how trust can be build. This applies for instance to descriptions of methods for trust building, trust building concepts or empirical investigations of trust building processes.	"Build trust and confidence: perceptions of risk are influenced by trust and confidence in institutions and procedures; it takes years to demonstrate competence and integrity, once trust is lost it can damage prospects for an SLO for future proposals in other technologies." (Gough et al. 2018: 24)
2. Functions of trust	This code is used for text segments that state functions of trust, meaning the effects and influence trust is considered to have in the context of wind farms or CCS technology.	"The relation between benefit and risk perceptions is mediated by trust, especially in the absence of knowledge about a hazard, with a higher trust in involved actors being related to higher perceived benefits, lower perceived risks, and a more positive acceptance of a hazard or technology." (Linzenich et al. 2020: 2)

2.1 Generating support	This code is used for text segments that outline the role of trust in generating support for a technology. This can, for instance, refer to statements that see trust as enabler of public or stakeholder acceptance or support. It also applies to text segments that position trust as preventing opposition.	"For the public to accept new technologies, trust and convictions play an important role." (Wallquist et al. 2012: 919)
2.2 Technology perception	This code is used for text segments that present trust as a factor for the perception of technologies. This can refer to arguments that connect trust and risk or benefit perception. It also applies to arguments that see the reduction to complexity of an issue as a function of trust.	"The strong body of literature developed over recent decades indicates that trust in public institutions is strongly related to risk perception […]." (Bronfman et al. 2012: 247)
3. Trust and participation	This code is used for all text segments that describe connections between trust and participation. Arguments against a connection of trust and participation would also receive this code.	"Most available research suggests that trust influences people's perception of the planning process as fair and (thus) fosters public participation and co-operation" (Botetzagias et al. 2013: 4)
3.1 Participation methods	This code is used for any descriptions of specific methods of participation that are connected to trust. For instance, participation approaches as trust building measures.	"Of our case studies, only the ET project proponents have gone far beyond the minimum regulatory requirement of two public meetings. They maintain information booths at community events and have hired a local "community relations manager" who knocks on doors, asks about peoples' concerns, finds community leaders to act as allies, and has a keen sense of regional organized opposition groups." (Fast/Mabee 2015: 32)
3.2 Concepts of participation	This code is used for text segments that define what participation means.	"Meaningful participation requires openness and the opportunity for participants to determine the processes and outcomes, it cannot therefore be undertaken with the assumption that certain participants (i.e. objectors) are wrong or less legitimate." (Aitken 2010: 1839)