Utilities Policy 70 (2021) 101181

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: http://www.elsevier.com/locate/jup

Using socio-technical analogues as an additional experience horizon for nuclear waste management A comparison of wind farms, fracking, carbon capture and storage (CCS) with a deep-geological nuclear waste disposal (DGD)

Dörte Themann *, Achim Brunnengräber

Freie Universität Berlin, Ihnestraße 22, 14195, Berlin, Germany

ARTICLE INFO

Keywords:
Socio-technical analogues
Nuclear waste management
Socio-technical ensemble

ABSTRACT

Energy technologies can be described as socio-technical ensembles, in which social, political, economic and technical dimensions are embedded. Based on this concept as well as other theoretical approaches dealing with the deployment and development of technologies (e.g. the multi-level perspective of Geels (2002)) this contribution investigates the dynamics and interactions that can occur within the socio-technical ensemble of a deep geological disposal (DGD) for high-level radioactive waste (HLRW). We compare socio-technical analogues and relate findings of three energy technologies with large-scale infrastructures to a DGD. The analysis is based on a systematic literature review and aims to gain indirect knowledge for nuclear waste management (NWM) deduced from the dynamics within the socio-technical ensembles of wind farms, fracking and carbon dioxide capture and storage (CCS). The analysis is based on a systematic literature review along four central dimensions with eight respective criteria e.g. public participation, conflicts, role of science, etc.

1. Introduction[1]

The criteria-based search for a deep geological nuclear waste disposal (DGD), in which high-level radioactive waste (HLRW) can be stored permanently and as safely as possible, is a unique process in the Federal Republic of Germany. The choice of the Gorleben site, which was primarily a political one, cannot be used as a model for such a process, unless it is regarded as a negative example. The possibility of applying empirical knowledge about DGD from other countries to Germany has already been explored (Brunnengräber, 2019a; Brunnengräber et al., 2018; Di Nucci et al. 2017). However, due to the different conditions of social contexts, the potential of transferring those findings are very limited. Therefore, we have chosen a different path with regards to the methodology, which enables us to gain indirect knowledge of the dynamics and designs of the search for a repository. In this way, possible problems – and possible countermeasures– can be identified early on. We are looking for socio-technical analogues, i.e. insights regarding factors that could have stabilizing or destabilizing effects on largescale infrastructure projects that we can gain from partly similar socio-technical ensembles, to then transfer them to nuclear waste management (NWM).

For this purpose, three major energy technologies[2] and systemic elements within their ensembles are analysed in comparison: wind farms, carbon dioxide capture and storage (CCS) and hydraulic fracturing (fracking). Although these technologies are highly different, they are all deployed in the context of large infrastructure projects and are socially contested. Two of them are set underground and generate negative perceptions towards their impact on health and ecosystems (e.g.

* Corresponding author.
E-mail addresses: d.themann@fu-berlin.de (D. Themann), achim.brunnengraeber@fu-berlin.de (A. Brunnengräber).

[1] This text is a contribution of the Environmental Policy Research Centre (Forschungszentrum für Umweltpolitik – FFU), Freie Universität Berlin to the project "Methods and measures to deal with socio-technical challenges in storage and disposal of radioactive waste– SOTEC-radio." The project is funded by the Federal Ministry for Economic Affairs and Energy form 2017 until 2020 (FK 02E11547C).

[2] Energy technologies do not only include technologies that serve for the generation of energy, but also those that result directly from its use. These include, for example, CCS or a repository for nuclear waste. With the extension of this term, we want to emphasise that all elements of a value chain can be part or interlinked in a socio-technical ensemble.

https://doi.org/10.1016/j.jup.2021.101181
Received 18 October 2019; Received in revised form 31 August 2020; Accepted 21 January 2021

groundwater risks) as well as on the climate. As it is the case with the extension of renewable energies, also wind farms show an increasing resistance potential deriving from maldistribution of benefits and procedural unfairness (see Leiren et al., 2020; WinWind, 2020). Moreover, especially the underground technologies are difficult to monitor and therefore carry with them known and unknown risks. The insights of those analogues towards supporting or (de-)stabilizing factors on the regime level (see Section 2) is going to be applied to NWM, to appraise potential challenges and dynamics the siting for a DGD would face.

The aim of our analysis is to describe the socio-technical ensembles of the three energy technologies and their respective large-scale infrastructures based on a set of criteria. In comparison, we work out their characteristics as well as their connection to a DGD. Besides, we will examine the usefulness of the analogues approach itself. Thus, a further aim is to assess the usefulness and appropriateness of this approach for anticipating dynamics and developments of contested technologies. Our contribution is structured as follows: We start with explaining the concept of socio-technical ensembles (Section 2) as well as the analytical framework for the comparison, including the criteria that are used (Section 3). In the following section, the energy technologies are briefly presented (Section 4). The main part focuses on identifying similarities and differences of these technologies (Section 5). Finally, we will compare the empirical results with our theoretical considerations (Section 6) and explain the possible implications of our analysis for NWM (Section 7).

2. The socio-technical ensemble

Scientific knowledge is by no means neutral or apolitical. Knowledge integrates the social and is at the same time part of it. The same interaction can also be observed for technologies (Jasanoff, 2004, p. 3). The interweaving of different technical, social, political and economic dimensions leads to a co-evolutionary (Markusson et al., 2012) or co-productive (Jasanoff, 2004) process; we summarize this under the term socio-technical dimensions. There are various approaches of different disciplines to how and why technologies assert themselves against others. According to Bijker, (1995), social actors take the initiative, form networks and initiate processes for preparing and making decisions about the development of certain technologies. This creates a socio-technical regime that shapes a technology in a specific way. Therefore, social interests and expectations as well as attributions of meaning and discourses have to be considered when looking for the reasons why technological trajectories and specific technologies prevail.

Geels' concept of a "multi-level perspective" offers an additional understanding for the dynamics of technologies. He understands transitions as the result of an interaction of multidimensional developments on three analytical levels: "niches (the locus of radical innovations), socio-technical regimes (the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems), and an exogenous socio-technical landscape" (Geels, 2014, p. 23, 2002). Technologies are therefore developed in a multi-level system in which both small-scale influencing factors at the edges as well as the deeply rooted socio-technical paradigms and paths at the centre of the technological system as a whole are taken into account. According to Geels, the regime (the meso level) is central and consists of cultural aspects and symbolic meanings, markets and user preferences, infrastructure, techno-scientific knowledge/science, industry, policy and networks (Geels and Schot, 2007, p. 401; Geels, 2002, p. 1263).

Also, Grieβhammer and Brohmann consider the "sociotechnical regime" to be the dominant and prevalent level. Such regimes contain specific power relations, the influence of certain institutions or different availabilities of resources. This interaction can promote competing technologies or incremental innovations at the regime level, but it can also prevent major changes. The development of visions or radical innovations often takes place in niches that challenge the regime. The landscape, meanwhile, represents superordinate processes and events which, like niches, can exert a certain pressure to change regimes (Grieβhammer and Brohmann, 2015, p. 17). However, the landscape can also be designed in a way that prevents innovations.

Instead of a technological "system", we like to refer to a "socio-technical ensemble" which is composed of the explained multitude of levels as well as several additional systematic elements (Bijker, 1995, p. 249). The term ensemble illustrates the interrelation between the technical facility or construction, different collective actors, stakeholder groups and institutions as well as different levels and subsystems of social action (Bijker, 1997). This definition as well as the MLP concept make clear, why a comparative analysis reduced to individual infrastructure projects would not be sufficient to deduce analogues in terms of understanding overall dynamics within an ensemble. Narratives and shock events occur on the landscape level, path dependencies strengthen the regime level, which are both independent from individual projects but shape the perception of collective actors and influence the deployment of a technology.

This ensemble concept applies to the management of HLRW as follows: at the regime level, nuclear energy is produced by powerful collective actors who have little interest in the construction of a DGD. This is because even the search for a disposal is difficult and the construction is costly, they can therefore contribute to the delegitimisation of nuclear energy. The critical public, civil society (environmental) groups and opposition to nuclear energy production have developed on the niches level. They have emphasised the uncompleted task of storing the HLRW as safely as possible. Actors in these niches formed parties (Die Grünen – The Greens) and brought the problem into governmental institutions, advocated for the phasing-out of nuclear energy and for the development of renewable energy technologies. In doing so, they challenged the regime.

External events such as the reactor catastrophes in Chernobyl (1986) and Fukushima (2011) can be considered as part of the socio-technical landscape as well. Similarly, technological innovations (such as photovoltaics and wind energy) developed at the niche level have fuelled a social discourse about renewable energies. The dynamics and interactions outlined here ultimately form the superordinate ensemble of a specific energy technology: the ensemble of nuclear energy. For a comparison of different energy technologies, not only individual factors play a role, but also the complex interactions or their "coupling" in the respective ensemble (Bijker, 1995, p. 250, 1997; Weingart ,1994).

3. The analytical framework – using socio-technical analogues

The approach to evaluate analogous technologies to produce more evident predictions towards the dynamics and developments of a certain future technology is part of technological impact assessment and comparative analysis. Although at first glance the approach seems to be valuable, not much literature is available towards using analogues for a forecasting assessment. This paper also aims to assess the usefulness and suitability of this approach for forecasting assessments of potentially contested technologies, especially the disposal site for HLRW.

Using socio-technical analogues, we intend to further investigate the dynamics and interactions that can occur within the socio-technical ensemble of a DGD and draw lessons especially for the site selection process as it started in Germany in 2013. The method to learn from historical analogue case studies has already been used by a research project in the UK (Markusson et al., 2012; Chalmers et al., 2013; Watson et al., 2014) for the analysis of the CCS technology.[3] Within this project researchers asked the question "what lessons can be drawn from historical analogue case studies about the conditions under which the uncertainties facing CCS technologies could be managed or resolved?" (Watson et al., 2014: p. 193). In contrast, the question of our contribution is more general in the way that we ask whether we can deduce or forecast possible future dynamics in the search for a DGD in Germany and what potentials does the approach of assessing socio-technical analogues offer for NWM?

A systematic comparison of analogues can only be achieved on the basis of criteria that enable us to reduce complexity and provide us with a framework of orientation. Markusson et al. mention the following elements: "(s)ocio-technical systems are therefore conceptualised as clusters of aligned elements, such as technical artifacts, knowledge, markets, regulation, policies, cultural meaning, rules, infrastructure, etc." (2012, p. 905). With those elements we mostly refer to the central regime level of an ensemble.

In order to describe the socio-technical ensembles and subsequently compare them, we have created an analytical framework that includes elements described in the theory of socio-technical ensembles, as mentioned e.g. by Geels (2002), Geels and Schot (2007) and Markusson et al. (2012). The criteria mainly represent elements or dimensions which Geels (2002) identified as significant for constituting the regime of a technology as events and aspects on the niches or landscape level are highly individual for each technology. Also, to analyse the niches or landscape level of the technologies would have meant to provide a broader actor analysis and to extent the research in terms of historical developments as well as the analysis of past events, shocking events and competing technologies. But to give a first impression, we also refer to conflicts which are also part of the niches level, because alternative societal values and visions derive from the micro niches level and challenge the established socio-technical regime level and its actors. Also, the dimensions and criteria cover aspects that we found in our earlier research on the DGD in Germany rather important, like risk perceptions, resistance, acceptance, regulatory mechanisms and participation (Brunnengräber and Di Nucci, 2019). We deduced four central dimensions and formulated eight criteria for comparison that can be applied equally to our four energy technologies. Our analytical framework comprises:

- **Cultural significance**: 1) Goals, visions and narratives, 2) Conflicting values and protests, 3) Social acceptance
- **Knowledge**: 4) Safety, risk potentials and risk perception, 5) Role of science
- **Policy and regulation:** 6) Participation and public participation, 7) Key institutions and regulatory mechanisms
- **Technical artifacts:** 8) Reversibility (withdrawal or change of decisions)

Nevertheless, to use this approach, one needs to be aware of its limits and its possible shortcomings. Donnelly (2003) points out that the exactness and precision of this approach is highly disputable. It can help guiding forecasting assessments, but exactness depends especially on the chosen analogues for the comparison. In addition, one should be aware of the vast amount of factors and dimensions that influence the development of a technology (ibid.).

4. Four energy technologies at a glance

In this section, the three analogous energy technologies as well as the DGD are briefly presented. The selection of the technologies was based on the consideration that all four technologies include large-scale infrastructure projects that involve far-reaching interventions in nature, land consumption, or even risks. Those energy technologies cause manifest social conflicts in terms of protest and therefore require early public inclusion and extensive participation measures. Fracking and CCS both need underground infrastructure and produce similar risk perceptions as a DGD. Wind energy instead can teach us a lot of general lessons about participation and resistance regarding large-scale infrastructure projects. Nevertheless, the technologies are still very different and are developed and executed in different contexts. So, the technologies only show partly analogous aspects.

4.1. Wind energy

Wind energy as we know it today has established itself in recent decades as a "technical environmental innovation" (Ohlhorst, 2009, p. 22). In contrast to nuclear or coal-fired power stations, which have led to centralised supply structures, wind energy is a decentralised renewable energy technology (Fuchs, 2016). Wind power initially developed in niche markets and as a form of energy arranged by citizens. Therefore, at the beginning, it was seen as a more democratic form of energy production and distribution. Today, however, wind energy is mainly produced in large wind farms, which are socially contested and are facing increasing protest from civil society and local actors (Di Nucci and Krug, 2018). Nevertheless, wind energy – alongside photovoltaics and biomass – is the most important renewable energy source in Germany. In 2018, 29.213 wind turbines were installed in Germany, which generated an output of 52,913 MW (BWE, 2019). In the EU-28 wind energy had in 2018 the second largest share of installed power generation in EU-28. The installed capacity amounts to 178.8 GW (WindEurope, 2019).

However, both in Germany and in several EU countries, wind energy has become a subject of social debate. The acceptance of wind farms rounds around 55 percent of the immediate neighbourhood (BWE, 2019). This is due to the real or perceived visual impact on landscapes, noise annoyance (including infrasound), public perception of health risks, local environmental disruption harming local fauna and flora, negative impact on recreation, tourism, land and real property value loss, but also due to lack of public involvement and participation.[4]

4.2. Hydraulic fracturing

Hydraulic fracturing or fracking is a method used to extract crude oil and natural gas from mainly non-conventional deposits. Non- or unconventional means that the gas or oil does not flow out of the well freely, but must be pressed out. So far, fracking has been practiced in Germany mainly in Lower Saxony, where three fracks were used to extract shale gas and 325 to extract tight gas as well as gas from conventional deposits (German Environment Agency (UBA) 2014). Since 2017, unconventional fracking has been prohibited in Germany, as the method still poses environmental and health risks and many aspects of

[3] Markusson et al. (2012) have tried to show the interactions of different dimensions. In a first step, they evaluated social science literature on CCS and named seven uncertainties, which they analysed with regard to CCS. They list: *Variety of pathways, safe storage, scaling up and speed up of development and deployment, integration of CCS systems, economic and financial viability, policy, politics and regulation und public acceptance* (Markusson et al., 2012: 906). In a second step, they identified case studies that represent historical analogues for each of these uncertainties. They wanted to find out which political implications the analysis of the analogues had for CCS governance (Chalmers et al., 2013; Watson et al., 2014).

[4] This paragraph bases on the findings of the EU Horizon 2020 project WinWind and mainly its deliverables 2.1 and 2.3 which included a vast literature review on drivers and barriers of wind energy development. See also: http://winwind-project.eu/(last accessed 19.09.2019).

the technology have not yet been sufficiently investigated. In principle, four test drillings for scientific purposes are permitted, but so far there have been no tests.[5] The world's largest natural gas producers are the USA and Russia. Both countries have continuously increased their production volumes. Between 2010 and 2017, Russia produced 610–692 billion cubic meters per year. The USA increased its production from 593 billion cubic meters in 2009 to 761 billion cubic meters in 2017 (Statista 2019a). The USA is by far the largest producer of non-conventional gases with a production volume of 543.6 billion cubic meters in 2014 (Russia: 21.3 billion cubic meters in 2014) (Statista, 2017). Worldwide, the production volume of natural gas was steadily increased from 0.976 trillion cubic meters in 1970 to 3.68 trillion cubic meters in 2017 (Statista, 2019b).

4.3. Carbon dioxide capture and storage

Carbon dioxide Capture and Storage (CCS) is used to reduce the concentration of CO_2 in the atmosphere and is a technology in the field of geo-engineering. The accumulated carbon dioxide is supposed to be captured and injected into underground storage facilities (UBA, 2018). The large-scale technology became known primarily through the calculations of the Intergovernmental Panel on Climate Change (IPCC), according to which the goal of the Paris Climate Agreement (2015) can only be achieved through "negative emissions" (Masson-Delmotte et al., 2018). However, the extent to which this technology actually works and to which it can be realized on a large scale is controversially discussed and there are contradictory scientific results. For UBA (2014), the use of CCS technology in Germany is not a necessary step to achieve national climate targets, provided that the expansion of renewable energies is continued (UBA, 2014). Worldwide, there are 17 large-scale industrial projects, of which 13 projects are located in the sector of oil production and where the produced CO_2 remains in the exploited oil reservoirs, while four projects are testing direct CO_2 injection (Schmidt-Hattenberger, 2018, p. 36).

4.4. Deep geological disposal for high-level radioactive waste

According to the World Nuclear Association (WNA), more than 370,000 tons of highly radioactive nuclear waste have accumulated worldwide over the past 75 years.[6] By 2040, according to tentative estimates Germany is expected to produce about 30,000 m^3 of heat-generating radioactive waste. Radioactive waste must be isolated from humans and the environment for several million years and stored as safely as possible (according to the report of the AkEnd, 2002, StandAG, 2017 and EndKo, 2016). In Germany, as elsewhere in the world, there is no DGD in operation and after the failed attempt at the Gorleben site, the search for a new site began in 2013. The objective consists of finding a site where a repository can be constructed in deep geological layers by 2031. Worldwide, several DGD for low and medium level radioactive waste exist already. In Germany, low-to intermediate-level radioactive waste is stored in the shaft installations of *Morsleben*[7] and *Asse II*.[8] The shaft installation *Konrad* is currently being converted into a repository for waste with minimal heat generation; Asse represents a serious danger because thousands of litres of water enter the mine every day.

5. Systematic comparison of the four energy technologies

In the following, the four energy technologies are compared based on the eight criteria mentioned above to determine whether problems and measures can be derived and be of significance for the site search, NWM and the construction of a DGD. The comparison of the socio-technical analogues does not only concentrate on the empirical level, but also includes a certain degree of abstraction in order to acquire more general statements. The following findings were based on a comparison of the named energy technologies, which resulted from an extensive analysis of secondary literature from 6 to 10 publications on the respective energy technologies.

5.1. Goals, visions and narratives

In this section we briefly sketch the narrative of the path to low-carbon technologies for wind energy, fracking and CCS. The political narratives about the technologies are linked to their assumed potential to mitigate global warming (keyword: "negative emissions") (Schirrmeister, 2014; IPCC, 2011; Metz et al., 2005; Ladage et al., 2016). Fracking and wind energy also correspond to the principle and narrative of independence from energy imports. CCS, for example also in combination with the production of bioenergy (BECCS), is referred to as a "negative emissions technology " (NET); this includes large-scale technological measures without which – according to the supporters' narrative – the Paris climate target will not be achievable. The most recent scenarios of the Intergovernmental Panel on Climate Change (IPCC) also include the use of nuclear power to achieve the climate target of 1.5° (Masson-Delmotte et al., 2018). On the other hand, a repository per se does not fit into these narratives and basically appears "only" as an eternal burden (Brunnengräber, 2019a). The repository cannot be described as a bridging technology, a security technology or a guardian of prosperity. Therefore, a positive narrative is still being looked for. The eternal burden is regarded as a necessary nuisance of the nuclear power plant that is allegedly a climate-friendly large-scale technology.

Fracking and above all CCS, may end up to a crowding out of investments in sustainable energy infrastructures (for CCS, see Krüger, 2015). Both technologies are based on a fossil and centralised energy infrastructure. They support the established economic growth and prosperity models as well as represent a kind of further development (innovation) of the old energy production and consumption path. Nuclear energy and consequently also the disposal of nuclear waste is part of this centralised energy regime that in the argumentation of its proponents could ensure climate-friendly business as usual economy. The

[5] Bundesregierung 2017: Kein Fracking in Deutschland. https://www.bundesregierung.de/Content/DE/Artikel/2016/07/2016-07-08-fracking-gesetz.html (last accessed 30.10.2018). Bundesrat setzt Fracking-Kommission ein. https://www.deutschlandfunk.de/energie-bundesrat-setzt-fracking-kommission-ein.697.de.html?dram:article_id=419929 (last accessed 26.06.2019).

[6] See: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx (last accessed 07.12.2018).

[7] Until 1998, low- and medium-level radioactive material was stored in the Morsleben mine. Now, it is supposed to be shut down. See: http://www.endlager-morsleben.de/Morsleben/DE/themen/endlager/endlager_node.html;jsessionid=CBC4390D051D2C21D65CD72B257FF7BD.2_cid349 (last accessed 01.10.2018).

[8] There are already significant problems and incidents evident in this case. For example, water is entering the mine so that radioactive waste stored there, now has to be retrieved and the mine will be shut down. See: http://www.asse.bund.de/Asse/DE/themen/was-ist/was-ist_node.html;jsessionid=38812BB3329A923EF155FA1C957961CB.1_cid349 (last accessed 01.10.2018).

prioritisation of certain technological innovations in this way is therefore also associated with lock-in[9] effects, previous forms of energy generation are not questioned. This can be seen very clearly in Great Britain, where the increased use of fracking and nuclear energy is regarded as a "part of the incumbent sociotechnical regime in the UK energy sector" (Johnstone et al., 2017, p. 155).

With regard to final repositories, references are made to the knowledge that has already been gained during the use of nuclear energy. Low and medium level radioactive waste has been stored underground.[10] These projects are linked in particular to negative associations – and narratives – resulting from the improper management of nuclear waste (see Gorleben or Asse II).

It also appears that society's overall assessment of technologies is closely linked to prevailing value patterns and the comparison of technologies. For example, CCS is rejected because of the preference for renewable energies (Schulz et al., 2010, p. 293). On the other hand, constructing a DGD as safely as possible can no longer be questioned: Only the "how" is negotiated and is prone to conflict. Now and then, alternatives, such as transmutation or transportation into space are still discussed in niches. However, these discourses in niches have little influence on the formulation of NWM in Germany. Today, DGD is currently regarded as the safest storage option, according to the current state of science and technology (EU-Directive, 2011/70, Nuclear Energy Agency (NEA) 2015; EndKo, 2016). But if the search for and the construction of a DGD fails, or if new scientific findings are available or when socio-political conditions and interests change, narratives – as experience shows – can emerge from the niches and gain significance.

5.2. *Conflicting values and protests*

When referring to conflict, we try to uncover the overall conflict lines that are embedded in a certain socio-technical ensemble, but especially we refer to conflicts between opponents and proponents of an energy technology or more specific between opposing civil society and advocating stakeholder groups like authorities and supply companies.

Overall, technological conflicts are not temporary disputes, but can be deep rooted in society. They can intensify over the years, only to then flatten out again. Both for fracking and for wind energy, conflicts have become more widespread in society (Hoeft et al., 2017). Wind energy in particular, which was initially highly supported, has increasingly led to regional conflicts in the course of its intensive expansion. Various reasons can be cited for the deepening of this conflict, such as contested land use, nature protection, feed stocks and landscape, lacking distributive justice or conflicts of values and uncertainties about scientific knowledge (e.g. health effects), etc. (Linnerud et al., 2018, p. 29). Similar dynamics can be observed for fracking. Dodge and Metze (2017) state that the conflict about fracking also intensified over time and is a "value-conflict" in which we deal with contested knowledge and interpretation of facts and counter-facts. Regarding fracking they also observe „conflicting interpretations, interests, and contradicting expert-knowledge" (Dodge and Metze, 2017, p. 2). Here a clear parallel to nuclear history in Germany and the disposal of radioactive waste is apparent. The past conflict between civil society opponents and authorities was strongly influenced by expert opinions and counter-assessments as well as political decision-makers who had the means and the power to assert their views. Disappointment in governmental agencies that helped a specific energy technology to break through has shaped the conflict to this day, which – albeit softened – persists and is marked by narratives and judgments. In Germany, for example, due to the generational change that will take place within the "Century Project Repository" (Brunnengräber, 2017), the historically developed conflict is likely to weaken over time. Overall, confidence especially of the critical civil society in the actors who act on the dominant socio-technical regime level within the ensemble or the large energy supply companies has also declined. Similar observations were made with regard to fracking. The gas and oil companies possess a strong political and legal power (see Gullion, 2015, p. 78).

But over the years, social scientists also noticed a change in resistance behaviour of citizens. Not only is the resistance against certain power sources embedded in a superior societal conflict about future power supply strategies. Bornemann and Saretzki (2018) refer in regard to the protests against fracking that this conflict is also contextualized by a change towards a specific societal mood ("gesellschaftliche Stimmungslage"). Maybe one can define this changed mood as a new protest culture, which is interpreted as an expression of a changed or rather empowered self-image of citizens and as a reduced legitimacy of established forms of democratic decision-making. But in what way resistance against fracking (or wind energy) is an expression of this "protest culture" needs further research (Bornemann and Saretzki, 2018, p. 566, after Locke, 2010). In this case, an empowerment of the critical public can be seen, which seems to harden at the regime level and could continue to cause conflicts in the entire field of energy technologies – fossil, nuclear or renewable.

5.3. *Social acceptance*

The acceptance of wind energy is relatively high compared to the acceptance of nuclear repositories. However, the acceptance of nuclear energy was also higher at the beginning of its use. In recent years, resistance against wind energy farm projects have become increasingly common, especially among local citizens' initiatives and supra-regional networks. And also, for wind energy the gap between the rather positive public opinion towards the German energy transition and the rejection of local or regional wind energy projects becomes apparent (for example Eichenauer et al., 2018). In addition, Weber et al. point out the more rural a region or the more sparsely populated it is, the higher the level of rejection appears to be (Weber et al., 2017). Since a DGD will hardly be built in a densely populated area, similar effects can be expected in this case.

The perceptions and opinions about CCS and fracking show a similar ambivalence concerning the acceptability. There is a cleavage between those who consider the technology as meaningful and pioneering, and those who see only risks and a continuing with business as usual (Schulz et al., 2010; Schirrmeister, 2014). Here, too, acceptance of the energy technologies declined over time, while opposition movements increased (see also section 5.2). On the other hand, a higher acceptance regarding fracking and CCS can be observed in the US-American context in areas that already have an extraction history or experience with the production of fossil energies (Seigo et al., 2014; Gullion, 2015; Wolff and Herzog, 2014). These areas and the associated positive perceptions do not however apply to the site search or the repository as a whole, since the integrity of the subsoil must be maintained during the final disposal. Earlier forms of usage (i.e. mining or gas production) or already carried out exploration drilling exclude these sites or regions. However, according to this interpretation, nuclear communities should also have a rather positive attitude towards the DGD, as they are already familiar with nuclear facilities in their vicinity, have a strong identification with the nuclear industry, suffer from economic dependencies that have arisen from the nuclear industry and the resulting value chain (Di Nucci, 2016) and depend strongly on the added value generated by the nuclear industry (Blowers, 2017, 2019; Di Nucci and Brunnengräber 2017).

Trust also seems to be an important factor for acceptance. In the

[9] According to Wieland, lock-in refers to a locally stable equilibrium point from which the trapped process can no longer free itself (Wieland 2009, p. 27). This does not mean that the process is irreversible or that its state can no longer be changed. However, a process in the lock-in state then requires external impulses or a "shock".

[10] BfE 2017: Was sind Endlager? https://www.bfe.bund.de/DE/ne/endlager/einfuehrung/einfuehrung_node.html;jsessionid=A64ECA4845864C66D9889A481D8FAA03.2_cid349 (last accessed 20.10.2018).

context of CCS, trust is attributed to independent experts and environmental organisations to a greater extent than to private companies or the industry, and in some cases also to governmental institutions (Seigo et al., 2014, p. 857). A similarly difficult situation can also be identified with regard to repositories, especially since trust in state institutions and power supply companies has been declining for decades. At the same time, it is particularly difficult to build trust when data and facts are controversial or non-existent (Neville and Weinthal, 2016, p. 591), as the compilation of geo-data due to the Repository Site Selection Act in Germany shows. The acceptance of a procedure is likely to decrease with the amount of difficulties encountered.

5.4. Safety, risk potentials and risk perception

Similar fears and dangers are perceived in the energy infrastructure projects of fracking, CCS and repositories. These include health threats, groundwater contamination or soil pollution. Furthermore, there are fears of oil spilling into the ground from wind turbines.[11] However, these fears are often diffuse as the negative effects of underground technologies cannot be observed. At the same time, many risks are also feared, such as CO_2 leaks from CCS, the emission of ionising radiation from final repositories as well as contamination of the soil or the food grown in the surroundings. The respective technologies also address specific aspects such as the negative impact on individual species (bats, birds) or certain ecosystems (e.g. forests) as it can be the case with wind energy.

Overall, there are still many uncertainties and unpredictable issues with fracking and CCS (e.g. Gullion, 2015, p. 55; Meyer-Renschhausen and Klippel, 2017, p. 84; Krüger, 2015, p. 177f.; SRU, 2013). Simultaneously, the ability of policy-makers and operators to manage and control these risks is considered rather low (Schulz et al., 2010, p. 289). There are great similarities to the “unknown unknowns” (Eckhardt and Rippe, 2016) of repositories (see Themann and Brunnengräber, 2019). This describes unforeseeable consequences of the use of technologies, to which societies are consequently unable to prepare themselves for. Ultimately, it is also a question of what level of risk is still acceptable. In the case of repositories, this shows the exigency and the deliberative moment inherent in the situation. The question of whether to deal with the legacies no longer arises. At the same time, the risk potential of various repository options, such as DGD or surface storage, can still be socially negotiated. It is precisely the uncertainties that arise from the use of technologies in the medium and long term that delegitimise a purely political-regulatory or purely scientifically based approach. Uncertainties must be debated in the public in order to be able to make decisions.

This can also lead to situations of dilemma. Thus, from DGD the choice between immediate closure or deep storage with retrievability arose. From a safety point of view, immediate closure was the preferred option. However, this contradicted the population’s need for reversibility of decisions. Social discourses led to the choice of the option of retrievability, which corresponds to the values of the population and leaves paths open, but also could be at the expense of security (EndKo, 2016, p. 32, 219).

With regard to safety considerations, the current state of knowledge is not yet sufficient for a long-term proof of safety. Sufficient monitoring strategies and options are lacking for the three underground technologies mentioned here (SRU, 2013, p. 26; Meyer-Renschhausen and Klippel, 2017, p. 122f.; Gullion, 2015, p. 55). Similar to repositories, fracking and CCS pose environmental and health risks that could result from the unintentional release of toxic gases and substances. There are also methodological problems in estimating possible effects of groundwater contamination due to the lack of baseline data. For example, delayed damage effects can occur (Meyer-Renschhausen and Klippel, 2017, p. 84f.). As far as CCS is concerned, there is currently no technology available for monitoring and controlling the stored CO_2 (Krüger, 2015, p. 164). Similar problems also arise for the monitoring of a DGD.

5.5. Role of science

The comparison of energy technologies’ ensembles demonstrates that a large-scale technology and its development are highly influenced and shaped by technical and natural sciences, but that despite – or precisely because of – scientific uncertainties and lack of evidence there is the need for political decision-making. Disciplinary claims to knowledge can be highly disputed, especially for large-scale technologies (contested knowledge). With regard to fracking, the opposition coalitions each use (natural) scientific findings for their arguments (Gullion, 2015). This can lead to a political confrontation based on scientific facts and counter-facts (ibid. p. 134pp.) and can cause scepticism towards science which may be considered to be perceived as biased (Neville and Weinthal, 2016, p. 595). Conversely, knowledge and arguments of activists and opponents were labelled as unscientific and emotional (Gullion, 2015, p. 137). This has already been observed at Gorleben. Here, a growing scepticism towards the established science developed, as it was no longer perceived as objective and neutral (Brunnengräber, 2018) and also the anti-nuclear movement and critical scientists felt marginalized (Brunnengräber et al., 2021).

Furthermore, when it comes to CCS (and in certain countries also fracking) a critical community of experts is sought to be marginalized (Krüger, 2015). There are many powerful supporters of CCS in politics and business who rely on scientific expertise. The use of geoengineering and large-scale technologies for climate protection is accompanied by scientific feasibility studies. As many assumptions regarding the positive effects cannot yet be proven, the operation will not be ready within the next decades and long-term problems cannot be ruled out (unknown unknowns), mistrust tends to be high. Nevertheless, wrong priorities can still be set (ETC Group et al., 2017), for instance if technological adaptation is still given greater weight than mitigation strategies.

The social sciences have submitted extensive research work on CCS projects, as described by Markusson et al. (2012, p. 905). According to an observation by Krüger (2015) on CCS projects, the social sciences are included as “acceptance researchers” and in consequence considered as contested actors. There is an “instrumental reference” to the social sciences in order to increase the acceptance of CCS through improved communication (ibid. p. 24–25). The anti-nuclear initiatives in Germany made a similar observation regarding the Gorleben conflict. In the German nuclear history social sciences also gave the impression of being “acceptance providers”. This results in the difficult role of the social sciences: they are (partly rightly) discredited by society or only noticed to a limited extent. Such perceptions in the context of the siting of nuclear waste repositories are certainly reflected in the social sciences today. As a consequence, the aim of inter- and transdisciplinarity was formulated and practiced in the research project ENTRIA – Disposal Options for Radioactive Residues: Interdisciplinary Analyses and Development of Evaluation Principles (2013–2019) (ENTRIA, 2019; Röhlig, 2019).

5.6. Participation and public participation

Superordinate factors such as trust, early participation throughout the entire process and information are considered essential for a fair participation (Reed, 2008). Values such as equality and empowerment of those involved, the integration of scientific as well as local knowledge and institutionalisation are also necessary for processes in which goals are still being negotiated (ibid.). In large-scale technology projects, however, participation opportunities are often offered too late as they

[11] Discussion at the second thematic workshop WinWind on wind energy in forests, Erfurt, 18.10.2018. See: http://winwind-project.eu/resources/outputs/(last accessed 11.12.2018).

are many times granted only after the project has been practically conceived and started. In many cases an opposition has already formed as consequence of late efforts for participation (Dütschke et al., 2017, p. 307p.). Under the Repository Site Selection Act (Standortauswahlgesetz - StandAG), the legally secured participation formats for repositories are also not provided from the start, but rather in a later planning phase. Nevertheless, the Federal Office for Nuclear Safety of Disposal (Bundesamt für kerntechnische Entsorgungssicherheit, BfE[12]) is already striving for early public participation and refers to this as "informal" public participation (BfE, 2018). It is not yet clear whether this will counteract the oppositional dynamics that have emerged in the cases of the other large-scale technologies.

Investigations into US-American fracking projects show that trust, which has been lost in past processes, can have an effect on new processes (Neville and Weinthal, 2016, p. 590). Persons or stakeholder groups who recall past breaches of trust can play a significant role in this matter (Levi, 1998, p. 86). With citizens' initiatives such as those related to Gorleben, this possible oppositional dynamic certainly also applies to the German siting process for a DGD. The historical context thus has a major influence on the social course of the search, the construction and the storage.

Similarities with the DGD are also evident in the forms of participation required. For example, the establishment of an accompanying body was proposed for the trial phase of CCS technology (Schulz et al., 2010, p. 294). The fact that a similar advisory body concept was also designed for the repository search process is interesting in light of the possible parallel nature between both ensembles. In the context of a nuclear waste repository the National Civil Society Board (Nationales Begleitgremium) was set up in 2016 (Schreurs and Suckow, 2019). But also for fracking in Germany the "InfoDialog Fracking" was established from 2011 to 2012. In the "InfoDialog" process, a scientific "neutral group of experts" and a "working group of social actors" were tasked with examining safety and environmental concerns regarding the fracking technology for the first time in a dialogue with citizens. This process led to a risk study[13] and shows a trend towards a greater exchange between science and citizens in order to identify risks. The proposal for a dialogue was also explicitly made with a reference to restoring trust, especially through the opening up of the scientific community. Consequently, independent supporters of the participation processes seem important in a context in which trust in the regulatory authorities and the state has declined or even eroded. With regard to repositories, various efforts have already been made to advance the search for sites by setting up advisory commissions (Isidoro Losada et al., 2019).

Additionally, a necessary condition for "good" participation is that people are suitably informed and understand the issues. Very low levels of knowledge and information can be observed in the population particularly in the cases of fracking and CCS (Duetschke et al., 2014; Costa et al., 2017). At the same time, specifically large-scale technologies and their risks appear to be only marginally negotiable. In particular, technical components and issues such as security or the energy strategy itself which are located on the socio-technical regime level are not discussed in a participation process (see for CCS: Seigo et al., 2014). Parallels can be seen in the handling of nuclear energy and HLRW. New forms of public participation have been tested since the StandAG, of which the first version was adopted in 2013.

5.7. Key institutions and regulatory mechanisms

Big Companies and their competition with each other act as a driving force for the development of a technology, although the state may very well have intervened initially to promote it (see the Erneuerbare Energien Gesetz, EEG – Renewable Energies Act). This plays a role in fracking and wind energy, as energy generation is intended to be based on considerations of supply security, climate protection or profit expectations. In such cases, simple and secure market access is the key to further development and investment in a technology. When it came to the use of wind energy, the German Federal Government became the initiator and designer of the legal-economic framework (Ohlhorst, 2009, p. 237). Due to the regulatory interventions of the state, the uncertainty and risk factors decreased to some extent and the technology attracted the interest of commercially oriented actors who drove the development process forward through their investments (ibid. p. 238).

However, the case of repositories is different due to the fact that there is no or barely any competition for the best technology. This eliminates the innovation motives and potentials that emerged for example with the EEG through incentives and reasonably reliable framework conditions. Nevertheless, the example of the EEG reveals the state as a driving force for innovation. However, it remains questionable what the state could do to trigger technological innovation in the case of repositories – e.g. dedicated research programmes, as research is currently (strategically) rearranging itself in this area of nuclear waste management. Barriers to innovation could arise for example from the lack of interest in the nuclear industry and the lack of skilled workers that is due to the nuclear phase-out. Or the processes get caught up in the complex multi-level policy between the Federal Government and the Länder, as it was the case in German waste management policy (Hocke and Brunnengräber, 2019).

Therefore, the search for a site and the construction of a DGD needs strong regulations from the Federal Government. The Federal Government and the Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) are the main regulators for repositories. Consequently, a repository will be built under the control of the central government; and thus, will be independent of competition conditions. This could cause different outcomes in the repository site selection process. Independence from a state of competition could allow for more space of inclusion and a higher degree of flexibility in the "learning procedure"[14] of the site selection process and especially towards the participation formats which are required by the StandAG. This possibility gets more evident with the perspective of continuous amendments to the EEG and re-regulation of renewable energy expansion. This shows that legislations can be adapted flexibly. In this respect, the EEG could serve as a model for actually implementing the requested mode of learning procedure in law by adapting the StandAG to the emerging challenges. It appears to be a balancing act between a reactive legislation that adapts, for example, to the demands for more participation and is therefore positively perceived, and a destabilization of the process. Destabilization could occur either through uncertainty of the participants due to a constantly adapting procedure that undermines continuity and planning security or through a lack of political willingness to use the space for more openness in such processes.

5.8. Reversibility

Wind energy in particular has an extremely flexible policy with the EEG, which can be adjusted to a certain extent to changing framework conditions. The StandAG could also provide room for testing different regulatory options, which are, however, frequently confronted with the

[12] The BfE has changed its name 2019 to Federal Office for the Safety of Nuclear Waste Management (Bundesamt für die Sicherheit der nuklearen Entsorgung, BASE).

[13] For more information see: https://www.erdgas-aus-deutschland.de/de-de/im-dialog/infodialog/infodialog-fracking (last accessed 07.07.2019). For a critical examination of this process, we recommend the essay by Saretzki and Bornemann (2014).

[14] The StandAG determines that the repository site selection process should be performed in a continuous mode of learning ("lernendes Verfahren") and self-scrutinizing.

argument of time pressure: the location for a repository should be determined by 2031. In addition, CCS and repositories are both technologies that create “hard facts” after a certain development phase, so that it becomes increasingly difficult to abandon the chosen paths over time (infrastructural lock-in). In the course of the site search and the construction of a repository, financial and infrastructural path dependencies will also occur. This is a possible threat towards the flexibility stated in the section before, because those path dependencies will rule out adaptation and flexible regulations from a certain point in time (which is also another argument to implement participation procedures in the site selection process as early as possible).

With regard to the social and technical interrelations within the ensemble of energy technologies, the question arises as to whether repositories might behave in a similar way as CCS, whose technology is also subject to the fear of a carbon lock-in (Krüger, 2015). Hence, CCS technology supports the old path of fossil energy use and prevents social change towards energy generation with low or no CO_2 emissions. Such a stabilisation of old paths could slow down innovations and change in a sustainable power supply strategy or encourage investment in the old path of nuclear energy. A nuclear lock-in could happen alike and could have similar effects. If a repository is under construction or in operation, nuclear energy use can be continued.

6. Insights from the socio-technical analogues

Overall, awareness is needed that repositories differ in several ways from the other energy technologies discussed here, with one difference being central: Wind farms, CCS and fracking are optional in their use and can be affirmed or denied by social discourse. The situation is different for the storage of high-level radioactive waste. With the production of HLRW, material as well as social facts were created that are irreversible and have led to considerable path dependencies, which can be understood as lock-ins and do not leave an infinite number of options open on how to handle and manage this waste, because of its properties. It also became clear, however, that some lessons can be drawn from the socio-technical analogues.

Our analysis showed that the usage of new technologies in the fossil energy industry could hinder transition processes towards a renewable energy path as they stabilize the socio-technical regime of fossil fuel usage. Finding a site and building a repository can also become a strategy of argumentation for certain actors in order to continue generating electricity from nuclear energy. This can be seen, for example, in the scientific and social debate on the establishment of CCS technology. The technology could prevent a turnaround in climate policy and pose the risk of a carbon lock-in in fossil fuels (Krüger, 2015, p. 22). A similar development could also take place in the debate on repositories. The increase of nuclear energy to achieve the 1.5-degree target plays a key role in the IPCC scenarios (Masson-Delmotte et al., 2018). Actors with great interpretive power from the fossil-nuclear industrial economy work in cooperation with governmental decision-makers and on the basis of scientific expertise to oppose change. They essentially shape the socio-technical regime and possibly act as a dominant driver in maintaining lock-ins and path dependencies (Geels, 2014).

Conflicts do not only arise between opponents from civil society, state authorities and science, but also within the sciences. Here, too, knowledge of certain technologies is contested. Different scientific findings and scenarios (with or without nuclear energy) can be diametrically opposed to each other. This creates uncertainty and distrust in society. From this analysis results that above all a dialogue must be conducted about expert dissent and values. The fact that a dialogue on values is necessary is also evident with regard to the uncertainties (unknown unknowns) with which CCS, fracking and repositories confront us. In the case of the four major technologies, we are also talking about very different time scales in which they are applied – although those time scales cannot be overlooked scientifically, especially for the repository (Brunnengräber, 2016; Themann and Brunnengräber, 2019).

Identified and unknown uncertainties require a societal debate about the risk associated with the technology, the risk a society is willing to bear, and what measures will be taken under uncertain circumstances. Here, a combination of scientific knowledge and other types of knowledge (e.g. local knowledge) is central. The greater the threat to protected goods such as water, soil or air, the more likely it is that actors will organise themselves in oppositional coalitions or networks. Simultaneously, an “instrumental recourse” to the social sciences is observed for controversial technologies such as CCS, which gives the critical public the impression of acquiring acceptance. Here, science must take active countermeasures. Stronger cooperation between science and society to link different forms of knowledge is just as urgent as social science research that uncovers and explains its assumptions, procedures and findings.

In the case of energy technologies and in particular DGD, trust in government authorities, scientific institutions or the industry is significantly reduced. At the same time, independent experts and environmental organisations have gained trust. Eventually, general insights into participation also derive from the results and from the social analogues of the energy technologies. The involvement of actors from civil society could be beneficial to unlock siting processes. Early and continuous participation – also in the formulation of the participation strategy itself – is a path to be pursued. The conflicts over wind energy farms show that the distribution of costs and benefits in terms of social justice as well as environmental justice could also be kept in mind for repositories.

Moreover, in contrast to other technologies, the repository lacks a positive narrative or a positive vision. Thus, it becomes clear that wind energy, CCS and, in part, fracking are discursively embedded as technologies to mitigate climate change or as bridging technologies for energy generation of lower CO_2 emissions. The wicked problem (Brunnengräber, 2019b) caused by a repository would again undermine the positive connotation of nuclear energy as a climate instrument (and thus keep the danger of a nuclear lock-in low), provided that both are brought together in the discourse. But this is hardly the case so far. Thinking about ways how innovative forces towards a repository could possibly unfold, only the concept of responsibility towards future generations comes to mind.

The StandAG certainly has room for flexible adjustments in order to meet the legal requirements of the learning process. On the other hand, this flexibility also involves planning uncertainties and insecurity among the public, as the examination of the EEG has shown. Many actors were discouraged by the frequent changes or were deliberately slowed down politically, which had a significant impact on market and investment behaviour. However, since the repository is not an industrial policy project that is implemented under market or competitive conditions, the possibility of legal adaptation can also be viewed positively: it is precisely this remoteness from the market that the learning process requires, that is otherwise organised between competing market players. In what way the nuclear repositories and their regulations and social processes might possibly be a very good example for long-term market independent innovations and respective innovation strategies needs further and far more amplified research. However, in terms of the potential uncertainties and frustrations mentioned, the experimental spaces opened up by the law should only be used within certain boundaries and very carefully. Legislative changes must also be negotiated, as was to some extent the case with the StandAG 2013 and its readjustment in 2017. The National Civil Society Board can give room for such an undertaking.

7. Conclusion - implications for the DGD ensemble

Overall, the concluding evidence to buttress recommendations derived from this preliminary analysis through the analogues approach is rather limited. A reason for this is that an in-depth and comprehensive analysis of the dominant networks and constellations of actors could not be carried out in this work. Their influence on the socio-technical ensembles described here need to be dealt with in greater depth in future works. Our contribution aimed to show, whether an approach based on the comparative analysis via analogues can be a fruitful way for anticipating unknown developments and dynamics within the DGD ensemble. We consider our approach to be feasible, but we are aware that the explanatory power for estimating the DGD ensemble is limited and calls for more detailed analyses. Especially the power structures between different stakeholder groups need to be further investigated jointly with the interplay within an ensemble. In order to understand the way they interact and what dynamics arise between the influencing factors, it would be necessary to provide reliable and validated methods. In this sense our attempt needs to be understood as an explorative try and should inspire upcoming research to dive deeper into the concept of ensembles and the MLP and to learn from dynamics of other large-scale infrastructure projects or societal relevant technology use.

What can be deduced from this first analysis for the socio-technical DGD ensemble is that the critical public described by Bornemann and Saretzki (2018) is a key player in the socio-technical ensembles of large-scale infrastructure projects. Its increased role, combined with the influence of disappointments from past decision-making processes, makes protests and resistance against infrastructure projects like radioactive waste repositories likely. However, it is evident that even a technology that previously induced a high level of social approval can later trigger major conflicts. Various reasons, such as contested land use, protection of nature, animals and the countryside, failed distributive justice, mistrust of dominant stakeholders or conflicting values can be responsible for this. The critical public also questions previous regime logics and forces institutions to change as well as to engage in a dialogue about existing strategies and values. This is necessary in order to absorb the social conflict and turn it into a productive one. In this context, the new institutional architecture in Germany is also a reaction to the key players, many of whom have been speaking out against nuclear energy and in favour of safe storage for decades (Drögemüller, 2018). In order to counter their criticism and rebuild trust in state institutions, early public participation and an open dialogue on the risks are necessary. The role of independent monitoring bodies in restoring trust must also be emphasised with regard to the socio-technical ensemble. Public participation and the integration of niche actors into the regime should also be pursued in order to regain the state's lost trust.

The socio-technical DGD ensemble is also characterised by a new relationship between society and science. Scientific results are no longer accepted unquestioningly. Particularly in the case of technologies, which are still subject to numerous uncertainties, a critical civil society has been irritated and disillusioned with regard to the independent role of science. Moreover, in some contexts the impression of "research that generates acceptance" or "legitimation research" has been created. Therefore, it seems important to provide a critical (independent) scientific support for the repository search and for science to enter into a direct exchange with the population.

The topics of safety and risks, which are often answered by natural scientists and technicians with appropriate technologies or concepts, offer important starting points for this. For the case of the underground technologies CCS, fracking and repositories, there are still considerable uncertainties and unsolved problems beyond all scientific findings. These include the question of what happens underground, how ecosystems are influenced or how monitoring is to be designed. The socio-technical ensemble, with its implicit uncertainties, makes an open dialogue of values imperative, which should consider the risks to be dealt with and the integration of other forms of knowledge.

Finally, ambivalence of energy policy should be incorporated into the overall picture of the socio-technical ensemble. For example, a DGD could support the fossil-nuclear energy path but could also give the possibility to deviate from it. A deviation seems possible if renewable energies are further expanded and the energy transition is promoted by state, political and private actors. The resistance of the old energy regime consisting of fossil-nuclear actors should then decrease. The first trends pointing to a destabilization of the old energy path are already unmistakable. Nevertheless, the technologies of CCS and fracking, which are controversial in Germany and have so far rarely been used, are regarded as bridging technologies for CO_2-neutral energy generation and will continue to be researched. Furthermore, the declining acceptance of large wind farms cannot be denied. This poses the question of whether the search for a disposal site with a simultaneous slowdown in renewables and the phasing out of coal-fired power plants in the coming decades could legitimise the renewed use of allegedly climate-friendly nuclear energy in Germany. The narratives surrounding the respective technologies according to Geels can come to play an important role as they influence the stability of a socio-technical regime. In times of the post factual, narratives become driving forces for or against certain technological developments. In view of that, the socio-technical DGD ensemble is ascribed with a potential for inhibiting transition processes towards renewables – the nuclear lock-in – which must be critically observed.

We would like to thank the SOTEC-radio team as well as the anonymous reviewers for their valuable comments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

AkEnd, 2002. Auswahlverfahren für Endlagerstandorte. Empfehlungen des AkEnd. Arbeitskreis Auswahlverfahren Endlagerstandorte, Köln. https://www.bundestag.de/endlager-archiv/blob/281906/c1fb3860506631de51b9f1f689b7664c/kmat_01_akend-data.pdf.

BfE, 2018. Zwischenlager für hochradioaktive Abfälle. Sicherheit bis zur Endlagerung. Bundesamt für kerntechnische Entsorgungssicherheit. Berlin. https://www.bfe.bund.de/SharedDocs/Downloads/BfE/DE/broschueren/bfe/broschuere_zwischenlager.pdf;jsessionid=D050E163B44D8AB47E089150C6B74AC3.1_cid391?_blob=publicationFile&v=12.

Bijker, Wiebe E., 1995. Sociohistorical technology studies. In: Jasanoff, Sheila, Markle, Gerald E., Petersen, James C., Pinch, Trevor (Eds.), Handbook of science and technology studies. Sage Publ, Thousand Oaks, Calif., pp. 229–256

Bijker, Wiebe E., 1997. Of Bicycles, Bakelites and Bulbs. Toward a Theory of Sociotechnical Change, 1. u.a.: MIT Press, Cambridge Mass (Inside technology).

Blowers, Andrew, 2017. The Legacy of Nuclear Power. Routledge, Oxon, New York.

Blowers, Andrew, 2019. The legacy of nuclear power and what should be done about it. Peripheral communities and the management of the nuclear legacy. In: Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), Achim Brunnengräber und Maria Rosaria Di Nucci (Hg.): Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison Volume III, 3. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 55–68.

Bornemann, Basil, Saretzki, Thomas, 2018. Konfliktfeldanalyse – das Beispiel „Fracking" in Deutschland. In: Holstenkamp, Lars, Radtke, Jörg (Eds.), Handbuch Energiewende und Partizipation. Springer VS, Wiesbaden, pp. 563–581.

Brunnengräber, Achim, 2016. Das wicked problem der Endlagerung. Zehn Charakteristika des komplexen Umgangs mit hochradioaktiven Reststoffen. In: Brunnengräber, Achim (Ed.), Problemfalle Endlager. Gesellschaftliche Herausforderungen im Umgang mit Atommüll. Nomos, Baden-Baden, pp. 145–166.

Brunnengräber, Achim, 2017. Jahrhundertprojekt Endlagerung. GAIA - Ecological Perspectives for Science and Society 26 (2), 94–95. https://doi.org/10.14512/gaia.26.2.7.

Brunnengräber, Achim, 2018. Klimaskeptiker im Aufwind. Wie aus einem Rand- ein breiteres Gesellschaftsphänomen wird. In: Kühne, Olaf, Weber, Florian (Eds.), Bausteine der Energiewende., 1st. Springer VS (RaumFragen), Wiesbaden, pp. 271–293.

Brunnengräber, Achim, 2019a. Ewigkeitslasten. Die "Endlagerung" radioaktiver Abfälle als soziales, politisches und wissenschaftliches Projekt. Nomos, Baden-Baden. https://doi.org/10.5771/9783845293479.

Brunnengräber, Achim, 2019. The wicked problem of long term radioactive waste governance. Ten characteristics of a complex technical and societal challenge. In: Achim Brunnengräber und Maria Rosaria Di Nucci (Hg.): Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison Volume III. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 335–355. S.

Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), 2019. Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison, 3. Springer VS, Wiesbaden.

Brunnengräber, Achim, Di Nucci, Maria Rosaria, Isidoro Losada, Ana María, Mez, Lutz, Schreurs, Miranda A. (Eds.), 2018. Challenges of Nuclear Waste Governance. An International Comparision, 2. Springer Fachmedien, Wiesbaden.

Brunnengräber, Achim, Isidoro Losada, Ana María, Di Nucci, Maria Rosaria, Themann, Dörte, 2021. Der Atommüll – eine soziotechnische Tatsache. Zur gesellschaftlichen Wahrnehmung von sozialen und technischen Belangen bei der Endlagerung hochradioaktiver Abfälle. In: Brohmann, Bettina, Brunnengräber, Achim, Hocke, Peter, Isidoro Losada, Ana María (Eds.), Robuste Langzeit-Governance bei der Endlagersuche. Soziotechnische Herausforderungen im Umgang mit hochradioaktiven Abfällen. transcript, pp. 79–105. In press.

BWE, 2019. Zahlen und Fakten. Statistische Kennziffern zur Erfolgsgeschichte Windenergie. Bundesverband WindEnergie. https://www.windenergie.de/themen/zahlen-und-fakten/. (Accessed 18 June 2019).

Chalmers, Hannah, Gibbins, Jon, Gross, Rob, Haszeldine, Stuart, Heptonstall, Phil, Kern, Florian, et al., 2013. Analysing uncertainties for CCS: from historical analogues to future deployment pathways in the UK. Energy Procedia 37, 7668–7679. https://doi.org/10.14512/gaia.26.2.7.

Costa, D., Pereira, V., Góis, J., Danko, A., Fiúza, A., 2017. Understanding public perception of hydraulic fracturing: a case study in Spain. J. Environ. Manag. 204 (Pt 1), 551–562. https://doi.org/10.1016/j.jenvman.2017.09.001.

Di Nucci, Maria Rosaria, 2016. NIMBY oder IMBY. Akzeptanz, Freiwilligkeit und Kompensationen in der Standortsuche für die Endlagerung radioaktiver Abfälle. In: Brunnengräber, Achim (Ed.), Problemfalle Endlager. Gesellschaftliche Herausforderungen im Umgang mit Atommüll. edition sigma in der Nomos Verlagsgesellschaft, Baden-Baden, pp. 119–143.

Di Nucci, Maria Rosaria, Krug, Michael, 2018. Akzeptanz von Windenergie in Regionen mit schwachem Windenergieausbau. Energiewirtschaftliche Tagesfr. 68 (4), 40–43.

Di Nucci, Rosaria, Maria, Brunnengräber, Achim, 2017a. In Whose Backyard? The Wicked Problem of Siting Nuclear Waste Repositories. European Policy Analysis 3 (2), 295–323.

Di Nucci, Rosaria, Maria, Brunnengräber, Achim, Losada, Isidoro, María, Ana, 2017b. From the "right to know" to the "right to object" and "decide". A comparative perspective on participation in siting procedures for high level radioactive waste repositories. Progress in Nuclear Energy 100, 316–325.

Dodge, Jennifer, Metze, Tamara, 2017. Hydraulic fracturing as an interpretive policy problem: lessons on energy controversies in Europe and the U.S.A. J. Environ. Pol. Plann. 19 (1), 1–13. https://doi.org/10.1080/1523908X.2016.1277947.

Donnelly, David F., 2003. Television, Future Role Of. In: Johnston, Donald H. (Ed.), Encyclopedia of International Media and Communications, 4. Elsevier, pp. 415–428.

Drögemüller, Cord, 2018. Schlüsselakteure der Endlager-Governance. Entsorgungsoptionen und -strategien radioaktiver Abfälle aus Sicht regionaler Akteure., 1st. Springer Fachmedien Wiesbaden GmbH, Wiesbaden (Energiepolitik und Klimaschutz).

Duetschke, Elisabeth, Schumann, Diana, Pietzner, Katja, Wohlfarth, Katharina, Höller, Samuel, 2014. Does it Make a Difference to the Public Where CO2 Comes from and Where it is Stored? Energy Procedia 63 (4), 6999–7010. https://doi.org/10.1016/j.egypro.2014.11.733.

Dütschke, Elisabeth, Schneider, Uta, Wesche, Julius, 2017. Knowledge, Use and Effectiveness of Social Acceptance Measures for Wind Projects. Z. Energiewirtschaft 41 (4), 299–310.

Eckhardt, Anne, Rippe, Klaus Peter, 2016. Risiko und Ungewissheit bei der Entsorgung hochradioaktiver Abfälle, 1st. vdf Hochschulverlag, Zürich.

Eichenauer, Eva, Reusswig, Fritz, Meyer-Ohlendorf, Lutz, Lass, Wiebke, 2018. Bürgerinitiativen gegen Windkraftanlagen und der Aufschwung rechtspopulistischer Bewegungen. In: Kühne, Olaf, Weber, Florian (Eds.), Bausteine der Energiewende. Springer, Wiesbaden, pp. 633–651.

EndKo, 2016. Verantwortung für die Zukunft- Ein faires und transparentes Verfahren für die Auswahl eines nationalen Endlagerstandortes. In: Abschlussbericht der Kommission Lagerung hoch radioaktiver Abfallstoffe. Kommission Lagerung hoch radioaktiver Abfallstoffe. https://www.bundestag.de/resource/blob/434430/bb37b21b8e1e7e049ace5db6b2f949b2/drs_268-data.pdf.

ENTRIA, 2019. Abschlussbericht. Ergebnisse und Leistungsbilanz. Technische Universität Clausthal. https://dokumente.ub.tu-clausthal.de/servlets/MCRFileNodeServlet/clausthal_derivate_00000549/ENTRIA%20Abschlussbericht.pdf. (Accessed 18 June 2019).

ETC Group, Biofuelwatch, Heinrich Böll Foundation, 2017. The Big Bad Fix: The Case Against Climate Geoengineering. Online verfügbar unter. https://www.boell.de/sites/default/files/bigbadfix.pdf?dimension1=division_iup.

Fuchs, Gerhard, 2016. Die Energiewende im Ländervergleich: Deutschland und das Vereinigte Königreich verfolgen eigene Transformationspfade. GAIA - Ecological Perspectives for Science and Society 25 (3), 222–224. https://doi.org/10.1016/j.egypro.2014.11.733.

Geels, Frank W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Pol. 31 (8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8.

Geels, Frank W., 2014. Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. Theor. Cult. Soc. 31 (5), 21–40. https://doi.org/10.1177/0263276414531627.

Geels, Frank W., Schot, Johan, 2007. Typology of sociotechnical transition pathways. Res. Pol. 36 (3), 399–417.

Grießhammer, Rainer, Brohmann, Bettina, 2015. Wie Transformationen und gesellschaftliche Innovationen gelingen können. Transformationsstrategien und Models of Change für nachhaltigen gesellschaftlichen Wandel. Nomos, Baden-Baden. ISBN print: 978-3-8487-2611-0, ISBN online: 978-3-8452-6732-6. https://doi.org/10.5771/9783845267326.

Gullion, Jessica Smartt, 2015. Fracking the Neighborhood. Reluctant Activists and Natural Gas Drilling. MIT Press, Cambridge, Massachusetts.

Hocke, Peter, Brunnengräber, Achim, 2019. Multi-Level Governance of Nuclear Waste Disposal. Conflicts and Contradictions in the German Decision Making System. In: Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison, 3. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 383–401.

Hoeft, Christoph, Messinger-Zimmer, Sören, Zilles, Julia, 2017. Bürgerproteste in Zeiten der Energiewende. Lokale Konflikte um Windkraft, Stromtrassen und Fracking. Studien des Göttinger Instituts für Demokratieforschung zur Geschichte politischer und gesellschaftlicher Kontroversen, 12. transcript Verlag, Bielefeld.

IPCC, 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III, Cambridge, United Kingdom and New York, NY, USA.

Isidoro Losada, Ana María, Themann, Dörte, Di Nucci, Maria Rosaria, 2019. Experts and Politics in the German Nuclear Waste Governance. Advisory Bodies between Ambition and Reality. In: Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison, 3. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 231–259.

Jasanoff, Sheila, 2004. States of Knowledge. The Co-production of Science and the Social Order. In: International library of sociology. Routledge, London.

Johnstone, Phil, Stirling, Andy, Sovacool, Benjamin, 2017. Policy mixes for incumbency: Exploring the destructive recreation of renewable energy, shale gas 'fracking,' and nuclear power in the United Kingdom. Energy Research & Social Science 33, 147–162. https://doi.org/10.1016/j.erss.2017.09.005.

Krüger, Timmo, 2015. In: Das Hegemonieprojekt der ökologischen Modernisierung. Die Konflikte um Carbon Capture and Storage (CCS) in der internationalen Klimapolitik. Edition Politik, 28. transcript Verlag, Bielefeld.

Ladage, Stefan, et al., 2016. Potenziale und Umweltaspekte. Hg. v. BGR - Bundesanstalt für Geowissenschaften und Rohstoffe. BGR - Bundesanstalt für Geowissenschaften und Rohstoffe. Hannover. https://www.bgr.bund.de/DE/Themen/Energie/Downloads/Abschlussbericht_13MB_Schieferoelgaspotenzial_Deutschland_2016.pdf%3F_blob%3DpublicationFile%26v%3D5.

Leiren, Merethe Dotterud, Aakre, Stine, Linnerud, Kristin, Julsrud, Tom Erik, Di Nucci, Maria Rosaria, Krug, Michael, 2020. Community Acceptance of Wind Energy Developments: Experience from Wind Energy Scarce Regions in Europe. Sustainability 12, 1754.

Levi, Margaret, 1998. A State of Trust. In: Braithwaite, Valerie A., Levi, Margaret (Eds.), Trust and governance, The Russell Sage Foundation series on trust, 1. Russell Sage Foundation, New York, pp. 77–101.

Linnerud, Kristin, Aakre, Stine, Leiren, Merethe Dotterud, 2018. Deliverable 2.1: Technical and socio-economic conditions. A literature review of social acceptance of wind energy development, and an overview of the technical, socio-economic and regulatory starting conditions in the wind energy scarce target regions. WinWind. EU.. https://winwind-project.eu/fileadmin/user_upload/Resources/Deliverables/Del2.1_final.pdf

Locke, Stefan, 2010. Neue Protestkultur – Revolte unter deutschen Dächern. Frankfurter Allgemeine Zeitung publishing date: 7st September 2010.

Markusson, Nils, Kern, Florian, Watson, Jim, Arapostathis, Stathis, Chalmers, Hannah, Ghaleigh, Navraj, et al., 2012. A socio-technical framework for assessing the viability of carbon capture and storage technology. Technological Forecasting and Social Change 79 (5), 903–918. https://doi.org/10.1016/j.techfore.2011.12.001.

Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., et al., 2018. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. In: The Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. IPCC, Geneva, Switzerland. https://www.de-ipcc.de/256.php. (Accessed 11 December 2018).

Metz, Bert, Davidson, Ogunlade R., Coninck, Heleen de, Loos, Manuela, Meyer, Leo, 2005. IPCC special report on carbon dioxide capture and storage. In: Intergovernmental Panel on Climate Change. IPCC. https://www.ipcc.ch/report/carbon-dioxide-capture-and-storage/.

Meyer-Renschhausen, Martin, Klippel, Philipp, 2017. Schiefergas-Boom in den USA. Technologie - Wirtschaftlichkeit - Umwelteffekte. Ökologie und Wirtschaftsforschung, 102. Metropolis-Verlag, Marburg.

Nuclear Energy Agency (NEA), 2015. Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources. OECD. Paris. https://www.oecd-nea.org/rwm/pubs/2015/7189-stakeholder-involvement-2015.pdf.

Neville, Kate J., Weinthal, Erika, 2016. Mitigating Mistrust? Participation and Expertise in Hydraulic Fracturing Governance. Review of Policy Research 33 (6), 578–602. https://doi.org/10.1016/j.techfore.2011.12.001.

Ohlhorst, Dörte, 2009. Windenergie in Deutschland. Konstellationen, Dynamiken und Regulierungspotenziale im Innovationsprozess. In: VS Research Energiepolitik und Klimaschutz. VS Verl. für Sozialwiss, Wiesbaden.

Reed, Mark S., 2008. Stakeholder participation for environmental management: A literature review. Biol. Conserv. 141 (10), 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014.

Röhlig, Klaus-Jürgen, 2019. The ENTRIA Project (2013-2018). First Steps towards Sociotechnical Radioactive Waste Management Research in Germany. In: Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison, 3. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 311–322.

Saretzki, Thomas, Bornemann, Basil, 2014. Die Rolle von Unternehmensdialogen im gesellschaftlichen Diskurs über umstrittene Technikentwicklungen: Der „InfoDialog Fracking". Forschungsjournal Soziale Bewegungen 27 (4), 70–82.
Schirrmeister, Mira, 2014. Controversial futures - discourse analysis on utilizing the "fracking" technology in Germany. Eur. J. For. Res. 2 (1) https://doi.org/10.1007/s40309-014-0038-5.
Schmidt-Hattenberger, Cornelia, 2018. Globale Entwicklung der CCS-Technologie und ihre Rolle als mögliche Klimaschutzmaßnahme. Energiewirtschaftliche Tagesfr. 68 (7/8), 35–38.
Schreurs, Miranda A., Suckow, Jorina, 2019. Bringing Transparency and Voice into the Search for a Deep Geological Repository. Nuclear Waste Governance in Germany and the Role of the National Civil Society Board - Nationales Begleitgremium (NBG). In: Brunnengräber, Achim, Di Nucci, Maria Rosaria (Eds.), Conflicts, Participation and Acceptability in Nuclear Waste Governance. An International Comparison, 3. Springer Fachmedien Wiesbaden, Wiesbaden, pp. 293–310.
Schulz, Marlen, Scheer, Dirk, Wassermann, Sandra, 2010. Neue Technik, alte Pfade? Zur Akzeptanz der CO2-Speicherung in Deutschland. GAIA - Ecological Perspectives for Science and Society 19 (4), 287–296.
Seigo, L'Orange, Selma, Dohle, Simone, Siegrist, Michael, 2014. Public perception of carbon capture and storage (CCS): A review. Renewable and Sustainable Energy Reviews 38, 848–863. https://doi.org/10.1016/j.rser.2014.07.017.
SRU, 2013. Fracking zur Schiefergasgewinnung. Ein Beitrag zur energie- und umweltpolitischen Bewertung. Sachverständigenrat für Umweltfragen (Stellungnahme, Nr. 18). https://www.umweltrat.de/SharedDocs/Downloads/DE/04_Stellungnahmen/2012_2016/2013_05_AS_18_Fracking.html.
StandAG, 2017. Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für hochradioaktive Abfälle. StandAG. http://www.gesetze-im-internet.de/standag_2017/BJNR107410017.html, 2017. (Accessed 11 December 2018).
Statista, 2017. Fracking. Dossier. Hg. v. Statista. https://de.statista.com/statistik/studie/id/37920/dokument/fracking-statista-dossier/. (Accessed 11 December 2018).
Statista, 2019a. Länder weltweit mit der höchsten Erdgasförderung in den Jahren 2009 bis 2017. https://de.statista.com/statistik/daten/studie/37383/umfrage/laender-nach-erdgasfoerderung/.
Statista, 2019b. Weltweite Erdgasförderung insgesamt in den Jahren von 1970 bis 2018. https://de.statista.com/statistik/daten/studie/40814/umfrage/welt-insgesamt—erdgasproduktion-in-milliarden-kubikmeter/, 2019.
Themann, Dörte, Brunnengräber, Achim, 2019. The nuclear legacy in the Anthropocene: interrelations between nature, technology and society. In: Hickmann, Thomas, Partzsch, Lena, Pattberg, Philipp H., Weiland, Sabine (Eds.), The Anthropocene Debate and Political Science, Routledge Research in Global Environmental Governance. Routledge, London and New York, pp. 182–199.
UBA, 2014. Wo wurden in Deutschland bisher Fracking-Operationen zur Erdgasförderung durchgeführt? https://www.umweltbundesamt.de/service/uba-fragen/wo-wurden-in-deutschland-bisher-fracking.
UBA, 2018. Carbon Capture and Storage. Hg. v. Umweltbundesamt. Online verfügbar unter. https://www.umweltbundesamt.de/themen/wasser/gewaesser/grundwasser/nutzung-belastungen/carbon-capture-storage.
Watson, Jim, Kern, Florian, Markusson, Nils, 2014. Resolving or Managing Uncertainties for Carbon Capture and Storage: Lessons from Historical Analogues. In: Technological Forecasting & Social Change, vol. 81, pp. 192–204.
Weber, Florian, Roßmeier, Albert, Jenal, Corinna, Kühne, Olaf, 2017. Landschaftswandel als Konflikt. In: Kühne, Olaf, Megerle, Heidi, Weber, Florian (Eds.), Landschaftsästhetik und Landschaftswandel. Springer VS (RaumFragen), Wiesbaden, pp. 215–244.
Weingart, Peter, 1994. Großtechnische Systeme. Ein Paradigma der Verknüpfung von Technikentwicklung und sozialem Wandel. In: Hilpert, Ulrich (Ed.), Zwischen Scylla und Charybdis? Zum Problem staatlicher Politik und nicht-intendierter Konsequenzen. VS Verlag für Sozialwissenschaften, Wiesbaden, pp. 175–192.
Wieland, Thomas, 2009. In: Neue Technik auf alten Pfaden? Forschungs- und Technologiepolitik in der Bonner Republik. Eine Studie zur Pfadabhängigkeit des technischen Fortschritts., 1stScience Studies. transcript Verlag, Bielefeld.
WindEurope, 2019. Wind energy in Europe in 2018 - Trends and statistics. In: WindEurope, Brussels. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf. (Accessed 19 September 2019).
WinWind, 2020. Del. 6.3 Principles & criteria for fair & acceptable wind energy. Berlin. https://winwind-project.eu/fileadmin/user_upload/Resources/Deliverables/Del_6.3_Principle_and_Criteria.pdf (Accessed 24 Febraury 2021).
Wolff, Josh, Herzog, Howard, 2014. What lessons can hydraulic fracturing teach CCS about social acceptance?. In: Energy Procedia, 63, pp. 7024–7042. https://doi.org/10.1016/j.egypro.2014.11.736. S.