Master's Thesis – master Sustainable Development

Operationalising intergenerational justice for long-term geological storage and disposal

A policy analysis of European policy concerning nuclear waste disposal and CCS

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Abstract

Intergenerational justice concerns itself with the just distribution of risks and benefits across generations, including people thousands of years into the future, and is inherent in the concept of sustainability. For two issues in particular, decisions need to made right now that carry large intergenerational justice considerations: disposal of high-level radioactive waste from nuclear power plants or other nuclear applications, and carbon capture and storage (CCS). Both will likely be achieved with long-term geological facilities, which need to be planned and managed in such a way that harm for future generations is minimised. The policies made today concerning nuclear waste disposal and CCS will thus impact the lives of generations far into the future and as such, care must be taken to safeguard intergenerational justice. However, there is no established framework for assessing how intergenerational justice for the distant future is operationalised and safeguarded in policy, despite the importance of applying the justice theory in practice.

The aim of this research is to develop an assessment framework for how intergenerational justice is operationalised in long-term policy and to apply this framework to different national nuclear waste disposal and CCS policies in order to determine how intergenerational justice should be operationalised in policy in order to best safeguard the rights of future generations.

The assessment framework was developed through a systematic literature review and consists of ten criteria, based on six principles: future impacts, vision of future, time scale, freedom of choice, financing, and discounting. This framework can be applied to any long-term policy in order to assess how well it safeguards intergenerational justice.

The framework was applied to the nuclear waste disposal policies of the Netherlands, the UK and Finland, as well as to the CCS policies of the Netherlands, the UK and Norway. In general, the nuclear waste disposal policies perform better than the CCS policies on all six principles of intergenerational justice, and the former can thus act in part as an example for the development of future CCS policies that better safeguard intergenerational justice. Still, the nuclear waste disposal policies have significant improvements to make, in particular when it comes to the principles of vision of future, freedom of choice, and discounting. All countries would do well to include more insights from the intergenerational justice literature in their policies, as currently, no policy is able to adequately operationalise intergenerational justice such as to safeguard this principle.

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1. Introduction

1.1 Problem contextualisation

> *"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."*
> (UN Brundtland Commission, 1987)

Future generations take a central position in the concept of sustainability, as delineated by the Brundtland Commission. The actions of humans today cannot undermine the rights of future generations. This concept of intergenerational justice applies not only to the next handful of generations, but also to people who will live tens of thousands of years into the future, and concerns itself with the just distribution of risks and benefits across generations (Thompson, 2010). Decisions for such a time scale need to be made right now for two issues in particular: disposal of high-level radioactive waste from nuclear power plants or other nuclear applications, and the capture and storage of carbon dioxide (CO_2). Both nuclear power and carbon capture and storage may play a role in ensuring a more sustainable, low-emission energy supply; however, the corresponding disposal and storage need to happen in such a way that harm for future generations is minimised, ergo in a sustainable and just way.

Nuclear practices, whether in the form of nuclear power plants, medical applications of radioactive material, or research activities, yield radioactive waste. This waste can remain radioactive for hundreds of thousands of years, which necessitates disposal of such waste until their potential harm has decreased significantly; the most promising method for doing so is through deep geological disposal (Taebi & Kloosterman, 2008). The nuclear waste that has been generated in the past century will thus need to be managed in such a way that its dangers for future generations are minimised.

Carbon capture and storage (CCS) is a climate change mitigation measure that entails the capture of CO_2 from a point source of emissions and its subsequent transport and long-term storage in order to isolate it from the atmosphere (Medvecky et al., 2014). Capturing carbon before it is able to enter the atmosphere helps protect current and future generations from the negative effects of a higher CO_2 percentage in the atmosphere, such as global warming and ocean acidification, and can therefore contribute to sustainability. However, care must be taken that the stored carbon will not escape storage back into the atmosphere and thereby burden future generations with the dangers of the CO_2 that was produced by the current generation. As for the disposal of nuclear waste, the storage of captured CO2 is most commonly proposed to take place in deep geological formations. Although the quantity of nuclear waste is much smaller than the proposed volume of stored CO_2, the dangers as a result of potential storage failure are much more severe for the former than for the latter (Toth, 2011). For both types of solutions, careful considerations are needed about the best way to minimise risks and burdens for future generations, which depends on what we consider to be our moral obligation to future generations.

The decisions for the use of nuclear power or CCS remain controversial, and this research does not attempt to provide an answer to the question of whether nuclear power or CCS should be utilised. Instead, it sets out to answer how geological nuclear waste disposal and CCS should be performed in order to best safeguard intergenerational justice, in case the decision is made to pursue these technologies.

1.2 Problem definition and knowledge gap

The policies made today concerning nuclear waste disposal and CCS will impact the lives of generations far into the future. As such, care must be taken to safeguard intergenerational justice. Previous research has identified which aspects of nuclear waste disposal or CCS are in particular subjected to issues of intergenerational justice, such as the use of a discount rate, the financing structure in place, and the preservation of choice for future generations (e.g., Boucher & Gough, 2012; Medvecky et al., 2014; Saraç-Lesavre, 2020; Schwarz, 2022; Taebi & Kloosterman, 2008; Toth, 2011). Jafino et al. (2021b) have focussed on addressing distributional justice, including an intergenerational dimension, in integrated assessment models and identified eleven requirements for such models based on ethical imperatives. However, there is no established framework for assessing how intergenerational justice for the distant future is operationalised and safeguarded in policy, despite the importance of applying the justice theory in practice; in particular, there is a need for such an assessment framework that can then be applied to geological nuclear waste disposal and CCS policies.

In developing policy for nuclear waste disposal and/or CO_2 storage, the principle of intergenerational justice can be operationalised in varying ways and to varying degrees. The International Atomic Energy Agency (IAEA) has formalised the expected obligations to future generations with respect to nuclear waste in a set of guidelines (IAEA, 2016, 2020), which have been adopted by the European Union (EU) and subsequently into its member states' policies (Directive 2011/70, 2011). For CCS, however, there is no set international or regional European policy and states have to decide on their own whether they want to pursue it as a mitigation option and therefore whether or not they include it in their own policies. Intergenerational justice can thus be interpreted and operationalised in different ways between countries, but also between nuclear waste disposal and CCS policies.

1.3 Research objective and questions

The aim of this research is to develop an assessment framework for how intergenerational justice is operationalised in long-term policy and to apply this framework to different national nuclear waste disposal and CCS policies in order to determine how intergenerational justice should be operationalised in policy in order to best safeguard the rights of future generations.

To this aim, four countries' policies are analysed as case studies to determine how intergenerational justice has been, and could be, operationalised in policy. Two European countries which have policies on both nuclear waste disposal and carbon storage, and whose policies can therefore be analysed for their operationalisation of intergeneration justice in both, are the Netherlands and the United Kingdom. The frontrunner when it comes to nuclear waste disposal is Finland, as the only country currently in the implementation phase of high-level nuclear waste disposal (Posiva, n.d.-b). However, Finland does not appear to currently have any plans to pursue CCS and the technology receives no mention in their 2030 energy and climate strategy (Finnish Ministry of Economic Affairs and Employment, 2019). The Finnish case study is therefore used in assessing the application of intergenerational justice in nuclear waste disposal policy. Conversely, Norway has no nuclear power plants but is a leading country in its deployment of CCS (International Energy Agency, 2022), and this case is used in the application of intergenerational justice in CCS policy. Finland and Norway can thus present experienced policy examples for respectively nuclear waste disposal and CCS.

The main research question is then: *How should the principle of intergenerational justice in relation to geological nuclear waste disposal and CO_2 storage be operationalised?* To answer this, four sub questions are defined:

1. How can the operationalisation of intergenerational justice be assessed in long-term national policies?

2. How have the Netherlands, the UK and Finland operationalised the principle of intergenerational justice in relation to geological nuclear waste disposal?
3. How have the Netherlands, the UK and Norway operationalised the principle of intergenerational justice in relation to geological CO_2 storage?
4. How can the Netherlands, the UK, Finland and Norway improve their nuclear waste disposal and/or CO_2 storage policies to better safeguard intergenerational justice?

The assessment framework developed in answer to sub question 1 is used in answering the following questions.

1.4 Relevance

A long-term solution needs to be found for the disposal of nuclear waste, irrespective of current decisions to continue with nuclear power generation or not, due to the waste that already exists in the world. The adoption of CCS, however, is a decision that still needs to be made or further developed in most places and only applies to current emitting sources. It is important to consider the justice implications of such a decision and how this could shape policies. The social relevance of this study therefore lies in providing insights into how policy makers can best safeguard intergenerational justice in their nuclear waste disposal or CCS policies and in identifying potential lessons that can be learnt from nuclear waste disposal policy for CCS policy and vice versa. The research results cannot only be used to improve the policies of the countries included in this study, but also provide examples for how to safeguard intergenerational justice for other countries; this is especially relevant for countries that still have yet to develop policies in these fields. The framework can be applied to assess whether governments are acting sufficiently to defend the rights of future generations.

This research makes a scientific contribution through its development of an assessment framework that can be applied to different issues related to intergenerational justice, and it therefore contributes to a better policy understanding. This framework can be applied outside of the policy context of nuclear waste disposal and CCS as well, for example on other long-term climate policies that also have a clear intergenerational character.

1.5 Overview of the research

The next chapter sets out the theoretical framework of intergenerational justice. Chapter 3 describes the case studies that are analysed in this study, namely nuclear waste disposal and

CCS, and gives the policy context for the four relevant countries. Then, chapter 4 provides the methodology that was used in performing this research, and chapters 5, 6 and 7 present the results. In particular, the assessment framework for intergenerational justice is described in chapter 5, which is used in chapters 6 and 7 for the policy assessment of the nuclear waste disposal and CCS policies, respectively. The results are discussed in chapter 8, and chapter 9 concludes.

2. Theoretical framework

This chapter provides the theoretical framework of intergenerational justice, which underlies the rest of the research. First, 'just transition' scholarship is described, followed by an overview of different theories of intergenerational justice, and finally three major policy implications of intergenerational justice are explained.

2.1 Just transition: climate, energy and environmental justice

Theories of 'justice' have a history spanning millennia. For this research in particular, those grouped under 'just transition' scholarship are most relevant. 'Just transition' has been defined to be "a fair and equitable process of moving towards a post-carbon society" (McCauley & Heffron, 2018), and is a recent grouping of three established fields of justice literature: climate, energy and environmental (CEE) justice. Climate justice focuses on the consequences of climate change, in particular their effects on vulnerable groups, and how this reflects or exacerbates justice issues (McCauley & Heffron, 2018). Energy justice literature focuses on the fair dissemination of the costs and benefits of energy services and applies principles of justice to all energy-related topics, including energy policy, and on a fair transition to a low-carbon energy system (Jenkins, McCauley, et al., 2016; Sovacool & Dworkin, 2015). Lastly, environmental justice concerns itself with the interaction between social factors and environmental benefits and harms (Sze & London, 2008).

Two dominant dimensions of these three justice scholarships are procedural and distributional justice. The former concerns itself with a just planning and decision-making process; it mandates equitable participation procedures that involve all stakeholders, e.g., when siting decisions need to be made (Jenkins, McCauley, et al., 2016). The latter addresses the just distribution of benefits and burdens over space and time. It concerns itself with the shape, unit and scope of the distribution, i.e., how it is distributed, what is distributed, and among whom it is distributed (Jafino et al., 2021). Distributive justice theory recognises that the benefits, e.g., of a certain climate technology, are often not felt in the same place and by the same people as the drawbacks and risks (Jenkins, Heffron, et al., 2016).

Geological storage and disposal can contribute to a sustainable just transition. Firstly, nuclear energy can provide low-carbon power generation and thereby minimise the climate effects of the electricity supply, with geological disposal then needed to minimise the negative effects of such nuclear power by storing the associated dangerous radioactive waste. Geological storage of carbon through CCS can reduce the emissions released into the atmosphere from different energy-intensive activities, and can thus similarly mitigate the climate change effects associated with a high atmospheric CO_2 content. However, geological storage and disposal also encounter facets of distributional injustice. The benefits of nuclear power, such as relatively clean electricity generation and useful medical and research applications, have been experienced by past and current generations, while future generations are left to experience many of the associated drawbacks and risks, i.e., radiation leakages from disposed nuclear waste. Similarly, both current and future generations would benefit from the reduced carbon emissions and therefore mitigated climate change impacts through CCS, but future generations bear the brunt of the risks associated with the storage. These are thus issues of distributive justice, and in particular, of intergenerational justice.

2.2 Theories of intergenerational justice

Intergenerational justice is the scholarship that concerns itself with the just distribution of risks and benefits between generations, and as such is a form of distributive justice (Thompson, 2010). Power imbalance is an inherent feature of the relation between generations: earlier generations are able to affect the resources and options available to later generations directly while this is unable to happen in reverse (Meyer, 2021). Additional features are that earlier generations' choices directly determine how many and which people will exist in the future, and the limited knowledge of the future, meaning there is an imperfect awareness of the long-term consequences of current actions and policies. In absence of other moral convictions, generations are likely to engage in 'buck-passing', meaning to benefit itself through goods that impose costs on future generations while avoiding goods that would impose costs on itself in favour of its successors (Gardiner, 2012).

For proximal generations, i.e., the immediate descendants of people alive today, it may be sufficient to appeal to a moral duty to incur extra costs for benefit of the future. And arguably, for a large part of human history, the influence of our choices and actions did not span much further than that (Thompson, 2010). Due to technological developments in the last couple of hundred years, however, humans have had an impact on the environment and planet that will still influence lives very far into the future, e.g., through climate change, and an appeal to the base human instinct to provide for our children may carry less weight. The field of intergenerational justice attempts to safeguard the rights and opportunities of future generations, irrespective of how far into the future they may exist. Different interpretations of intergenerational justice originate from different fields of philosophy, and the most prominent of these are described below.

2.2.1 Mutual advantage theory

The mutual advantage theory describes that if all actors act perfectly rationally in their own self-interest, they will cooperate and share with others as this will be found to be mutually advantageous. This theory is rooted in Hobbesian social contract theory. Influential modern thinkers include Brian Barry and Gauthier.

Mutual advantage theory invites discussion on some of its shortcomings when applied to intergenerational justice. Mainly, critiques are due to the fact that not all generations overlap. Gauthier (1986) argues that younger, contemporaneous generations will ensure the older generations treat other generations fairly. However, when there is a large generational gap between actions and their consequences, as in nuclear waste disposal and CCS, such a safeguard is not in place and the conditions for good cooperation may not be respected by all generations (Gosseries & Mainguy, 2008). Additionally, non-overlapping generations threaten the mutual character of the benefits of cooperation (Gosseries & Mainguy, 2008).

2.2.2 Utilitarianism

Utilitarianism was developed in the 19th century by Jeremy Bentham, and has found proponents in John Stuart Mill and others. This theory conceptualises justice as that which maximises the aggregate welfare of the population. It is not inherently concerned with the equal distribution of benefits or welfare. As such, a utilitarian would be willing to sacrifice the welfare of a few for the betterment of the rest, and it can therefore be said to have sacrificial tendencies (Gosseries & Mainguy, 2008). Derek Parfit (1984) has raised concerns over the ‘repugnant conclusion’ of utilitarianism, namely that the theory’s aggregate nature would prefer an extreme increase in population with impoverishment of every individual as a consequence over a situation with no population growth, yet higher individual welfare, as long as the total welfare is higher in the former situation than in the latter. Similarly, Robert Nozick (1974) has described the ‘utility monster’: utilitarianism would allow for the situation in which the wellbeing of nearly everybody is sacrificed for one person, if this particular ‘utility monster’ receives more utility from a unit of a resource than any other person. Another critique raised by Parfit (1984) is that of the nonidentity problem: if a certain policy of decision would mean different people come into existence, the people cannot be said to be better or worse off because of the policy, as they would not have existed at all otherwise (Duckworth, 2013).

Applied to the intergenerational context, utilitarianism may lead to sacrificing the welfare of earlier generations for the benefit of later generations. This rests upon the assumption that capital may be invested wisely to yield more resources and welfare in the future. As a result, earlier generations should invest more in order to benefit future generation (Gosseries & Mainguy, 2008). What may exacerbate this sacrificial character is the presence of intergenerational descending altruism, i.e., parents who wish to save more for their future children. To attenuate this sacrificial character, there are two major solutions. First, the use of diminishing marginal utility, which acknowledges that the satisfaction produced by a good declines as more of it is consumed (Berkman et al., 2016). A resource should then be allocated there where it would maximise the additional welfare (Gosseries & Mainguy, 2008). Secondly, a social discount rate can be applied, which is described in detail in section 2.3.1 below.

2.2.3 Libertarianism

The famous philosopher John Locke is widely regarded as the father of libertarianism, and has stated that private property is appropriate "at least where there is enough and as good left for others" (Locke, 1690, as cited in Gosseries & Mainguy (2008)). This 'Lockean proviso' has been applied to intergenerational justice by Nozick (1974), among others, who limits a generation's use of resources such that "enough and as good" is passed on to future generations (Duckworth, 2013). Efforts have been undertaken to determine what constitutes 'enough; and 'as good.' Gosseries & Mainguy (2008) define the principle as "each generation must leave to the next at least as much as what the next generation could have appropriated if the current generation had not contributed by its actions to a net improvement or deterioration of what the following generation would otherwise have inherited." However, this would absolve current generations from any responsibilities for future generations if it had been past generations that have incurred the harm for future generations.

2.2.4 Sufficientarianism

Sufficientarianism is concerned with ensuring all individuals have enough to cover their basic needs, and is not concerned with a fair distribution after a certain threshold of welfare has been reached for everyone. An example of a sufficientarian view of intergenerational justice can be found in the Brundtland report, which defines sustainability as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" (Gosseries & Mainguy, 2008; UN Brundtland Commission, 1987) Complications of sufficientarianism lay in defining the exact threshold, as well as in how to apply it in a situation where it is not possible for every individual to reach the threshold (Meyer, 2021).

2.2.5 Egalitarianism

Egalitarianism aims to reduce or eliminate all inequalities between individuals. Applied intergenerationally, this means it aims to reduce all inequality between current and future generations, as well as inequalities among future contemporaries (Meyer, 2021). If some individuals are disadvantaged due to external circumstances, e.g., a natural disaster, the rest of society should shoulder the cost of compensation. In an intergenerational context, this means that even if current generations are not affected by projected future events, we have a savings obligation with respect to the future generation(s) that would be affected by this (Gosseries & Mainguy, 2008). However, egalitarianism runs into the problem of preferring a situation in which everyone would be worse off, but equally, over a situation in which everyone is better off, but unequally (Meyer, 2021).

2.2.6 Rawlsian just savings

John Rawls has developed the principle of 'just savings', which determines how current generations should save resources for future generations. In this, he distinguishes two phases. First, there is the accumulation phase, in which current generations should save for future generations if there are no sufficient funds available yet to ensure future generations could meet a sufficientarian threshold. Then, the steady-state stage follows, in which sufficient resources and institutions have been established that can ensure justice for future generations, and no further savings are necessary.

2.3 Policy applications of intergenerational justice

These theories of intergenerational justice can be applied to different (policy) fields. It can be applied to what current generations owe to future generations, but also to the rights between older and younger generations alive contemporaneously, and even what past generations may still owe to current generation, e.g., in discussions about reparation payments to people whose ancestors were enslaved (Meyer, 2021). It is particularly relevant to environmental policy, as the past and current depletion of our planetary resources greatly influences the lives of future generations. On the one hand, such resource exploitation has enabled current and future generations to live according to a higher standard of welfare, but on the other hand it means future generations will not have access to the same resources and corresponding opportunities as previous generations while they will also be the ones facing the most negative consequences, e.g., through the effects of climate change.

Decisions that are made now about nuclear waste disposal and carbon storage, in particular, will be felt hundreds of thousands of years into the future. Intergenerational justice considerations for policy for such distant future can appear in different ways, the three most important of which are discussed below.

2.3.1 Discounting

First, policy needs to reflect the decision on how to value future risks and benefits. Often applied in cost-benefit analyses, a common method to assess future risks and benefits is by discounting. Things in the present can be valued higher (monetarily) for different reasons. First, as humans are often impatient, they would prefer to receive some resource today rather than tomorrow (Dasgupta, 2008). Secondly, money received today could be invested in order to generate more value in the future and can thus be assumed to have higher value than future money (Liu et al., 2021). This is compounded by the presence of a positive interest rate. Lastly, if it is assumed that future generations will be wealthier than the current generations, egalitarian considerations can allow discounting future money due to declining marginal utility. This means that one additional unit of consumption would improve welfare of the richer future generations less than it would for the poorer current generation, and it would therefore be considered just to apply a positive discount rate (Dasgupta, 2008; Davidson, 2015). To illustrate, application of a typical 6% discount rate means a benefit of €100 next year would be valued as €94 today (Davidson, 2015). Such a discounting approach is little contested when applied to projects spanning several years. However, when applied to projects with a very long time-span, such as nuclear waste disposal or CCS, even an extremely low discount rate would devalue any risks far enough into the future (Lind, 2007). The same discount rate of 6% would mean a climate disaster valued at a billion euros a hundred thousand years into the future would not be worth even a cent of investment today to circumvent. This becomes especially contentious when these risks are measured in human lives. As Hansson (2015) has shown, even a low discount rate of 0.5% would mean than the loss of ten billion lives five millennia into the future, likely meaning the full extinction of the human race, would be preferable over the loss of one human life today. Some have therefore argued for a (near-)zero discount rate to avoid this issue of devaluing future impacts too much, especially when the risks that are discounted involve loss of human life (Barrage, 2018; Hansson, 2015). Others have argued for a declining or hyperbolic discount rate, such that events further into the future are discounted less than events in the near future (Al Yaqoobi & Ausloos, 2022; Almansa & Martínez-Paz, 2011; Ellingwood & Lee, 2016).

2.3.2 Long-term financing options

Another policy implication of intergenerational justice is found in determining who bears the financial burdens of carrying out policies that may apply far into the future. For example, future costs of nuclear waste disposal or CCS may include care and maintenance costs of the storage facility, but also potential costs in case of storage failure for reinforcement or clean-up (Cohen, 1981). Based on the Polluter Pays Principle (PPP), Padilla (2002) presents two options for current generations to compensate future generations for the costs they might incur in the future. First, compensation through an associated project which would generate value for future generations, such as reforesting; secondly, by setting up monetary funds to allow direct financial compensation of future generations. However, such solutions may be hard to uphold into the far distant future and may not provide appropriate coverage of the costs (Boston et al., 2021). Additionally, unexpected costs may exceed the amount of funds set aside in advance, and some financial burden will therefore likely befall future generations (Saraç-Lesavre, 2020).

2.3.3 Preservation of choice for future generations

The third major policy implication of intergenerational justice is about the preservation of choice for future generations. Even if decisions and policies are made with the utmost care reflecting the current state of research, it is possible that these decisions may prove to not have been the ideal ones at some point in the future as a result of new insights. Additionally, societal values may change, and future generations may want to have the ability to make different choices than their predecessors had made. As such, it can be considered just to avoid lock-in and preserve the largest range of choices available for future generations (Clark, 2020; Ferretti, 2023; Jafino et al., 2021).

In the practical example of nuclear waste disposal, concerns about the freedom of choice are exemplified by the consideration between reversibility and permanent enclosure of the disposal site. Proponents of including reversibility into the disposal site design, and thus allowing relatively easy access to the nuclear waste, argue that this would allow future generations to make alternative decisions about disposal techniques or recycling if there are new (scientific) developments that support this (Gowda & Easterling, 2000). This is thus seen as granting more sovereignty to future generations by allowing them to make their own choices with regard to the waste (Schwarz, 2022a). Proponents of permanent enclosure of the disposal site, however, argue that retrievability may pose health and safety risks for future generations who interact with the waste, and that it may oblige future generations to invest time and money into securing or improving design choices made by their ancestors (Kermisch, 2016; Okrent, 1999; Toth, 2011). Instead, they propose to completely isolate the disposal site from potential external influences, including human involvement.

3. Case study description

3.1 Nuclear waste disposal

Nuclear power generation harnesses the inherent nuclear energy of atoms by splitting a heavy element such as uranium into smaller elements, thereby releasing some of this energy that can then be harnessed and converted into useful power (Ferguson, 2011). This process is called nuclear fission. It is a major low-carbon power generation source, second only after hydropower in its contribution to low-carbon electricity generation. In total, nuclear power provides approximately ten per cent of the world's electricity, and 32 countries have operational nuclear power plants (IEA, 2023; World Nuclear Association, 2023d).

In the process of nuclear fission, however, radioactive waste materials are generated. In particular, the spent fuel rods will remain radioactive for an extremely long time, up to millions of years. This waste is considered high-level waste. In addition, low- and intermediate-level waste is generated throughout the supply chain of nuclear power, e.g., during mining of the radioactive uranium or through contamination with radioactive material in the power plant (Ferguson, 2011). Low-level waste typically has half-lives of less than thirty years, and thus only needs to be stored for a couple of centuries; intermediate level waste has longer half-lives and needs to be stored for up to a few thousand years (Canadian Nuclear Safety Commission, 2021; Ferguson, 2011). Next to waste from nuclear power generation, a small amount of waste is also produced through other applications of nuclear energy, such as medical or research applications.

Currently, all nuclear waste is stored aboveground, often at the nuclear power plants themselves (World Nuclear Association, 2023b). Immediately after the fuel rods have been used, they are stored in pools to allow them to cool down and reduce their radioactivity for a couple of years, after which they are sealed in containers and stored on-site. For low and intermediate level waste, such temporary storage can be sufficient to reduce radioactivity levels to a non-hazardous amount, but high-level waste will remain dangerous to the environment and human life for thousands of years to come. As such, a more permanent disposal solution needs to be found, as aboveground on-site storage can pose risks in case of natural disasters or external attacks (Romanato & Rzyski, 2006).

Different options have been proposed for such nuclear waste disposal. Unconventional proposals include disposal in ocean sediment (World Nuclear Association, 2023b) or expulsion of the waste into space (Kim et al., 2016), but the one regarded as most feasible is deep geological disposal. This involves disposal of the nuclear waste in naturally stable geological formations underground (Apted & Ahn, 2017). Safety is ensured by using multiple barriers, both artificial and natural; the waste is encased in metal containers, which are stored in deep tunnels in the bedrock, which are then buffered and back-filled to ensure minimal interaction of the waste with the environment. The deep, stable bedrock ensures protection against natural disasters, such as earthquakes and tsunamis, and against intentional or accidental human involvement. This way, the waste can be stored for hundreds of thousands of years, enough time to ensure radioactivity has reduced to safe levels.

Extensive safety measures need to be taken throughout the process of nuclear waste disposal, as introduction of radioactive material into the environment, such as by leakage into groundwater, could have widespread impacts on the organisms living near the disposal site, including future human generations (Ferguson, 2011). Additionally, the disposal sites need to be protected from harmful human involvement.

Decisions on nuclear waste management will need to be taken regardless of whether nuclear power generation is continued or halted in the future, as all the waste that has been generated in the past has still only been temporarily stored aboveground. However, as such disposal facilities will have to remain operational far into the future, this means that decisions made by the current generation will affect generations hundreds of thousands of years from now. This therefore introduces issues related to intergenerational justice, as certain choices pertaining to how much freedom of choice is granted to future generations and whether future generations are expected to contribute time and money into remedying the current generations' problems, impact whether future generations are considered to be treated fairly.

Another intergenerational justice consideration is introduced through the choice to produce nuclear power through open or closed fuel cycles. The former involves using the nuclear fuel in a once-through method, meaning spent fuel from a reactor is not reprocessed and instead stored away after being irradiated once (Taebi et al., 2012). The spent fuel remains highly radioactive and necessitates safe disposal for hundreds of thousands of years. The latter cycle involves the reprocessing of spent fuel in order to reuse the material in another fuel cycle, and the leftover waste remains radioactive for about a 'mere' ten thousand years. The reprocessing procedure, however, is not only very costly and technically challenging, but also involves the separation of uranium and plutonium for reuse. The existence of separated plutonium can pose serious proliferation risks due to its potential use in nuclear weapons (Taebi & Kloosterman, 2008). There is therefore an intergenerational justice consideration as to how the proliferation risks for current generations are weighted against the increased risks for future generations that go paired with a longer disposal time. This choice is reflected in policy decisions. For example, the US policy reflects their explicit preference for an open fuel cycle, while Russia's policies promote the reprocessing of nuclear fuel (Taebi & Kloosterman, 2008).

3.2 Carbon Capture and Storage

Carbon capture and storage involves the direct capture of CO_2 at a point-source of emissions, e.g., from a carbon-intensive factory, its treatment, transport and finally storage. As this technology reduces the amount of CO_2 that is released into the atmosphere, it has been proposed as an important emissions-reduction measure in global efforts to achieve the global climate targets (Akerboom et al., 2021).

CCS is still a relatively new technology and there were only 30 operational projects in 2022, with the largest capacity located in the United States and Norway, but many more projects are in development (Global CCS Institute, 2022). Captured CO_2 has been used in enhanced oil recovery before, which increases the productivity of an oil well, and although this may store part of the CO_2 that is injected, it simultaneously enables further increased emissions by burning the fossil fuels recovered (Al-Shargabi et al., 2022).

After the CO_2 has been captured from the source, which can take place during oxyfuel combustion, pre-, or post-combustion, the gas is compressed to very high pressures (Kanniche et al., 2010). After compression, the CO_2 is transported from the industry site to its permanent storage site, most commonly by pipeline. Storage can be done in gaseous form in deep geological formations, through ocean storage in the water column or on the sea floor, or by chemically binding the CO_2 with metal oxides into mineral carbonates and storing it in solid form (Metz et al., 2005). The first is the most common and promising approach for large-scale CCS, and involves injecting the pressurised CO_2 gas into the subsurface, such as in depleted gas or oil fields or saline formations, whose bedrock then provides a natural barrier to contain the CO_2.

During transport and storage, leakages can occur that have negative effects on the environment and human health. The sudden release of large amounts of CO_2 can cause asphyxiation of plants and animals, or could poison a water source (Metz et al., 2005). A slow release of CO_2 into the environment carries similar effects to the ones caused by the current high amount of CO_2 in the atmosphere. For example, leakages from storage sites below the seabed can cause increased ocean acidification (Shaffer, 2010). Additionally, continuous leakage, even at low rates, could undo the climate mitigation effects the storage was meant for in the first place (Toth, 2011). To minimise the risk of such events, monitoring has to take place, which can be done both above and below ground (Metz et al., 2005). As such, intergenerational justice considerations are relevant for CCS. Similar to the case of nuclear waste disposal, future generations will have to carry the burden of monitoring and will risk environmental hazards as a direct consequence of decisions taken by the generations alive today. Simultaneously, however, CCS acts as a mitigation measure and therefore can reduce the negative effects that future generations would otherwise have experienced from climate change (Toth, 2011).

3.3 European Union policy context

3.3.1 General climate policy

The European Green Deal was approved in 2020 and presents policy initiatives to move the EU to climate-neutrality by 2050, with an intermediate target of 55% greenhouse gas (GHG) emission reductions by 2030, compared to 1990 values (European Council, 2023). The 2021 European Climate Law legally obliges member states to reach these collective targets (European Parliament and The Council, 2021). The law also places a limit of 225 Mton CO_2 on the contributions of net removals to the 2030 target. Every five years, the European Commission assesses the progress towards the EU targets, as well as the national measures in place in each of the member states. Thirty per cent of the EU's long-term budget for 2021-2027 and the Next Generation EU Recovery Plan has been allocated towards climate-related projects (European Commission, n.d.).

3.3.2 Nuclear policy

Nuclear energy provided 22% of electricity production in the EU in 2022 (Eurostat, 2023). The decision to use nuclear power is left up to the member states, but the EU provides legislation to guarantee safe procedures in nuclear power plants and during storage and disposal of nuclear waste (Cordina, 2023). The Council Directive 2013/59/Euratom lays down the basic safety standards for nuclear activities (Directive 2013/59, 2013).

The Council Directive 2011/70/Euratom creates a legal framework for the safe management of radioactive waste. All member states must create a national framework that complies with the directive and includes their national programme on waste management implementation, safety arrangements, licensing systems, control systems, enforcement actions, allocation of responsibilities, requirements for public participation and information, and the financing scheme in place (Directive 2011/70, 2011). The national programme must include, amongst others: the overall objectives and their milestones, an inventory of current and expected radioactive waste, the plans for waste management from generation to disposal, post-closure plans for the disposal facility, necessary research and demonstration activities, assessment of the programme costs, and the financing scheme (Directive 2011/70, 2011). Every three years, the member states must report on their implementation of the directive.

3.3.3 CCS policy

A regulatory framework for CCS is provided through Council Directive 2009/31/EC, which sets out, amongst others, regulation for selection of storage sites, exploration permits, storage permits, and operation, closure and post-closure obligations (Directive 2009/31, 2009). In contrast to the Directive 2011/70 described above, this directive does not oblige all member states to set out a national CCS policy or programme. Instead, it provides the legal framework for countries with CCS ambitions.

3.4 Netherlands policy context

3.4.1 General climate policy

The Netherlands has set binding GHG emission reduction targets of 49% by 2030 and 95% by 2050, with respect to 1990 levels, which are set into the country’s Climate Act (Rijksoverheid, 2019). Additionally, electricity production should be 100% climate neutral by 2050. No legal targets have been set for energy savings or the share of renewable energy in the energy mix; instead, these are considered means to achieve the emission reduction targets. The Climate Plan describes the policies in place to achieve these targets for the period 2021-2030, and is to be revised every five years (Nederlands Ministerie van Economische Zaken en Klimaat, 2020). The progress of the climate policy is reported on annually. Dutch climate policy is based on being ‘technology neutral’; it does not target specific potential solutions, but instead keeps technical possibilities open as much as possible (Nederlands Ministerie van Economische Zaken en Klimaat, 2020).

The current energy mix of the Netherlands is still heavily dominated by natural gas and oil, respectively 43% and 36% of the energy supply in 2021 (IEA, 2022d). The share of renewables (wind, solar, hydro) is steadily increasing, and accounted for 4% in 2021. The share of nuclear power has remained nearly constant between 1990 and 2021 at 1.4%.

3.4.2 Nuclear power

There is one operational nuclear power plant in the Netherlands, located in Borssele, which has been operating since 1973. Closure was originally planned for 2033, but the possibility to postpone closure is currently being investigated as the government is now aiming for increased nuclear power production (Rijksoverheid, n.d.-c). Preparations are being made for two new nuclear power plants, which should increase the share of nuclear energy in the electricity mix from approximately 4% to 9-13%, but no licenses have been granted yet (Rijksoverheid, n.d.-b). Next to the power plant in Borssele, two other nuclear reactors are used in the Netherlands for research and medical applications (Rijksoverheid, n.d.-a). The radioactive waste is currently being stored aboveground, where it will remain for a period of at least 100 years. Deep geological disposal is envisioned from around the year 2130 onwards, but a definitive decision on the disposal solution will be taken around the year 2100 (Ministerie van Infrastructuur en Milieu, 2016b).

3.4.3 CCS

There are no operational CCS projects in the Netherlands, but several projects are currently under development. Three previous attempts have failed due to public opposition or political or financial problems (Akerboom et al., 2021; Hulsbeek, 2023).

The Porthos project in Rotterdam is among the most advanced in development among CCS projects in Europe (Akerboom et al., 2021; Norwegian Ministry of Petroleum and Energy, 2019). Construction is expected to start in 2024. Once operational, it should be able to store up to 2.5 Mt CO_2 per year for up to 15 years in a depleted natural gas field below the North Sea (NOS Nieuws, 2023). Another CCS project currently being developed is Aramis, also located in Rotterdam. Its planned storage capacity is more than 400 Mt CO_2, and start-up is expected for 2028 (Aramis, 2023). Both projects are ‘open-access’ so that industrial customers can be added incrementally (Aramis, 2023; Porthos, 2023).

The Netherlands does not have a separate CCS policy document in place. Instead, the topic is integrated into the wider ‘Climate Plan 2021-2030’ (Nederlands Ministerie van Economische Zaken en Klimaat, 2020). In particular, it is discussed among the ‘industry’ section of the climate policy; is not granted its own (sub)chapter in the policy document.

3.5 UK policy context

3.5.1 General climate policy

The UK has committed to net-zero GHG emissions by 2050 compared to 1990 levels (Committee on Climate Change, 2020). The main climate policies can be found in the Net Zero Strategy (UK Government, 2021), which are based on the 2020 ‘Ten Point Plan for a Green Industrial Revolution’ (UK Government, 2020). These ten points describe the government’s increased climate efforts for offshore wind, low carbon hydrogen, nuclear power, zero emission vehicles, green public transport, aviation and shipping industries, built environment, CC(U)S, the natural environment, and finance and innovation.

Like the Netherlands, the UK energy mix is dominated by natural gas and oil, respectively 40% and 35% of the 2021 energy supply (IEA, 2022e). Renewables (wind, solar, hydro) make up 4% of the energy supply, and nuclear power contributes 7%.

3.5.2 Nuclear power

There are currently five operational nuclear power stations in the UK, with two more reactors under construction (World Nuclear Association, 2023c). Four of these reactors are expected to be closed before this end decade (EDF Energy, 2021; Leggett, 2023). Following the energy crisis in 2022, a renewed commitment to nuclear power was announced, dubbed ‘Great British Nuclear,’ aiming for local nuclear power to supply 25% of the UK’s electricity consumption by 2050 (UK Government, 2023; World Nuclear Association, 2023c). In March 2023, consultations were launched about classifying nuclear energy as ‘environmentally sustainable’, thereby granting it the same incentives as renewable energy (Lawson, 2023).

The (high-level) radioactive waste generated through these nuclear activities is stored aboveground for at least fifty years before disposal. The final disposal solution is still being developed, and is described in the 2018 policy document ‘Implementing geological disposal – working with communities’ (UK Government Department for Business, Energy & Industrial Strategy, 2018) As nuclear waste management is considered a devolved policy issue, Northern Ireland, Scotland and Wales carry responsibility for it in their own countries. Northern Ireland and Wales are sponsors of the deep geological disposal programme part of the UK policy, while Scotland aims for near-surface disposal facilities. The UK government policy thus applies only in England. The current UK policy in place still complies with the EU Council Directive 2011/70/Euratom as it was published in 2018, before the Brexit process was finalised.

3.5.3 CCS

One of the points in the Ten Point Plan is “investing in carbon capture, usage and storage,” and the aim is to capture 10 Mt CO_2 a year by 2030 in four industrial CCUS clusters (UK Government, 2020). There are no operational CCUS facilities in the UK yet, but the first two clusters (East Coast Cluster and HyNet Cluster) are planned to be operational by the mid-2020s (Hands, 2021).

The UK has not set out a separate CCUS policy. Instead, it is integrated into the wider 2017 Clean Growth Strategy (UK Government, 2017). This strategy applies for the entire UK, although the devolved governments may additionally have their own separate policies and plans. The UK specifically aims for carbon capture, usage, and storage (CCUS) instead of carbon capture and storage (CCS).

3.6 Finland policy context

3.6.1 General climate policy

Finland has set one of the world’s most ambitious climate targets in their 2022 Climate Act: net-zero by 2035 and net negative after that (Finnish Ministry of the Environment, n.d.; Lo, 2022). The policies to achieve this target consist of the Long-term Climate Plan, Adaptation Plan, Medium-term Climate Plan and Climate Plan for the Land Use Sector (Finnish Ministry of the Environment, n.d.). A Climate Report is published annually, which sets out the progress towards the climate targets (Finnish Ministry of the Environment, 2023).

Finland has a more diverse energy mix, with biofuels and waste, oil and nuclear power making up the three largest shares at 35%, 22% and 20% in 2021, respectively (IEA, 2022b).

Renewables (wind, solar, hydro) contributed 7% of the 2021 energy supply. Finland currently has no plans for CCS.

3.6.2 Nuclear power

Finland has five operational nuclear reactors in two locations, Loviisa and Olkiluoto, the most recent of which started operation in April 2023 (World Nuclear Association, 2023a). The reactors are amongst the world's most efficient nuclear reactors, with an average capacity factor of nearly 95% over the last decade. The reactors have been uprated since they first became operational, and no reactors have been permanently closed down so far (World Nuclear Association, 2023a). According to a 2022 survey of public opinion on nuclear energy in Finland, 60% of respondents viewed nuclear power positively and only 11% negatively (TVO, 2022).

The country is also a frontrunner when it comes to nuclear waste disposal. The world's first deep geological repository for spent nuclear fuel, called Onkalo, has been under construction since 2004 and is to start operation in the mid-2020s. It will be the disposal facility for the high-level radioactive waste generated in Loviisa and Olkiluoto (Posiva, n.d.-c) and it should be able to host 12,000 tonnes of spent fuel, enough to also accommodate waste from planned additional reactors at Loviisa and Olkiluoto (World Nuclear Association, 2023a). It reaches depths of 400-450 meters into the bedrock (Posiva, n.d.-a).

The Finnish national policy for nuclear waste disposal is set out in the 2022 policy document 'Management of spent nuclear fuel and radioactive waste in Finland' (Finnish Ministry of Economic Affairs and Employment, 2020).

3.7 Norway policy context

3.7.1 General climate policy

Norway aims to reduce their GHG emissions with 55% by 2030, which is an increased ambition from the original target set under the Paris Agreement of 40% (Norwegian Government, 2022). Additionally, by 2030 the overall energy intensity of the economy should be 30% lower than in 2015 (IEA, 2022a). By 2050, Norway aims to be a 'low-emission society', meaning 90-95% GHG emission reductions from 1990 values, and this target has been set into the Climate Change Act (Norwegian Ministry of Climate and Environment, 2018, 2021). Every five years, these climate targets are updated by the Norwegian government, and an annual report to parliament describes the progress towards the targets (Norwegian Ministry of Climate and Environment, 2018). As Norway already has near-zero emissions from electricity generation, the remaining reductions will mostly have to take place in transport and industry, which are often more challenging to achieve (IEA, 2022a).

Despite not being part of the European Union, Norway works closely together with the EU on climate and energy matters as a result of its participation in the EU internal energy market, and Norway will participate in EU climate legislature until 2030 (IEA, 2022a).

The largest share of Norway's energy mix is contributed by hydropower, at 40% of the total energy supply and 91% of electricity generation in 2021 (IEA, 2022c). Other important contributors to the total energy supply are oil (32%) and natural gas (16%). Wind and solar power make up 3% of the energy supply and 8% of electricity generation, meaning electricity generation in Norway is sourced nearly 100% from renewables. Norway has never had any nuclear power plants (Norwegian Radiation and Nuclear Safety Authority, 2021).

3.7.2 CCS

Norway is particularly well suited to CCS due to the large storage capacity on the Norwegian continental shelf under the North Sea and the existing expertise and resources from the country's oil and gas industries (CLIMIT Programme board, 2022). CCS is considered a priority in the Norwegian climate approach (IEA, 2022a). Norway currently hosts the only two large-scale operational CCS projects in Europe, which capture CO_2 from natural gas production and store it in formations below the seabed (Akerboom et al., 2021; Norwegian Ministry of Petroleum and Energy, 2019; Norwegian Petroleum, 2023).

The Longship project currently under construction is a large-scale CCS project that will initially capture approximately 400 kt CO_2 per year from a cement factory in Brevik, and is expected to take on an additional 400 kt CO_2 per year from a waste incineration facility in Oslo (CCS Norway, 2023b; IEA, 2022f). The CO_2 will be injected into a saline aquifer beneath the seabed (IEA, 2022f). A societal goal was defined during the project development, namely that "the demonstration of CCS shall provide the necessary development of CCS to ensure that Norway and the EU's long-term climate targets can be achieved at the lowest possible cost" (Norwegian Ministry of Petroleum and Energy, 2019). The project is meant to demonstrate that CCS can be implemented safely and overcome technical, regulatory and commercial challenges, while reducing costs of future projects (CCS Norway, 2023a). Approximately two-thirds of the project costs are covered by the Norwegian government.

Norway has not set out a separate CCS policy document. Instead, it is included in the ‘Energi21 Strategy 2022’, which describes the “national strategy for research, development and commercialisation of new climate-friendly energy technology” (Energi21, 2022).

4. Methodology

This chapter describes the methodology used in this study. First, it is set out how a systematic literature review was performed and used to develop the assessment framework; then, it is described how this framework was used in the assessment of nuclear waste disposal and CCS policies of four different countries; finally, the data sources and their collection are described.

4.1 Development of assessment framework

In answer to the first sub question, a framework was developed to assess how intergenerational justice is operationalised in policy. A systematic literature review was conducted to identify a list of policy characteristics that can help assess qualitatively how intergenerational justice is safeguarded in long-term policies, building upon the theoretical framework presented above. The relevant literature was found using Web of Science. The search lines that were used are "intergenerational just* OR intergenerational equity (Abstract) and policy OR assess* (Abstract)", which has yielded 375 results on Web of Science on 16-03-2023. The resulting articles were thus not limited to being related to nuclear waste disposal or CCS, as the assessment framework was developed for wider application to long-term policies. An initial selection was performed based on title and abstract, in which articles were excluded that did not focus on distant future generations, and only those articles that appeared to describe characteristics of intergenerational justice relevant for policy assessment were included. This yielded ninety articles for the final selection, which were read in detail to determine the presence of principles of intergenerational justice that are or should be reflected in policy. These did not need to be stated explicitly as 'principles' in the articles, but were any aspect of intergenerational justice that was deemed important by the author of the text, e.g., by stating it "should be taken into consideration" (Al Yaqoobi & Ausloos, 2022), is "essential" (Boston et al., 2021; Ellingwood & Lee, 2016), or is a "key requirement" for intergenerational justice (Jafino et al., 2021). Twenty-four articles contained such principles, and in the end six principles were identified, broken down into a total of ten policy criteria. Only one of these articles provides a clear assessment framework for intergenerational justice in policy, albeit in urban planning (Lamorgese & Geneletti, 2013). Although their framework was not applicable to nuclear waste disposal or CCS policy due to the focus on short-term policies, their framework structure of principles and corresponding policy criteria was adopted to the assessment framework developed in this research. Following their demarcation, the criteria reflect the different aspects of a principle and aid in interpreting them.

4.2 Policy analysis and assessment

The assessment framework developed in answer to the first sub question was then applied to the policies of the four countries in order to assess their operationalisation of intergenerational justice. It is therefore an 'interpretative' policy analysis, meaning the examination of "the framing and representation of problems and how policies reflect the social construction of 'problems'" (Browne et al., 2019).

In answer to the second sub question, policies on nuclear waste disposal from the Netherlands, the UK and Finland were analysed. In answer to the third sub question, policies on CCS from the Netherlands, the UK and Norway were analysed. The collection of these policies is described below in section 4.3. The relevant policy documents were coded in the programme Nvivo, based on the six principles identified in the assessment framework. Each policy was then assessed on the ten assessment criteria and it was identified whether each criterium was satisfied, partly satisfied, or not satisfied. Satisfied means the criterium is mentioned in policy and receives full explanation or argumentation; partly satisfied means the criterium is mentioned in policy but with limited explanation or argumentation, or alternatively, one part of the criterium is satisfied but the other is not; not satisfied means the criterium is not mentioned in policy, or alternatively, the criterium is mentioned but receives zero explanation or argumentation.

To answer the fourth sub question, the gaps in the policies were identified for each country based on the assessment framework, and the results were compared between the three relevant countries for both nuclear waste disposal and CCS. Based on the policy gaps and examples from the other countries, suggestions were made on how the four countries could improve their policies to better safeguard intergenerational justice.

4.3 Data sources and collection

The policy documents that form the foundation of the analysis were collected from the corresponding government websites. The national nuclear waste disposal policies were selected to be those that were established in fulfilment of the EU Council Directive 2011/70, and were identified through the national transposition measures for this directive (EUR-Lex, 2023).

Accordingly, the nuclear waste disposal policy documents analysed were the 2016 Dutch policy document ‘National programme for the management of radioactive waste and used nuclear fuel’ (*Het nationale programma voor het beheer van radioactief afval en verbruikte splijtstoffen,* Nederlands Ministerie van Infrastructuur en Milieu, 2016); the 2018 UK policy document ‘Implementing geological disposal – working with communities’ (UK Government Department for Business Energy & Industrial Strategy, 2018); and the 2020 Finnish policy document ‘Management of spent nuclear fuel and radioactive waste in Finland’ (Finnish Ministry of Economic Affairs and Employment, 2020).

For CCS, none of the three relevant countries have designated CCS policy documents in place, and this topic is instead integrated into their wider energy policies (see sections 3.4.3; 3.5.3; and 3.7.3). The policy documents analysed were therefore the Dutch Climate Plan 2021-2030 (*Klimaatplan 2021-2030,* Nederlands Ministerie van Economische Zaken en Klimaat, 2020), the 2017 UK Clean Growth Strategy (UK Government, 2017), and the Norwegian ‘Energi21 Strategy 2022’ (Energi21, 2022).

5. Assessment framework

The assessment framework was developed based on a systematic literature review. It takes the shape of a list of principles and corresponding criteria that should be present in a policy that properly safeguards intergenerational justice for distant future generations, similar in shape to the framework developed by Lamorgese & Geneletti (2013). It is not specified to either nuclear waste disposal or CCS but to intergenerational justice for distant future generations in general, as to allow its application to both types of policies. Six principles have been identified, which emerged naturally from the close reading and coding of the articles, and which have been broken down into a total of ten policy criteria. An overview of the principles of intergenerational justice in long-term policy, their corresponding criteria, and references can be found in Table 1. Each of the six principles are discussed separately below.

5.1 Future impacts

Six articles mentioned the inclusion of future impact and risk assessment in long-term policy. In particular, the articles advocate for the assessment of what the impacts of the project are (Chandler, 2021; Lamorgese & Geneletti, 2013; Minnerop, 2022; Petz, 2023) and of how benefits and burdens are distributed (Halsband, 2022; Jafino et al., 2021; Lamorgese & Geneletti, 2013). For this principle, three policy criteria have been identified that reflect the different aspects of future impact and risk assessment that were described in the six relevant articles: 1) Should different potential impacts and risks be considered throughout the project life span, and at which moments in time; 2) Has it been determined how and by whom these impacts will be managed; and 3) Has it been decided which risk level is considered acceptable?

5.2 Vision of future

Five articles mentioned the importance and yet complexity of making assumptions about what future generations will look like in terms of size (Okrent, 1999), economic development (Al Yaqoobi & Ausloos, 2022; Dasgupta, 2008), technological development (Al Yaqoobi & Ausloos, 2022), and preferences and values (Halsband, 2022; Jafino et al., 2021). These visions of the future can influence certain policy components, such as the choice of discount rate (Al Yaqoobi & Ausloos, 2022; Dasgupta, 2008) and perceived distribution of risks and benefits (Halsband, 2022; Okrent, 1999). Based on the aspects of this principle mentioned above, the associated criterium with this principle is defined as: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research? Here, ‘reliable research’ is understood to mean independent scientific research or research commissioned by governmental institutions.

5.3 Time scale

Two articles explicitly mentioned the need for a clear delineation of the time horizon of the policy and the planned project it applies to (Halsband, 2022; Schwarz, 2022b). Additionally, the time scale influences the projected future impacts, the vision of future, and the discount rate. To reflect this, two criteria have been formulated: 1) For how long will this policy be in place and is this policy subject to change due to new insights; and 2) How long is the envisioned lifetime of the disposal/storage site?

5.4 Freedom of choice

Nine articles mentioned policy considerations of freedom of choice for future generations. These aspects include the importance of not limiting possible ways of life for future generations by our actions (Clark, 2020; Ferretti, 2023; Minnerop, 2022), designing facilities and projects for maximum adaptability and whether to allow for the retrievability of disposed goods (Ellingwood & Lee, 2016), and protection against irreversible choices (Lamorgese & Geneletti, 2013). However, there is no consensus on whether to allow for the retrievability of disposed goods, e.g., nuclear waste, or whether to permanently enclose them (Gowda & Easterling, 2000; Kadak, 2000; Schwarz, 2022b; Taebi et al., 2012), as both have been argued to safeguard future generations’ freedom. One criterium has been determined, namely: Does the policy attempt to preserve freedom of choice and opportunity for future generations? For the case studies of nuclear waste disposal, this criterium is understood to include the choice of retrievability versus permanent closure of the facility.

5.5 Financing

Seven articles mentioned the need and opportunities for the inclusion of financing structures in long-term policies (Al Yaqoobi & Ausloos, 2022; Boston et al., 2021; Ellingwood & Lee, 2016; George et al., 2016; Halsband, 2022; Lamorgese & Geneletti, 2013; Nordlander et al., 2020). Policy aspects include what costs are expected over the lifetime of the project (Ellingwood &

Lee, 2016; George et al., 2016), who is responsible for payment (Boston et al., 2021; Halsband, 2022; Lamorgese & Geneletti, 2013), and how the financing is structured (Al Yaqoobi & Ausloos, 2022; Boston et al., 2021; George et al., 2016; Nordlander et al., 2020). Based on this, a criterium has been defined as: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the project? Here, 'a clear financing structure' includes a description of what the expected costs are, who is responsible for the payment, and through what financing structure these costs are expected to be managed.

5.6 Discounting

Eleven articles mentioned the application of a discount rate in long-term policy. In particular, the articles acknowledged the varied options for discount rate found in literature (Al Yaqoobi & Ausloos, 2022; Almansa & Martínez-Paz, 2011; Ellingwood & Lee, 2016; George et al., 2016), but expressed the need for a choice of discount rate, including the choice of a zero discount rate (Almansa & Martínez-Paz, 2011; Barrage, 2018; Davidson, 2012; Halsband, 2022; Lueddeckens et al., 2022; Petz, 2023; Polasky & Dampha, 2021). Four of the articles mention that it should be clear how the discount rate has been set and on what assumptions it is based (Dasgupta, 2008; Halsband, 2022; Lueddeckens et al., 2022; Polasky & Dampha, 2021). Two criteria have been formulated for this principle: 1) Has a decision been made on the application of a (social) discount rate to future costs and risks, and 2) What shape does the discount rate take? By 'shape', it is meant whether the discount rate is e.g., constant, linear, exponential or hyperbolic. The second criterium is only applicable in case of an affirmative answer to the first.

Table 1

Six principles of intergenerational justice in long-term policy and their corresponding criteria, along with the literature on which they are based.

Principle	**Criterium**	**References**
Future impacts	1. Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?	Chandler, 2021; Halsband, 2022; Jafino et al., 2021; Lamorgese & Geneletti, 2013; Minnerop, 2022; Petz, 2023
	2. Has it been determined how and by whom these impacts will be managed?	
	3. Has it been decided which risk level is considered acceptable?	
Vision of future	4. What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?	Al Yaqoobi & Ausloos, 2022; Dasgupta, 2008; Halsband, 2022; Jafino et al., 2021; Okrent, 1999
Time scale	5. For how long will this policy be in place and is this policy subject to change due to new insights?	Halsband, 2022; Schwarz, 2022)
	6. How long is the envisioned lifetime of the disposal/storage site?	
Freedom of choice	7. Does the policy attempt to preserve freedom of choice and opportunity for future generations?	(Clark, 2020; Ellingwood & Lee, 2016; Ferretti, 2023; Gowda & Easterling, 2000;

		Kadak, 2000; Lamorgese & Geneletti, 2013; Minnerop, 2022; Schwarz, 2022b; Taebi et al., 2012)
Financing	8. Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?	Al Yaqoobi & Ausloos, 2022; Boston et al., 2021; Ellingwood & Lee, 2016; George et al., 2016; Halsband, 2022; Lamorgese & Geneletti, 2013; Nordlander et al., 2020
Discounting	9. Has a decision been made on the application of a (social) discount rate to future costs and risks?	Al Yaqoobi & Ausloos, 2022; Almansa & Martínez-Paz, 2011; Barrage, 2018; Davidson, 2012; Ellingwood & Lee, 2016; George et al., 2016; Halsband, 2022; Lueddeckens et al., 2022; Petz, 2023; Polasky & Dampha, 2021
	10. What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?	

6. Nuclear waste disposal policy assessment

The assessment framework developed in the previous chapter is used to assess how well the nuclear waste disposal policies of the Netherlands, the UK and Finland manage to safeguard intergenerational justice. Each policy is assessed on the ten assessment criteria and it is identified whether each criterium was satisfied, partly satisfied, or not satisfied. Table 2 (chapter 7) provides an overview of the policy assessment per criterium. Page numbers given in brackets refer to the relevant policy document for each of the case studies.

6.1 Dutch nuclear waste disposal policy

The Dutch policy for nuclear waste disposal is set out in the 2016 policy document 'National programme for the management of radioactive waste and used nuclear fuel' (*Het nationale programma voor het beheer van radioactief afval en verbruikte splijtstoffen,* Ministerie van Infrastructuur en Milieu, 2016a). In short, Dutch nuclear waste will be stored aboveground for a period of at least 100 years, and deep geological disposal is envisioned from around the year 2130 onwards (p. 4). A definitive decision on the disposal solution will be taken around the year 2100 (p. 4).

6.1.1 Principle 1: Future impacts

Criterium 1: Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

The National Programme acknowledges the need for an environmental impact assessment of any final disposal facility. However, no environmental assessment has taken place yet, despite such a recommendation from the Dutch Commission for Environmental Assessment (*Commissie voor de milieueffectenrapportage*). The policy considers the concept of disposal to still be so abstract that the current plans cannot be said to determine the later decision-making, and as such not yet requiring an environmental assessment (p. 11). It does state that "naturally, the environmental effects in the process towards final disposal must be fully included in the decision-making process in due course" (trans. by author, p. 11). The criteria for starting the first environmental assessment are planned to be defined by the end of 2030 (p. 43).

For any disposal solution, it has to be shown that the current and future population is protected sufficiently against harmful radiation in all phases of the waste management, including effects on ground- and drinking water (p. 25). All Dutch nuclear facilities have an accepted security package, which adheres to the most recent international recommendations from the IAEA (p. 22). Exposure to radiation should be justified, be 'as low as reasonably achievable', and remain below established values, as part of the national policy for nuclear safety and radiation protection (p. 21). It is acknowledged that risk of radiation may not only occur due to accidents or natural phenomena, but also due to human interference; deep geological disposal is assumed to prevent this by using several barriers, both artificial and natural (p. 26, 28).

One sub-appendix is dedicated to the monitoring of disposal facilities (appendix E.1.1). During the life span of the disposal facility, monitoring provides the information needed to take decisions about the project; additionally, it is said to contribute to building trust about the disposal, for the facility user, the public and the authorities (p. 56). It is described how closure of the disposal facility may provide challenges for continued monitoring; for example, monitoring cables may compromise the impermeability of the rock and thus create risks for the perfect closure of the facility.

The potential impacts and risks of nuclear waste disposal have not yet been clearly identified, but will be identified in the future before the disposal site is built. Additionally, there is an explanation on the importance of monitoring throughout the lifespan of the facility and how it will take place. As such, criterium 1 is rated as 'satisfied'.

<u>Criterium 2:</u> Has it been determined how and by whom these impacts will be managed?

Appendix C describes the role of the national Authority for Nuclear Safety and Radiation Protection (*Autoriteit Nucleaire Veiligheid en Stralingsbescherming*, ANVS). Its responsibilities include preparing legislation and policy; granting permits and the associated assessments; and supervision and enforcement (p. 52). The implementation of the nuclear waste policy is the responsibility of the Central Organisation for Radioactive Waste (*Centrale Organisatie voor Radioactief Afval*, COVRA). This is described in its own appendix (Appendix D). COVRA is in charge of collecting, processing, storing and disposing of all Dutch radioactive waste (p. 53). All steps of radioactive waste management are thus grouped under one organization, and ANVS supervises this process (p. 53). After delivery of the waste to the disposal facility, the legal ownership and the associated (financial) responsibilities are transferred to COVRA (p. 31).

As the policy includes a clear delineation of roles and responsibilities for the final disposal management, criterium 2 is rated as ‘satisfied’.

<u>Criterium 3:</u> Has it been decided which risk level is considered acceptable?

There is no mention of any assessment of risk level or of which risk level is considered acceptable. There is merely one mention that exposure to radiation should be ‘as low as reasonably achievable’, but this is not further specified. As such, criterium 3 is rated as ‘not satisfied’.

6.1.2 Principle 2: Vision of future

<u>Criterium 4:</u> What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

The National Programme acknowledges the uncertainty about what the future may look like and what characteristics future generations may have on six of its pages. It recognizes that there is no guarantee that society will be able to safeguard the same level of active management in the future (p. 28). Additionally, it acknowledges the potential for changing social and political conditions and acceptance, as well as changes in (the interpretation of) legal guidelines and even possibly a change in basic values (p. 38).

It is assumed that drilling techniques will continue to develop in such a way that retrieving the waste even after permanent will always remain possible, which indicates a belief in the technical prowess of future generations (p. 29).

In the policy document the risk is acknowledged that the waste producers may not possess the means to maintain the disposal facility, and thus the legal ownership of the waste is transferred to COVRA after delivery to the facility (p. 31). This thus recognises the future uncertainty of the ventures producing nuclear waste today. Even for the relatively near-future generations alive in 2130, it is recognised that there may be technical or societal uncertainties that could postpone the implementation of the final waste disposal project (p. 36). The policy document recognises the difficulty in communicating knowledge about the waste and the disposal facilities with future generations, and explicitly notes the potential impermanence of digitally stored information (p. 57).

The National Programme makes very few assumptions about future generations and instead clearly sets out the uncertainty about what the future may look like. Criterium 4 is therefore rated as ‘satisfied’.

6.1.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The National Programme is updated every ten years, and may be adapted based on international, technical and societal developments (p. 8, p. 11). Every ten years there is an extensive evaluation of COVRA as well. Additionally, every five years an evaluation of all technical, organizational, procedural and administrative services is performed (p. 21). Criterium 5 is therefore rated as ‘satisfied’.

Criterium 6: How long is the envisioned lifetime of the project?

The National Programme describes how the final disposal facility should be operational around the year 2130. Before this, there will be central waste storage aboveground in order to save enough waste and money to realise the disposal facility (p. 24). There is no further description of the lifetime of the project. Criterium 6 is therefore rated as ‘not satisfied’.

6.1.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

The National Programme explicitly attempts to preserve freedom of choice for future generations; for example, it states that “future generations are enabled to choose a management method for the long term based on their insights, with as little burden as possible” (trans. by author, p. 25) and that “the possibility is kept open to deal flexibly with the choice of management option for the long term” (trans. by author, p. 28). It is mentioned on nine pages that the policy attempts to preserve freedom of choice and opportunity and/or reduce the burdens on future generations (p. 25, 26, 28, 29, 31, 36-39). Most mentions of ‘future generations’ refer to those alive until the final disposal facility is realised around the year 2130 and indicate those generations’ freedom to choose the best disposal option or change the current plans (p. 25, 28, 36, 37, 39). When generations in the far future are mentioned, it is to reflect the need for passive waste management and thus reduce the burdens on future generations (p. 26, 28, 31).

Retrievability is set as one of the requirements for a waste disposal solution and is granted its own sub-chapter (section 4.3.3). In it, the pros and cons of retrievability are set out (p. 29). Additionally, it is described how it gets progressively more difficult to retrieve waste from a retrievable disposal facility until it will eventually practically function as a non-retrievable disposal facility (p. 29). For now, the policy states waste needs to be retrievable at least from the operational phase of the facility until its closure when all waste has been placed (p. 29). The final decision on the period of retrievability is left to future generations (p. 29, 37). Due to its straightforward attempts to preserve freedom of choice and opportunity for future generations, criterium 7 is rated as ‘satisfied’.

6.1.5 Principle 5: Financing

<u>Criterium 8:</u> Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

The National Programme states that one of the key bases of the policy is that “for all costs for the management of radioactive waste the ‘polluter pays’ principle is used” (p. 31). This principle is described in detail in its own subchapter (section 4.5). The National Programme states that “different measures are in place to ensure that sufficient financial means are available for a safe management of radioactive waste,” which have been laid down in regulations based on the Dutch Nuclear Energy Act (p. 31).

Radioactive waste management organization COVRA charges producers of radioactive waste all estimated costs for processing, storage and disposal, based on contemporary insights. After the waste has been delivered, the legal ownership of the waste and its connected (financial) risks are transferred to COVRA (p. 31, 32). COVRA’s capital is invested during the period of above-surface waste storage in order to generate enough funds for preparing, constructing, operating and closing the final disposal facility (p. 32). COVRA and the growth of its capital are monitored a supervisory board, and every three years updates are reported on the amount of money available for the final disposal facility (p. 32, 45).

There is no explicit mention of potential costs that may arise after the disposal facility has been closed and there is no clear financing structure for the long-term costs of the site. As such, the policy satisfies the first part of criterium 8 by clearly describing short-term financing, but does not satisfy the second part; criterium 8 is thus rated as 'partly satisfied'.

6.1.6 Principle 6: Discounting

<u>Criterium 9:</u> Has a decision been made on the application of a (social) discount rate to future costs and risks?

In the 2016 National Programme, there is one mention of discounting, namely in describing that it is mandatory to discount the research costs for the final disposal in the COVRA tariffs (p. 31). This decision is not further explained or argued, nor is it explained why the decision for mandatory discounting has been taken for these costs, as opposed to others. Criterium 9 is therefore rated as 'not satisfied'.

<u>Criterium 10:</u> What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no description of what discount rate is chosen or what shape it takes. Criterium 10 has been rated as 'not satisfied'.

6.2 UK nuclear waste disposal policy

The 2018 policy document 'Implementing geological disposal – working with communities' sets out the UK government's policy on long-term disposal of higher activity radioactive waste (UK Government Department for Business Energy & Industrial Strategy, 2018). This government policy applies only in England. The policy focuses on involving local communities throughout the decision process on waste disposal.

6.2.1 Principle 1: Future impacts

<u>Criterium 1:</u> Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

The 'Implementing geological disposal' document mentions "radioactive discharges to air and water" (p. 21, 22, 30, 31) and "land contamination" (p. 31) as potential impacts of disposal. It dedicates chapter 4, titled 'Protecting people and the environment', to the measures taken to minimise these impacts.

Before construction starts, each facility needs to demonstrate that they meet the safety, security and environmental protection standards of the Environment Agency and Office for Nuclear Regulation (p. 27). Safety arguments need to be presented for the entire lifetime of the disposal facility, from its design to its closure (p. 29), and each disposal facility requires an 'environmental permit' and a 'nuclear site licence' (p. 27). During construction, there will be continued testing of the site to ensure the standards are met (p. 41).

Once the disposal facility is closed, "it will no longer require any human intervention (although the surrounding environment could still be monitored for as long as society wished to do so)" (p. 22). A combination of barriers in the disposal facility, including the rock formation in which the disposal facility is built, is assumed to provide long-term safety (p. 30).

As the potential impacts and when they will be assessed are described in the policy document, criterium 1 is rated as 'satisfied'.

<u>Criterium 2:</u> Has it been determined how and by whom these impacts will be managed?

A sub-chapter titled 'Roles and responsibilities' describes the relevant authorities and their responsibilities (p. 10-11). The UK Government Department for Business, Energy and Industrial Strategy is responsible for radioactive waste management policy (p. 10). The Nuclear Decommissioning Authority (NDA) is responsible for implementing governmental long-term radioactive waste management policy (p. 10-11). Radioactive Waste Management Limited (RWM), a subsidiary of the NDA, is responsible for implementing geological disposal of higher activity radioactive waste, including "safety, security and environmental protection" and compliance with regulatory requirements (p. 11). The environmental impacts of the waste are controlled throughout the lifetime of the disposal facility by RWM (p. 31). The Environment Agency implements and enforces environmental protection legislation in England. They work together with the Office for Nuclear Regulation to regulate radioactive waste disposal (p. 30). Depending on the site selection, development of a disposal facility will also involve Natural England and the Marine Management Organisation (p. 31). These regulators do not participate in siting decisions, but require a facility to meet the “requirements for protection of people and the environment” (p. 31). The joint regulation is expected to continue throughout the lifetime of the facility, until it has been determined “at an appropriate time after the facility has been closed” that no further regulation is needed (p. 32).

Due to the clear delineation of roles and responsibilities in managing nuclear waste disposal, criterium 2 is rated as ‘satisfied’.

Criterium 3: Has it been decided which risk level is considered acceptable?

There is no mention of any assessment of risk level or of which risk level is considered acceptable. As such, criterium 3 is rated as ‘not satisfied’.

6.2.2 Principle 2: Vision of future

Criterium 4: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

The only brief description of what the future might look like is found in the description of the ‘community investment funding’, as the operation of a geological disposal facility is projected to ‘provide jobs and benefits to the economy for more than 100 years’, and employ around 600 members of staff per year during the project (p. 54). However, there are no further assumptions found in the policy document about what future generations may look like, especially for the distant future. Criterium 4 is therefore rated as ‘not satisfied’.

6.2.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The ‘Implementing Geological Disposal’ document does not clearly state for how long this policy will be in place. It mentions once that appropriate solutions will continue to be reviewed, but there is no description of when potential new insights will be used to update the policy (p. 18). Criterium 5 is therefore rated as ‘not satisfied’.

Criterium 6: How long is the envisioned lifetime of the project?

The deep geological facility is said to remain functional "for a very long period" (p. 22), but no clear envisioned lifetime of the project is given. Criterium 6 is therefore rated as 'not satisfied'.

6.2.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

It is acknowledged that alternative long-term waste management options may be discovered and developed at some point in the future, and the policy therefore indicates there will be continued review of 'appropriate solutions' (p. 18). This thus provides some freedom of choice for near-future generations, before a geological disposal facility has been closed permanently.

With regards to the retrievability versus permanent closure of the disposal site, the policy document outlines the plan to keep the disposal facility open for waste acceptance and construction for 'around one hundred years', after which the operational phase comes to an end and the facility is closed permanently (p. 25-26). It is argued that "permanently closing a [geological disposal facility] at the earliest possible opportunity once operations have ceased provides for greater safety, greater security, and minimises the burden on future generations" (p. 26). Criterium 7 is therefore rated as 'satisfied'.

6.2.5 Principle 5: Financing

Criterium 8: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

The 'Implementing Geological Disposal' document dedicates four paragraphs to a description of the funding for the geological disposal facility (p. 25), and describes separately the funding available for the (potential) host communities of the facility (chapter 6).

The major principle underlying the UK financing policy is that "the costs of the development and operation of a [geological disposal facility] will be met by the waste owners" (p. 25). If the waste is publicly owned, this therefore means the UK government carries financial responsibility. Before new nuclear power stations are constructed, the operators are mandated to have an approved 'funded decommissioning programme'. Additionally, they enter into a contract with the government about on which terms the government will take responsibility of the nuclear waste, including for which price (p. 25). There is no indication of whether this financing structure also applies to long-term costs; in fact, there is no mention at all of potential long-term costs of the facility.

Chapter 6 describes in relative detail what funds are available for the siting process and for (potential) host communities. In particular, 'Community Investment Funding' of up to £2.5 million annually per community is available for the communities involved in the siting process (p. 54). These funds are not meant to finance the facility itself, but instead for investments into the local community, e.g., for community facilities or economic development opportunities (p. 55). The final chosen host community will receive additional government investment (p. 56). A property support scheme may be applied where appropriate (p. 57).

Criterium 8 is rated as 'partly satisfied' as no clear financing structure for the long-term costs is described.

6.2.6 Principle 6: Discounting

<u>Criterium 9:</u> Has a decision been made on the application of a (social) discount rate to future costs and risks?

<u>Criterium 10:</u> What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no mention of discounting in the 2018 'Implementing geological disposal' policy document; neither of the criteria under Principle 6 are met. Both criteria are therefore rated as 'not satisfied'.

6.3 Finnish nuclear waste disposal policy

The Finnish national policy for nuclear waste disposal is set out in the 2022 policy document 'Management of spent nuclear fuel and radioactive waste in Finland' (Finnish Ministry of Economic Affairs and Employment, 2020). Finland is currently in the process of developing a deep geological depository.

6.3.1 Principle 1: Future impacts

Criterium 1: Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

The Finnish policy describes how different licenses need to be obtained during the lifespan of the disposal facility, namely a construction licence, an operating license, and a decommissioning license or closure under an operating license (p. 16). The licensing procedures take place through an "evidence-based and documented decision-making process" (p. 16). All three include safety assessments, including long-term safety after the closure of the disposal facility, are based on computational analyses and additional reviews. The safety measures against radiation exposure are set out in detail in chapter 3, titled 'Ensuring the safety of the general public, the environment and workers against the dangers arising from ionising radiation.' A radiation exposure assessment must take place before waste disposal commences (p. 22). Additionally, continuous safety monitoring takes place (p. 18), and every fifteen years, a safety review of the facilities must be submitted to the Radiation and Nuclear Safety Authority (STUK) for approval (p. 24).

The safety of the disposal facility is passively guaranteed by multiple barriers, both artificial and natural, and the safety of the facility should be compromised by the failure of one of the barriers (p. 25). Security arrangements have to be in place to protect the facilities against threats of intentional harm (p. 25). In managing the nuclear waste, (inter)national obligations on non-proliferation are also taken into account (p. 29).

The safety case presents the post-closure safety assessment, for a period of approximately one million years for high-level waste (p. 24). The operator needs to define the necessary post-closure monitoring measures, as well as potential restrictions on the use of the site (p. 67).

Finally, an environmental impact assessment of the national programme has already been carried out, and the results are reported on in a designated chapter of the policy document (chapter 13).

The Finnish national programme provides an extensive overview of when impacts and risks need to be considered throughout the entire lifetime of the disposal facility, including post-closure, and criterium 1 is therefore rated as 'satisfied'.

Criterium 2: Has it been determined how and by whom these impacts will be managed?

Chapter 4 sets out the responsibilities of different relevant authorities, namely the Ministry of Economic Affairs and Employment, the Ministry of Social Affairs and Health, and STUK. The Ministry of Economic Affairs and Employment creates the legislative and administrative framework for Finnish nuclear energy activities, and oversees the waste management measures (p. 30). The Ministry of Social Affairs and Health is responsible for overseeing compliance with the Radiation Act. STUK is an independent expert and regulatory organisation (p. 32). Their responsibilities include monitoring radioactivity near nuclear facilities, overseeing the implementation of security and emergency measures, and the transport of nuclear materials and waste (p. 31). A "responsible manager" for the disposal facility must be approved by STUK, and has to ensure compliance with STUK's regulations (p. 25). The policy provides a visual overview that delineates the responsibilities of the different ministries and STUK (p. 32).

The Finnish State carries the ultimate responsibility for Finnish nuclear waste management; however, it does not have a waste management organisation themselves. Instead, the operators who have generated the waste have this primary responsibility and as such, the disposal is carried out by the operators. Once the disposal facility has been permanently closed, responsibility for the nuclear waste is transferred to the State (p. 16).

As the policy includes a clear delineation of roles and responsibilities for the final disposal management, criterium 2 is rated as 'satisfied'.

<u>Criterium 3:</u> Has it been decided which risk level is considered acceptable?

In the first several thousand years after closure of the disposal facility, the radioactive dose to the "most exposed people" cannot exceed 0.1 mSv annually, and for other people the average annual dose must be negligible (p. 24). After this period of time, the amount of released radioactive material into the environment must be lower than radionuclide-specific constraints set by STUK, which correspond to the radiation occurring "from the presence of natural radioactive substances in the ground" (p. 24).

As for risk assessment, the policy states that "nuclear and radiation safety requirements and measures are dimensioned and allocated to the risks of the use of nuclear energy and use of radiation in accordance with the graded approach, taking into account normal operation and possible occurrences and accidents" (p. 29). These requirements are based on international recommendations from the IAEA and the Western European Nuclear Regulators' Association (p. 29).

As the level of risk to the population that is acceptable is clearly stated and argued, here represented by the maximum dose of radiation received, criterium 3 is rated as 'satisfied'.

6.3.2 Principle 2: Vision of future

Criterium 4: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

No explicit assumptions can be found in the 2022 policy document about what future generations may look like. Criterium 4 is therefore rated as 'not satisfied'.

6.3.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The Finnish national programme clearly describes how the policy will be checked and updated regularly. In particular, "a national self-assessment must be carried out and an international peer review must be requested every ten years (…) [and] the national programme must be updated based on the results of the self-assessments and peer reviews" (p. 95). If no immediate updates arise from the peer review or if there are significant changes in the policy context, the programme will be updated before the next peer review (p. 96). Additionally, it is indicated what further research will be included in future iterations of the policy, such as a decision on the need for monitoring after closure (p. 68). The policy gives a clear description of how it will be monitored and updated, and as such criterium 5 is rated as 'satisfied'.

Criterium 6: How long is the envisioned lifetime of the project?

The Finnish national programme includes a visual overview of the timeframe for the disposal facilities, including operation and closure (p. 75), as well as a textual description of the process until closure of the disposal facility per disposal site in a dedicated chapter (chapter 9, p. 70-75). The lifetime of a spent fuel disposal facility is set at "approximately one million years" (p. 24). Criterium 6 is therefore rated as 'satisfied'.

6.3.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

Finnish policy with regards to the question of retrievability versus permanent closure is to close the disposal facilities as soon as possible after all nuclear power plant sites have been decommissioned and all waste has been disposed of (p. 37, p. 52, p. 58). After closure, the site should not require further monitoring or control. This stage is not expected be reached before the 22nd century (p. 67). Despite the focus on the full closure of the depositories, the policy mentions in one paragraph that it does “require the ability to retrieve the fuel after the closure of the disposal facility (…) if required for safety reasons” (p. 62), but it does not elaborate on this. There is no further mention of freedom of choice or opportunity in other aspects. Criterium 7 is therefore rated as ‘partly satisfied’.

6.3.5 Principle 5: Financing

Criterium 8: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

A separate chapter titled ‘Assessment of the costs of the national programme and the financing scheme in force’ sets out the Finnish financing policy (chapter 11). This chapter also includes current estimates of what the decommissioning and disposal costs would be per nuclear facility in the country, where possible (p. 81-82). The overall policy is twofold: the one generating the nuclear waste is “fully responsible for the costs of waste management measures”, but simultaneously, the Finnish State ensures that “adequate funding is available for the management of spent fuel and radioactive waste” in case the operator is not able to fulfil its financial responsibilities (p. 82-83).

These state funds are collected, stored and invested through the National Nuclear Waste Management Fund, which is available for all waste generated from the use of nuclear energy (p. 30). It consists of three assets: the ‘financial provision fund’, the ‘nuclear safety research fund’ and the ‘nuclear waste research fund’. The first is most important for nuclear waste management, and funds for it are collected from nuclear energy operators (p. 84). After the operators have successfully carried out their waste management, the funds are returned to them

(p. 85). Every three years an independent evaluation takes place of the estimated costs for nuclear waste management, on the basis of which the adequacy of the cost estimates and funds is assessed (p. 99).

The Finnish policy acknowledges the continued need for post-closure financing and describes how after the decommissioning of the disposal facility and the operator's waste management obligation has expired, there is a continued obligation for operators to pay a fee for post-closure monitoring and control of the disposal facilities (p. 85). Once the disposal facility has been closed and the operator of the nuclear facility has paid the State "for the future monitoring and control of the spent fuel and radioactive waste", the State obtains the ownership of and responsibility for the nuclear waste (p. 37).

As the policy provides a clear financing structure for both the short- and long-term disposal costs, criterium 8 is rated as 'satisfied'.

6.3.6 Principle 6: Discounting

<u>Criterium 9:</u> Has a decision been made on the application of a (social) discount rate to future costs and risks?

<u>Criterium 10:</u> What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no mention of discounting in the 2022 policy document; neither of the criteria under Principle 6 are met. Both criteria are therefore rated as 'not satisfied'.

7. CCS policy assessment

The assessment framework developed in chapter 5 is used to assess how well the CCS policies of the Netherlands, the UK and Norway manage to safeguard intergenerational justice, in a similar approach to chapter 6. Each policy is assessed on the ten assessment criteria and it is identified whether each criterium was satisfied, partly satisfied, or not satisfied. Table 2 at the end of this chapter provides an overview of policy assessment per criterium.

7.1 Dutch CCS policy

The Netherlands does not have a separate CCS policy document in place. Instead, it is integrated into the wider 'Climate Plan 2021-2030' (*Klimaatplan 2021-2030*), in which the term 'CCS' was mentioned ten times (Nederlands Ministerie van Economische Zaken en Klimaat, 2020). In particular, it is discussed among the 'industry' section of the climate policy; is not granted its own (sub)chapter in the policy document.

7.1.1 Principle 1: Future impacts

Criterium 1: Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

Criterium 2: Has it been determined how and by whom these impacts will be managed?

Criterium 3: Has it been decided which risk level is considered acceptable?

There is no mention of any future impacts or risks of CCS in the Climate Plan; none of the three criteria under Principle 1 are met and are thus all rated as 'not satisfied'.

7.1.2 Principle 2: Vision of future

Criterium 4: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

The Climate Plan describes in relative detail the uncertainty about what the future will look like up until 2050, with respect to technological, economic, and political developments (p. 24). It is acknowledged that changes in these factors may support a more rapid energy transition, but could also hinder it. However, these uncertainties are only described until 2050; at that point in time, the Netherlands is assumed to have "a flourishing, circular and globally leading industry, with virtually zero greenhouse gas emissions" (p. 30). The policy lacks any description of what the future and its future generations may look like after that point. Criterium 4 is therefore rated as 'partly satisfied'.

7.1.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The 'Climate Plan 2021-2030' policy document describes the Dutch policy up until 2030, and works towards the Dutch climate targets set for 2050 (p. 24). It is detailed how the policy will be amended and updated to different extents every one, two and five years (p. 59). This is not specified further for CCS. Criterium 5 is therefore rated as 'satisfied'.

Criterium 6: How long is the envisioned lifetime of the project?

There is no mention of the envisioned lifetime of a CCS project in the 'Climate Plan 2021-2030'. Criterium 6 is therefore rated as 'not satisfied'.

7.1.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

On page 24 of the 'Climate Plan 2021-2030', it is described how the government aims to keep all technological pathways for the energy transition open. Such a 'technology neutral' approach to the market is assumed to lead to the lowest possible transition costs. As such, the government attempts to preserve the freedom of choice of future generations, albeit based on financial arguments as opposed to a potential moral duty to future generations. There is no indication, however, that such freedom of choice is applied into the more distant future after the climate targets for this century have been reached, and thus does not extend throughout the lifetime of a CCS facility. Criterium 7 is therefore rated as 'partly satisfied'.

7.1.5 Principle 5: Financing

Criterium 8: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

The financing of CCS is described in one paragraph of the policy document. There are subsidies in place for CCS projects through the national SDE++ subsidy scheme for applications which lack a cost-effective transition alternative, and the subsidies are capped for industrial CCS at 7.2 Mton CO_2 (p. 31). This subsidy scheme is available until 2035 for CCS, except for projects with negative emissions. Apart from these subsidies, the financial responsibilities for CCS appear to be borne by the project developers. There is no mention of the long-term costs of the CCS facilities and no description of who bears responsibility for these costs. Criterium 8 is therefore rated as 'partly satisfied'.

7.1.6 Principle 6: Discounting

Criterium 9: Has a decision been made on the application of a (social) discount rate to future costs and risks?

Criterium 10: What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no mention of discounting within the 'Climate Plan 2021-2030'; neither of the criteria under Principle 6 are met. They are therefore both rated as 'not satisfied'.

7.2 UK CCS policy

The UK has not set out a separate CCS policy. Instead, it is integrated into the wider 2017 'Clean Growth Strategy' (UK Government, 2017). This strategy applies for the entire UK, although the devolved governments may additionally have their own separate policies and plans. The UK specifically aims for carbon capture, usage, and storage (CCUS) instead of carbon capture and storage (CCS). The term CCUS appears a total of 63 times in the policy document. Three pages are dedicated to the CCUS policies, as part of the 'industry' section of the document (p. 69-71).

7.2.1 Principle 1: Future impacts

Criterium 1: Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

Criterium 2: Has it been determined how and by whom these impacts will be managed?

Criterium 3: Has it been decided which risk level is considered acceptable?

There is no mention of any future impacts or risks of CC(U)S in the 'Clean Growth Strategy; none of the three criteria under Principle 1 are met. They are therefore all three rated 'not satisfied'.

7.2.2 Principle 2: Vision of future

Criterium 4: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

The 'Clean Growth Strategy' mentions uncertainty about what the near future may look like, namely about what emission reduction technologies will be in place by 2050 and what the economy will look like then (p. 55). However, there is no discussion about what the more distant future after 2050 may look like. Criterium 4 is therefore rated as 'partly satisfied'.

7.2.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The 'Clean Growth Strategy' and the progress towards its targets will be monitored annually (p. 121). However, there is no clear delineation for how long this strategy will be in place or how it will be updated. Criterium 5 is therefore rated as 'not satisfied'.

Criterium 6: How long is the envisioned lifetime of the project?

The policy includes the aim to deploy CCUS at scale during the 2030s (p. 126). There is no mention of the envisioned lifetime of a CC(U)S project in the 'Clean Growth Strategy'. Criterium 6 is therefore rated as 'not satisfied'.

7.2.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

There is no mention of preservation of choice or opportunity for future generations in the ‘Clean Growth Strategy’. Criterium 7 is therefore rated as ‘not satisfied’.

7.2.5 Principle 5: Financing

Criterium 8: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

The UK government has invested more than £130 million in research and development (R&D) and innovation support for CCUS (p. 69) and its BEIS Energy Innovation Programme will grant up to £20 million for a CCUS demonstration programme (p. 50, p. 71). This financial support is aimed at reducing the costs of CCUS deployment. The ‘Clean Growth Strategy’ does not include any description of long-term financing for a CC(U)S project. Criterium 8 is therefore rated as ‘partly satisfied’.

7.2.6 Principle 6: Discounting

Criterium 9: Has a decision been made on the application of a (social) discount rate to future costs and risks?

Criterium 10: What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no mention of discounting within the ‘Clean Growth Strategy’; neither of the criteria under Principle 6 are met. Both are therefore rated as ‘not satisfied’.

7.3 Norwegian CCS policy

Norway has not set out a separate CCS policy document. Instead, it is included in the ‘Energi21 Strategy 2022’, which describes the ‘national strategy for research, development and commercialisation of new climate-friendly energy technology’ (Energi21, 2022,p. 1). CCS is described in its own subchapter (section 3.8) and in total the term ‘CCS’ appears 113 times in the document.

7.3.1 Principle 1: Future impacts

Criterium 1: Should different potential impacts and risks be considered throughout the project life span, and at which moments in time?

The Energi21 Strategy acknowledges that “CCS will require land, have an impact on the local environment and may in some cases lead to new types of emissions that need to be monitored and reported” (p. 89). Additionally, it is described how CCS will lead to increased energy consumption, and may therefore indirectly lead to even larger land requirements, as well as water consumption. Before the establishment of any CCS facility, therefore, these impacts need to be assessed and monitored (p. 89). There is no description of whether monitoring will take place while the facility is operational, nor of any potential risks that may occur during the operational phase. Criterium 1 is therefore rated as ‘partly satisfied’.

Criterium 2: Has it been determined how and by whom these impacts will be managed?

It has not been made explicit how the impact assessment and monitoring will be performed, or by whom. Criterium 2 is therefore rated as ‘not satisfied’.

Criterium 3: Has it been decided which risk level is considered acceptable?

There is no mention of what risk level is considered acceptable when assessing and monitoring the impacts of the CCS facility. Criterium 3 is therefore rated as ‘not satisfied’.

7.3.2 Principle 2: Vision of future

Criterium 4: What assumptions are made about future generations (size of population, scientific development, economic development, behaviour and preferences) and are these assumptions based on reliable research?

The Energi21 Strategy document mentions uncertainty about what the future energy system will look like (p. 26). However, there is no further discussion of what the future and its future generations may look like. Criterium 4 is therefore rated as ‘not satisfied’.

7.3.3 Principle 3: Time scale

Criterium 5: For how long will this policy be in place and is this policy subject to change due to new insights?

The 2022 Energi21 Strategy is the fifth iteration, after the first was published in 2008. It is “revised regularly” (p. 18), but it is not indicated for exactly how long this strategy will be in place and what would spark its update. Criterium 5 is therefore rated as ‘not satisfied’.

Criterium 6: How long is the envisioned lifetime of the project?

CCS is mentioned to entail the ‘permanent storage of carbon’ (p. 8, p. 89), which gives some indication as to the envisioned lifetime of the project. However, there is no further delineation of the lifetime of the project. Criterium 6 is therefore rated as ‘partly satisfied’.

7.3.4 Principle 4: Freedom of choice

Criterium 7: Does the policy attempt to preserve freedom of choice and opportunity for future generations?

There is no mention of preservation of choice or opportunity for future generations in the Energi21 Strategy. Criterium 7 is therefore rated as ‘not satisfied.

7.3.5 Principle 5: Financing

Criterium 8: Has a clear financing structure been decided on for both the short-term (<500 years) and long-term construction and maintenance costs of the site?

The Energi21 Strategy describes the funding in place for CCS research through the CLIMIT programme, which is a collaboration between the Research Council of Norway and Gassnova (p. 91). Additionally, Norwegian CCS projects have received funding though the Horizon Europe research programme (p. 91). Still, the document lacks a clear description of a financing structure for both the short-term and long-term costs of a CCS facility. Criterium 8 is therefore rated as ‘partly satisfied’.

7.3.6 Principle 6: Discounting

Criterium 9: Has a decision been made on the application of a (social) discount rate to future costs and risks?

Criterium 10: What shape does the discount rate take (e.g., is it linear, exponential, hyperbolic)?

There is no mention of discounting within the Energi21 Strategy; neither of the criteria under Principle 6 are met. Both are therefore rated as ‘not satisfied’.

Table 2

Table overview of the policy assessment per criterium

Principle	Criterium	Nuclear waste disposal			CCS		
		Netherlands	UK	Finland	Netherlands	UK	Norway
Future impacts	1	+	+	+	-	-	+/-
	2	+	+	+	-	-	-
	3	-	-	+	-	-	-
View of future	4	+	-	-	+/-	+/-	-
Time scale	5	+	-	+	+	-	-
	6	-	-	+	-	-	+/-
Freedom of choice	7	+	+	+/-	+/-	-	-
Financing	8	+/-	+/-	+	+/-	+/-	+/-
Discounting	9	-	-	-	-	-	-
	10	-	-	-	-	-	-

+ = satisfied: the criterium is mentioned in policy and receives full explanation or argumentation.

+/- = partly satisfied: the criterium is mentioned in policy but with limited explanation or argumentation; alternatively, one part of the criterium is satisfied but the other is not.

- = not satisfied: the criterium is not mentioned in policy; alternatively, the criterium is mentioned but receives zero explanation or argumentation.

8. Discussion

In this chapter, the results from chapters 5, 6 and 7 are integrated and discussed. First, it is described how intergenerational justice should be operationalised; then, the policy assessment results are discussed, both among and between nuclear waste disposal and CCS policies. Finally, the limitations of the study are described and suggestions for future research are given.

8.1 How should intergenerational justice be operationalised?

Based on the criteria defined in the assessment framework and using examples from the policy analysis, it is possible to determine how the principle of intergenerational justice should be operationalised in policy.

First, the policy should include a clear overview of what potential impacts and risks should be considered throughout the project life span, and at which moments in time. This can take the shape of an (environmental) impact assessment, such as the one already performed for the Finnish nuclear waste disposal policy and the one planned in the Dutch nuclear waste disposal policy, in addition to the description of potential impacts and risks that can already be identified at this moment in time. All three nuclear disposal policies describe potential harms of radiation exposure on the environment and the human population, including the risk of contamination of ground- and drinking water, and acknowledge the need for further impact assessments. None of the CCS policies analysed acknowledge any potential impacts or risks of implementing a CCS facility. The Council Directive 2009/31 requires any potential CCS facility to be subjected to an environmental impact assessment, but does not require the national policies to include such an assessment.

For each of these potential impacts and risks, it should be determined how and by whom these will be managed. This is well described in the three nuclear waste disposal policies analysed, as they clearly set out the relevant ministries and organisations responsible for different aspects during the life cycle of a disposal facility. A similar designation of roles is found lacking completely in the three CCS policies.

Additionally, the policy should include a decision on what risk level is considered acceptable. This can, for example, be measured in terms of acceptable radiation exposure in the case of nuclear waste disposal, such as in the Finnish national policy. Conversely, for CCS this could be measured in the fraction of stored CO_2 that is allowed to leak in a set period of years.

The policy should be transparent about what assumptions about future generations underly the projected long-term effects of the policy. These assumptions can pertain to the size of population, scientific development, economic development, behaviour and preferences. For example, if the facility requires future maintenance or monitoring, there is an implicit assumption that the future generations in charge of this will have the capacity to perform these tasks. The Dutch nuclear waste disposal policy is alone in having fully acknowledged the difficulty of knowing what far-future generations may look like and that these may not be capable of maintaining a disposal facility to the level that current generations would be.

It should be clear for how long the policy will be in place and whether it is subject to change due to new insights. Revisions to the policy can be scheduled for every couple of years, and the continued accuracy and relevance of the policy can be evaluated regular updates to parliament about the progress on the policy and through independent reviews, as described in the Dutch and Finnish nuclear waste disposal policies.

Moreover, the policy needs to make clear how long the envisioned lifetime of the disposal or storage site is. It is important to know the lifespan for which the facility should at minimum remain functional, even if this is in the order of a million years and thereby in our human perception nearly permanent. The Finnish nuclear disposal policy does this by setting out a clear timeline of the disposal facilities, which includes a demarcation of the total lifetime as approximately one million years.

The policy needs to attempt to preserve freedom of choice and opportunity for future generations. It can be stated explicitly in the policy, as done in the Dutch nuclear waste disposal policy, that future generations are enabled to choose freely for their preferred method of waste management; alternatively, it can be implied by acknowledging the need for continued reviewing of solution options into the future or a focus on a ‘technology neutral’ approach, as in the UK nuclear waste disposal policy and the Dutch CCS policy, respectively. For nuclear waste disposal policies, this includes a choice on whether to allow retrievability of the waste, and for how long. Both the UK and Finnish policies aim to close the disposal facility as soon as possible after all the waste has been disposed of. The Netherlands leaves the choice for permanent enclosure or continued retrievability after all the waste has been placed up to future generations.

A clear financing structure needs to be decided on for both the short term (<500 years) and the long-term construction and maintenance costs of the site. This needs to include a description of expected costs, allocation of responsibility for the payment, and how the financing is structured. These financing structures can rely mostly on state funding, and/or involve a transfer of financial responsibility to the government at a certain point in the lifespan of the facility, as described for the three nuclear waste disposal policies. Alternatively, projects can be market funded, and may receive additional support in the form of subsidies and grants by the government, as set out in the three CCS policies. This criterium is the only one that is satisfied or partly satisfied in all policy documents. This is the policy area that may be most easily applied in practice and is fundamental for the development of both technologies. Still, the Finnish nuclear waste disposal policy is the only one that fully satisfies this criterium by also including a clear long-term financing plan that ensures sufficient funds after closure of the storage site.

Finally, the policy needs to include a decision on the application of a (social) discount rate to future costs and risks, and if applicable, describe what shape this discount rate takes. Despite the large focus on discounting in the literature on intergenerational justice, this is not reflected in the policies analysed; none of the policies managed to (partly) satisfy the associated criteria. There was only one mention of discounting found, in the Dutch nuclear waste disposal policy, despite all countries using discounting in short-term cost-benefit analyses (Norwegian Ministry of Finance, 2012; Romijn & Renes, 2013; Smith, 2021; Williams et al., 2023). Although the difficulties in applying a discount rate on the very long-term into the future are acknowledged in the literature, the choice for any or no discount rate does need to be made and substantiated (Almansa & Martínez-Paz, 2011; Barrage, 2018).

8.2 Discussion of results

Across the board, the nuclear waste disposal policies perform equal to or better than the CCS policies on the assessment criteria for intergenerational justice. This reflects the fact that all of the countries have a dedicated nuclear waste disposal policy document, which extensively covers this topic on its own, while CCS policy is only described amongst the countries' wider climate policies. In general, nuclear waste disposal policy appears to be better developed than CCS policy. In part, this is likely due to the stricter legal requirements the EU has placed for nuclear waste disposal policy compared to CCS policy. In meeting the EU requirements, all countries will have to describe, at least to some extent, an allocation of responsibilities and safety arrangements, as well as their financing scheme, thereby working towards criteria 2 and 8, respectively. In contrast, there is no requirement for countries to have any extensive CCS policies in place and it is therefore left to the countries' own initiative to work towards intergenerational justice in their CCS policy.

The potential dangers of nuclear energy have achieved prominence in the public awareness as a result of accidents such as those in Chernobyl or Fukushima, which is reflected in the more extensive risk description and assessment of nuclear waste and its disposal that is found in all three nuclear waste disposal policies assessed in this study. All three policies describe potential harms of radiation exposure on the environment and the human population, including the risk of contamination of ground- and drinking water, and acknowledge the need for further impact assessments. CCS, however, enjoys much lower public awareness on the technology in general and especially its associated risks (Leiss & Krewski, 2019). Due to it being a relatively new development, there is more focus on it as an emerging innovation that requires more research and development, as opposed to a technology that may have consequences for thousands of years into the future. This is illustrated by the type of funds that are available for CCS, which are mostly research and development grants, and the descriptions of planned CCS projects as "demonstration projects" (Norwegian Ministry of Petroleum and Energy, 2019).

There is one further difference between nuclear waste disposal and CCS that is important to mention. The need for nuclear waste disposal is inevitable and imminent due to the existing waste that has already been generated over the past decades, including non-nuclear power waste, irrespective of whether a future role is envisioned for nuclear power. In contrast, an active choice needs to be made for implementation of CCS, although it seems likely that it will be needed in some amount in order to meet the global climate targets. This may further explain the difference in quality and extent of the policies in these two fields.

For the Netherlands and the UK, both their nuclear waste disposal and CCS policies have been analysed, and thus a comparison can be made within the policies for each country. Dutch nuclear waste disposal policy performs as good as or better than the Dutch CCS policy on all criteria of the policy assessment, as can be seen in Table 2. In particular, the Dutch nuclear waste disposal policy satisfies criteria 1 and 2, which are not satisfied in their CCS policy, and also satisfies criteria 4 and 7, which are only partly satisfied in the CCS policy. The starkest difference is found in the way potential future impacts of nuclear waste disposal are discussed compared to those of CCS. Where the Dutch nuclear waste disposal policy clearly sets out potential impacts and the way these should be managed in several sub-chapters, there is no mention at all of any future impacts or risks of CCS in the Dutch Climate Plan. Similar to the Dutch policy, the UK nuclear waste disposal policy performs as good as or better than the UK CCS policy on nine out of ten criteria of the policy assessment. Only criterium 4 (vision of future) is not satisfied in the nuclear waste disposal policy, while it is partly satisfied in the CCS policy. Nuclear waste disposal policy satisfies criteria 1, 2 and 7, while the CCS policy does not satisfy any of these criteria.

Of the three national nuclear waste disposal policies assessed, Finland performs best on the assessment criteria used in this study by satisfying six out of ten criteria and partly satisfying one. This reflects the position they have as a frontrunner in nuclear waste disposal; a Finnish final disposal facility is currently already under construction, whereas the Netherlands and the UK have not yet finalised any decisions on their disposal. What sets the Finnish policy apart from the other two, in particular, is the discussion of which risk level is considered acceptable (criterium 3), and a clear timeline of the entire lifetime of the disposal facility, including an assessment of how long the facility is expected to remain in use (criterium 6). The Netherlands and the UK both completely lack these aspects. Additionally, Finland has the most extensive description of their financing scheme, which is alone in also including the long-term costs. The Dutch nuclear waste disposal policy satisfies five criteria and partly satisfies one. It is the only policy analysed that clearly acknowledges the uncertainty about what the future may look like, along with the recognition that future generations may not be capable of maintaining a long-term storage facility. The UK only satisfies three criteria and partly satisfies one. The current UK policy in place still complies with the EU Council Directive 2011/70/Euratom as it was published in 2018, before the Brexit process was finalised. In the future, however, there is no legal need for the UK to continue complying with this regulation and as such, future iterations of the policy may look different. In particular, the parts of the policy meeting criteria 2 and 8 may regress, as these are now still partly ensured by the EU Directive.

Of the three CCS policies assessed, the Netherlands performs best, yet they still only satisfy one of the criteria and partly satisfy three more. Although a frontrunner in CCS applications, Norway only partly satisfies three criteria. The UK partly satisfies two. In fact, the UK policies perform worst for both case studies. The only criterium all three countries partly satisfy is criterium 8, financing. Despite the experience with or well-developed plans for CCS projects that all three of these countries have, there appears to not be much concern for intergenerational justice considerations in their policies.

There is a clear need for improvements in CCS policy in order to safeguard intergenerational justice. None of the three country policies analysed can act as a sufficiently good example, as none satisfy a majority of the criteria. Instead, nuclear waste disposal policies can act as examples for certain aspects of intergenerational justice, such as descriptions of potential future impacts and safeguarding freedom of choice. Still, these policies themselves are also found lacking in other areas, such as in delineating an acceptable risk level (criterium 3), clarity on the view of the future underlying the policy (criterium 4), clarity on the envisioned lifetime of the relevant projects (criterium 6), and especially in setting out a well-argued decision on a discount rate (criteria 9 and 10). In nuclear waste disposal, Finland confirms its position as a frontrunner by not only having the most practical experience in constructing a disposal facility, but also by having a policy in place that best safeguards intergenerational justice from the ones analysed in this research. All countries would do well to include more insights from the intergenerational justice literature in their policies, as this provides much-needed insights into e.g., what the future may look like, how freedom of choice can be safeguarded, and on the importance of making clear decisions on discounting.

8.3 Limitations of the study and suggestions for future research

For each country, only one policy document was analysed in order to provide the most equal ground for comparison. However, this means that other relevant policy documents may have been left out of the analysis. This may be especially relevant for CCS, as this does not have a dedicated policy document in any of the three countries analysed. The language barrier, however, made it difficult to find any additional potentially relevant policy documents for Norway, and as such the analysis was limited to the main energy policy documents for the three countries. Future research could thus expand on the research scope by also including additional (policy) documents. Alternatively, a similar assessment could be performed on a country's legislation instead of policy, and evaluate any potential differences between the two scopes.

Although the principles and corresponding criteria for intergenerational justice in policy were distilled with care through an extensive literature review, the use of other criteria would yield different results and may assess the policies differently with respect to how well they safeguard intergenerational justice. The assessment framework developed in this research has been applied to nuclear waste disposal policy and CCS policy, but can also be applied to other long-term policy fields as a way to assess how well the policies safeguard intergenerational justice. Future research could thus apply this framework in different contexts and evaluate its use in these new applications. Due to its more general applicability, however, the framework is not able to capture intergenerational justice considerations that are unique to any technology, such as the choice for open or closed nuclear fuel cycles.

Synthesising the policy assessment into one table (Table 2) provides a clear overview of the results and enables direct comparison between the countries and cases. However, this therefore reduces the level of detail in showing the differences between the policies. Two policies can both be rated 'sufficient' on a certain criterium, but there can still be a difference in how extensively the criterium is covered in each policy.

9. Conclusion

The aim of this research was to develop an assessment framework for how intergenerational justice is operationalised in policy and to apply this framework to different national nuclear waste disposal and CCS policies in order to determine how intergenerational justice should be operationalised in policy so as to best safeguard the rights of future generations.

To this aim, first an assessment framework for intergenerational justice in long-term policy was developed based on a systematic literature review. This framework consists of ten criteria, based on six principles: future impacts, vision of future, time scale, freedom of choice, financing, and discounting. This framework can be applied to any long-term policy in order to assess how well it safeguards intergenerational justice. This answers the first sub question, namely "How can the operationalisation of intergenerational justice be assessed in long-term national policies?".

In answer to the second sub question, "How have the Netherlands, the UK and Finland operationalised the principle of intergenerational justice in relation to geological nuclear waste disposal?", the assessment framework was used to assess the major nuclear waste disposal policy document from each country. In nuclear waste disposal, Finland confirms its position as a frontrunner by not only having the most practical experience in constructing a disposal facility, but also by having a policy in place that best safeguards intergenerational justice from the ones analysed in this research. The Netherlands manages to satisfy half of the criteria of intergenerational justice. The UK only satisfies three criteria, and lacks in their view of the future and clear description of time scale especially. None of them describe their discounting approach.

Similarly, the assessment framework was applied to answer the third research question, "How have the Netherlands, the UK and Norway operationalised the principle of intergenerational justice in relation to geological CO_2 storage?". For each country, the relevant parts of the countries' national energy and climate policies for CCS were assessed. Despite the planned and/or operational CCS projects in each of the three countries, the policies are found severely lacking in how they operationalise intergenerational justice and the vast majority of criteria are not satisfied in all three countries. The Netherlands performs best among the three, but still only satisfies one criterium.

By comparing and discussing the policy assessments for both cases, it was possible to answer the fourth sub question, “How can the Netherlands, the UK, Finland and Norway improve their nuclear waste disposal and/or CO_2 storage policies to better safeguard intergenerational justice?”. Not one of the countries whose policies were analysed managed to satisfy all assessment criteria, meaning there is clear room for improvement for all. In particular, there is a great need for improvements in CCS policy in order to safeguard intergenerational justice, as the vast majority of criteria are not satisfied by any of the countries. Despite the global frontrunner position the Netherlands, the UK, and especially Norway take in the execution of CCS projects, none of them can act as a satisfactory example for how to safeguard intergenerational justice through policy. Instead, examples can be found in nuclear waste disposal policies for certain aspects of intergenerational justice, such as descriptions of potential future impacts and safeguarding freedom of choice. Still, these policies themselves are also found lacking in other areas, such as in delineating an acceptable risk level, clarity on the view of the future underlying the policy, clarity on the envisioned lifetime of the relevant projects, and especially in setting out a well-argued decision on a discount rate. All countries would do well to include more insights from the intergenerational justice literature in their policies, as this provides much-needed insights into e.g., what the future may look like, how freedom of choice can be safeguarded, and on the importance of making clear decisions on discounting.

Ultimately, the answer to the main research question, “How should the principle of intergenerational justice in relation to geological nuclear waste disposal and CO_2 storage be operationalised?” can thus be found in the ten criteria a policy should satisfy, focusing on future impacts, vision of future, time scale, freedom of choice, financing, and discounting. For most of these criteria, examples of proper application can be found in (one of) the nuclear waste disposal policies of the Netherlands, the UK and Finland. Currently, no policy is able to adequately operationalise intergenerational justice such as to safeguard this principle.

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