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A Legal Perspective on Nuclear Back-End Management in the Circular Economy

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A Legal Perspective on Nuclear Back-End Management in the Circular Economy

To what extent can circular economy principles enhance the sustainability of nuclear energy? To what extent does the Dutch regulatory framework for nuclear back-end management allow for the transition to a circular economy?

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1. Introduction

Reducing resource depletion, combatting climate change, the sustainability of nuclear energy, and protecting future generations from adverse impacts of the current generations' decisions, are global topics of discussion.[1] When examining these through the circular economy lens, their interconnection becomes apparent.

Raw materials, including metal ore and minerals, are extracted faster than the planet is able to replenish.[2] This results in resource depletion, which can have negative consequences on the economy, growth and well-being of future generations.[3] In response, the European Commission ('EC') established the European Union ('EU') Circular Economy Action Plan ('CEAP') in 2015, subsequently renewed in 2020.[4] It imposes obligations upon member states to enhance the sustainability of the EU economy and transition from the existing linear economy to a circular economy ('the circular economy transition').[5] In a circular economy raw material extraction is reduced by reusing and recycling waste and injecting it back into the economy as 'secondary raw materials', instead of disposing it.[6] Eliminating waste and pollution, extending the

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[1] 'Global Issues' (*United Nations)* <https://www.un.org/en/global-issues/> accessed 16 August 2022; and Liam Geraghty, 'UN set to take 'future generations' movement global' (*BigIssue*, 10 November 2021) <https://www.bigissue.com/news/un-takes-future-generations-movement-global/> accessed 16 August 2022.

[2] Simon Jowitt and others, 'Future availability of non-renewable metal resources and the influence of environmental, social, and governance conflicts on metal production' (2020) Communications Earth & Environment 1; and EEA, *Well-being and the environment: Building a resource-efficient and circular economy in Europe* (Signals 2014, 2014) 9.

[3] Jowitt (n 2); and IenW, *National Agreement on the Circular Economy* (Letter of Intent, 2017) 2.

[4] Commission, 'Circular Economy Action Plan: For a cleaner and more competitive Europe' (Action Plan, 2020).

[5] 'The EU's Circular Economy Action Plan: Setting the world's largest single market on a transition towards a circular economy' (*Ellen MacArthur Foundation*, 2020) <https://archive.ellenmacarthurfoundation.org/assets/downloads/EU-Case-Study-june2020-EN.pdf> accessed 16 August 2022.

[6] Kendall Harrow, 'A Circular Economy: Designing out Waste' (*MarketVector*, October 2020) <https://www.mvis-indices.com/mvis-onehundred/a-circular-economy-designing-out-waste> accessed 16 August 2022.

useful life of materials, and regenerating natural systems are the three circular economy principles to achieve this goal ('the Principles').[7]

The circular economy transition is also a strategy to combat climate change. The average global temperature has increased by 0.85°C between 1880 and 2012, causing significant damage to the environment, wildlife and humans.[8] To protect future generations, strategies are needed to mitigate climate change. Waste, pollution and the regeneration of natural systems are recurring topics in the debate on how to combat climate change, which illustrates the relevancy of the Principles. The CEAP recognises the connection between the circular economy and climate change by stating that circularity is a "prerequisite for climate neutrality."[9]

Greenhouse gas ('GHG') emissions are the main drivers of climate change. Two-thirds constitute carbon dioxide ('CO2'). It mostly originates from the burning of fossil fuels, including oil, coal and gas, which accounts for 84.3% of global energy production.[10] The application of the Principles implies that such pollution must be reduced and energy production cannot be dependent on exhaustible resources. Consequently, the energy sector needs to find more sustainable energy sources to ensure that the quality of life of future generations is not negatively impacted.[11] International bodies, including energy agencies, agree that nuclear energy can provide such a sustainable source.[12] Hence, nuclear energy can be seen as an enabler of the circular economy and a strategy for minimising resource depletion, combatting climate change

[7] Nitin Patwa and others, 'Towards a circular economy: An emerging economies context' (2021) 122 Journal of Business Research 725.
[8] 'Climate Change'' (*United Nations*) <https://www.un.org/en/global-issues/climate-change> accessed 16 August 2022.
[9] Commission (n 4) 20.
[10]'(n 8); and Hannah Ritchie, Max Roser, 'Energy mix' (*Our World in Data*, 2020) <https://ourworldindata.org/energy-mix#citation> accessed 16 August 2022.
[11] Gary Frey, Deborah Linke, 'Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way' (2002) 30(14) Energy Policy 1261.
[12] ENCO, *Possible Role of nuclear in the Dutch Energy Mix in the Future* (Final Report, 2020) 17.

and protecting future generations. This demonstrates the connection between the global topics of discussion in the circular economy transition, and the important role of nuclear energy in it.

Nevertheless, critics argue that nuclear energy cannot be part of the circular economy, which is discussed in chapter 2.[13] As a response, the first research question investigates *to what extent circular economy principles can enhance the sustainability of nuclear energy*. This thesis then examines whether circular methods in nuclear back-end management, which includes the decommissioning of nuclear power plants and radioactive fuel and waste management, can be adopted under the current relevant regulatory framework in the Netherlands. Hence, the second research question discusses *to what extent the Dutch regulatory framework for nuclear back-end management allows for the transition to a circular economy*. The Netherlands is the subject of the analysis for reasons explained in section 1.1.

The findings demonstrate that the Principles can be incorporated in nuclear back-end management, which can enhance the sustainability of nuclear energy and the circular economy transition. This offers a new strategy to minimise resource depletion, mitigate climate change, and protect future generations. However, the adoption of circular back-end strategies must be supported by an adequate regulatory framework, which the Netherlands does not have. There are severe limitations that do not encourage and hinder circular practices. Hence, it does not provide an adequate basis for the circular economy transition, and improvements to the framework should be made.

[13] Joshua Pearce, 'Limitations of Nuclear Power as a Sustainable Energy Source' (2012) 4 Sustainability 1173, 1180.

1.1. Research Scope and Contribution

This thesis focuses on the decommissioning of nuclear power plants and radioactive waste and spent fuel management.[14] This stage can impact nuclear energy's sustainability, as explained in chapter 3, which has been neglected by scholars and regulators so far.[15] According to Dutch law, radioactive waste constitutes radioactive substances with no intention of further use.[16] All materials subjected to radiation from the reactor can be radioactive waste.[17] Spent nuclear fuel, meaning the remaining fuel after it has been used in nuclear power plants, may constitute radioactive waste if no further use is foreseen. Hence, it is included in the scope.[18] Other sources of radioactive waste are not considered. Discussions about the regulatory framework for conventional waste and the appropriateness of international law in enhancing the circular economy transition fall outside the scope of this thesis, as separate analyses are required.

The Netherlands has one operating nuclear power plant in Borssele and one in secure containment awaiting decommissioning in 2045 in Dodewaard, two research reactors, one uranium enrichment plant, and one radioactive waste storage facility COVRA.[19] The country is exploring the possibility to construct two new nuclear power

[14] 'Nuclear Back End Webinar Series' (*IAEA*) <https://www.iaea.org/about/organizational-structure/department-of-nuclear-energy/division-of-nuclear-fuel-cycle-and-waste-technology/nuclear-back-end-webinar-series> accessed 16 August 2022.
[15] M. Pasqualetti, 'Decommissioning as A Neglected Element in Nuclear Power Plant Siting Policy in the US and UK' in Andrew Blowers and David Pepper (eds), *Nuclear Power in Crisis* (Routledge 2019).
[16] Besluit basisveiligheidsnormen stralingsbescherming 2017 IenM/BSK-2017/135624, Article 30.
[17] Umberto Pagano, 'Nuclear Power and Circular Economy: is there Chemistry?' (*VELTHA*, 15 March 2022) <https://www.veltha.eu/blog/nuclear-power-and-circular-economy-is-there-chemistry/> accessed 16 August 2022.
[18] Besluit kerninstallaties, splijtstoffen en ertsen 1969 668/372 W.J.A., Article 10(7)(1).
[19] RIVM, *Aanbevelingen voor het tweede Nederlandse nationale programma voor het beheer van radioactief afval en verbruikte splijtstoffen* (Briefrapport, 2021) 19, 20.

plants, and aims to achieve a circular economy by 2050.[20] The Netherlands is the subject of the analysis, because its regulatory framework for nuclear back-end management is based on the International Atomic Energy Agency ('IAEA') Safety Standards ('Safety Standards'). These are international non-binding requirements and guidance documents, which influence legal systems of the IAEA's 175 members.[21] Using a regulatory framework which is based on internationally recognised standards extends the relevancy of the findings to the majority of legal systems and offers a strategy to address resource depletion and climate change on a global scale.

The thesis' contribution is twofold by having scholarly and practical dimensions. First, the research contributes to theoretical research and jurisprudence relating to the circular economy concept and transition. It explains how the application of the Principles in nuclear back-end management can enhance nuclear energy's sustainability and the circular economy transition, which offers a new strategy to address the global topics of discussion. Second, this dissertation provides examples of how the Principles can be applied in practice to nuclear back-end management to give national and international institutions an understanding of how this theoretical concept can be integrated in legal systems. This can contribute to international experience-sharing, which is important in the nuclear sector. Countries can learn from the Netherlands and translate the findings into their own national legal system, which could avoid mistakes and speed up the review of regulations. The research findings can also

[20] 'Nuclear makes comeback in the Netherlands (*World Nuclear News*, 15 December 2021) <https://world-nuclear-news.org/Articles/Nuclear-makes-a-comeback-in-the-Netherlands> accessed 23 August 2022; and 'National Agreement on the Circular Economy' (*Government of the Netherlands*, 2017) <https://www.government.nl/topics/circular-economy/documents/discussion-documents/2017/01/24/national-agreement-on-the-circular-economy> accessed 16 August 2022.
[21] 'List of Member States' (IAEA, 2 March 2022) <https://www.iaea.org/about/governance/list-of-member-states> accessed 16 August 2022.

improve legal coherence between countries following the Safety Standards, which can be "mutually reinforcing and essential for the implementation of global commitments."[22] This is of significance in the circular economy transition, since resource depletion, mitigating climate change, and protecting future generations are of global concern.

1.2. Research Methodology and Structure

The first research question is answered by an in-depth academic literature review to conceptualise the relationship between the circular economy goals, the Principles, and nuclear energy. It reveals that the academic conversation about the importance of applying the Principles to nuclear energy production has not started yet, which supports the gap-filling role this research question has. The thesis also relies on reports and other secondary sources, due to the lack of academic debate in the field of nuclear back-end management. This is especially the case in chapter 3, which provides a non-legal and descriptive basis necessary for answering the second research question.

Doctrinal research is most suitable to answer the second research question, as it offers an overview of the regulatory framework, a thorough understanding of existing laws and regulations, and the possibility to analyse the relationship between different regulatory instruments.[23] It is a reform-oriented research, which reviews the existing framework and recommends amendments.[24] A doctrinal approach with legal dimension using mostly primary sources, including international conventions, EU directives and

[22] J. Rodriguez-Anton and others, 'Analysis of the relations between circular economy and sustainable development goals' (2019) 26(8) International Journal of Sustainable Development & World Ecology 708.
[23] Terry Hutchinson, Nigel Duncan, 'Defining and Describing What We Do: Doctrinal Legal Research' (2012) 17(1) Deakin Law Review 84, 101.
[24] Ibid.

national legal instruments, determines what the law is.[25] Government reports are used as supporting documents. A doctrinal approach with practical dimension is conducted to illustrate the real-world application of the regulatory framework.[26] This approach is based on secondary sources, including industry and government reports. The doctrinal research is backed by academic literature where possible, and examples of other countries with the same or similar international law obligations (depending on institutional membership) are drawn upon to demonstrate good practices.

The research's main limitation is the exclusive focus on legal considerations. Political, social, safety and economic factors are not accounted for. However, these factors are of high importance in the field of nuclear energy production.[27] For instance, potential opportunities to improve circularity may face economic and safety constraints, and would not be accepted by the public.[28] It is recommended that future research addresses this shortcoming by examining the interplay between legal and non-legal considerations.

The following chapter explains the importance of incorporating the Principles into nuclear energy generation by providing a comprehensive conceptual framework of the circular economy and its link to nuclear energy. Chapter 3 then identifies methods in nuclear back-end management that reflect the Principles. The general issues of the Dutch regulatory framework are discussed in chapter 4, before analysing whether the

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[25] Terry Hutchinson, 'Doctrinal Research: Researching the Jury' in Dawn Watkins and Mandy Burton (eds), *Research Methods in Law* (2nd edn, Taylor & Francis 2018) 29.
[26] Ibid.
[27] Pagano (n 17); and Kristina Gillin, 'Nuclear decommissioning in a circular economy' (*Nuclear Engineering International*, 2 November 2021) <https://www.neimagazine.com/features/featurenuclear-decommissioning-in-a-circular-economy-9208806/> accessed 16 August 2022.
[28] IAEA, *Recycle and reuse of materials and components from waste streams of nuclear fuel cycle facilities* (Report, 2000) 41.

circular methods identified in chapter 3 can be adopted under this framework. Finally, chapter 5 concludes the thesis by answering both research questions.

2. The Importance of Circularity in Nuclear Energy Production

This section conceptualises the relationship between the circular economy and nuclear energy production to demonstrate the significance of enhancing the sustainability of nuclear energy through the Principles. For this, it is decisive to understand the circular economy concept first.

2.1. Conceptualising the Circular Economy

The current economy is 'linear', meaning that products are produced, consumed and disposed.[29] Raw materials are wasted, the environment is polluted, and the planet cannot replenish its resources.[30] This contributes to the depletion of exhaustible resources and climate change.[31] The concept of the circular economy was introduced in action plans at international and national levels to address these issues.[32] The Dutch government describes the circular economy as one in which products are reused as often as possible. Broken products are repaired or recycled to turn waste into new raw materials, which can then be reinjected into the economy.[33] There is a 'closed loop' where raw materials remain in the economy indefinitely, and no waste is created. Other

[29] Furkan Sariatli, 'Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability' (2017) 6(1) Visegrad Journal on Bioeconomcy and Sustainable Development 31, 32.
[30] EEA (n 2) 9.
[31] IenW (n 3) 2.
[32] Commission (n 4).
[33] 'Circular Economy' (*Government of the Netherlands*) <https://www.government.nl/topics/circular-economy/from-a-linear-to-a-circular-economy> accessed 16 August 2022.

definitions of the circular economy concept share basic features, but there is no commonly agreed definition.[34]

According to Hervé Corvellec, the circular economy concept creates enthusiasm by providing a theoretical framework which has the potential to solve global issues, including resource depletion and climate change. In practice, however, many issues arise when implementing the concept.[35] His literature review concludes that there are "unaddressed assumptions, blind spots, tensions, contradictions, unthought-of consequences, and taken-for-granted advantages of a circular transition."[36] Of importance for this thesis is the criticism that the concept does not acknowledge that matter is never destroyed, but only converted into different forms.[37] Achieving a truly circular economy with a 'closed loop' and no waste is, therefore, scientifically impossible. Hence, the thesis attempts to identify methods and regulatory options with the aim to 'close the loop' *as far as possible*.

2.1.1. The Circular Economy Principles

Most definitions of the circular economy reflect three main principles.[38] First, waste and pollution should be eliminated or reduced.[39] Following the aforementioned criticisms, *eliminate* wate and pollution is adapted to *minimise* waste and pollution in

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[34] Antonis Mavropoulos, Anders Waage Nilsen*, Industry 4.0 and Circular Economy* (John Wiley & Sons 2020) xxxiii.
[35] Herve Corvellec and others, 'Critiques of the Circular Economy' (2021) 26 (2) Journal of Industrial Ecology 421.
[36] Ibid 428.
[37] Ibid 423.
[38] Patwa (n 7) 725; and Ellen MacArthur Foundation, *Completing the picture: How the circular economy tackles climate change* (2021) 3.
[39] 'Circular Economy' (*Corporate Finance Institute*, 2 December 2019) <https://corporatefinanceinstitute.com/resources/knowledge/economics/circular-economy/> accessed 16 August 2022.

this thesis. This Principle reduces the potential harm to humans and the environment and, consequently, the risk of burdening future generations.[40] Second, the useful life of materials should be extended, which implies the use and reuse of materials as often as possible.[41] This reduces the extraction of new raw materials and minimises the volume of waste by reusing already existing materials, which secures the availability of resources for future generations. Lastly, natural systems should be regenerated. This addresses the already existing damages to the environment by restoration for the benefit of future generations.[42]

Despite the criticisms of the circular economy concept, the Principles promote efficient resource consumption, the protection of future generations, and efforts to combat climate change. Hence, introducing the Principles into regulatory systems is a necessary step towards addressing the issues of global concern.

2.2. Energy Production in the Circular Economy

The introduction explained that fossil fuels are the primary source of energy.[43] This way of energy production depletes the planet's resources and is responsible for driving climate change.[44] Therefore, it is not compatible with the circular economy concept. Nuclear energy may be a sustainable alternative energy source.

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[40] IAEA (n 28) 39.
[41] (n 39).
[42] Piero Morseletto, 'Restorative and regenerative: Exploring the concepts in the circular economy' (2020) 24 Journal of Industrial Ecology 763, 768.
[43] International Energy Agency, *Key World Energy Statistics 2020* (Report, 2020) <https://www.iea.org/reports/key-world-energy-statistics-2020> accessed 1 July 2022.
[44] 'Causes and Effects of Climate Change' (*United Nations*) <https://www.un.org/en/climatechange/science/causes-effects-climate-change> accessed 22 August 2022.

Nuclear energy is generated through fission using uranium, plutonium or thorium, which is the nuclear fuel in nuclear power plants.[45] It can be part of the strategy to achieve a circular economy by providing a clean and sustainable energy source, which has been acknowledged by scholars.[46] It can contribute to the reduction of waste and pollution, and raw material consumption, thereby directly reducing adverse environmental impacts and protecting future generations.[47] However, this position is highly debated by other scholars and the public.[48]

Three arguments against characterising nuclear energy as sustainable are most commonly heard. First, nuclear waste is generated, which requires storage for over 100,000 years and would put an undue burden on future generations to manage and live with the waste.[49] The World Nuclear Association explains that the "exceptionally high energy density" means that little fuel is needed to generate large amounts of energy, resulting in small amounts of waste.[50] In comparison to other low-carbon sources, it can be observed that the amount of waste from nuclear energy is the lowest. For instance, according to an analysis of material throughput per energy source, Jemin Desai and Mark Nelson found that solar energy would generate over 300 times more waste than nuclear if it produced as much energy over a 25 years period.[51] In consideration of the practical impossibility of achieving a truly circular economy, as explained before,

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45 Pagano (n 17).
46 Anzhelika Karaeva, 'Public Attitude towards Nuclear and Renewable Energy as a Factor of Their Development in a Circular Economy Frame: Two Case Studies' (2022) 14(3) Sustainability 1283.
47 Marc Rosen, 'The Circular Economy and Energy' in Aldo Alvarez-Risco and others (eds), *Towards a Circular Economy* (Springer 2022); and Pagano (n 17).
48 Pearce (n 13) 1180; and Andra Leimanis, 'Nuclear Energy: Still Unsustainable' (*SyracusePeaceCouncil*, 2016) <http://peacecouncil.net/nuclear-energy-still-unsustainable> accessed 18 August 2022; and 'Six Reasons Why Nuclear Power is Not Sustainable' (*SAPL*) <https://saplnh.org/about-nuclear/why-nuclear-power-is-not-sustainable/> accessed 25 August 2022.
49 Pearce (n 13) 1181; and Leimanis (n 48).
50 'Nuclear Energy and Sustainable Development' (World Nuclear Association, April 2020) <https://world-nuclear.org/information-library/energy-and-the-environment/nuclear-energy-and-sustainable-development.aspx> accessed 16 August 2022.
51 Jemin Desai, Mark Nelson, 'Are we headed for a solar waste crisis?' (*Environmental Progress*, 21 June 2017) <https://environmentalprogress.org/big-news/2017/6/21/are-we-headed-for-a-solar-waste-crisis> accessed 22 August 2022.

nuclear energy is sustainable by creating the least amount of waste in proportion to the energy output. Nevertheless, the radioactive waste created can bear some risks for humans, wildlife and the environment.[52]

Second, every stage of the energy production cycle emits CO2, although less than fossil fuels.[53] However, this is only a very little amount, and other low-carbon energy sources also create emissions.[54] Nuclear energy emits around 12g CO2 per kilowatt hour. This is similar to wind energy, but lower than solar energy.[55]

Lastly, this way of energy production contributes to resource depletion, as nuclear fuel is not a renewable resource.[56] Nevertheless, the fuel does not have other significant roles than generating energy.[57] Its usage means that other resources can be used where they are most needed.[58]

It follows that, although nuclear energy has some unsustainable characteristics which may suggest a conflict with the circular economy transition, it can still contribute to the circular economy objectives by reducing emissions, the amount of waste in volume, and the need for raw material extraction. Especially in comparison with other low-carbon energy sources, the importance of nuclear energy in the circular economy transition becomes apparent. This conclusion is coherent with the findings of J. Bruggink and B. der van Zwaan.[59]

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[52] J. Vives i Battle and others, 'Environmental risks or radioactive discharges from a low-level radioactive waste disposal site at Dessel, Belgium' (2016) 162-163 Journal of Environmental Radioactivity 263.
[53] Leimanis (n 48).
[54] Pagano (n 17).
[55] (n 50).
[56] 'Six Reasons Why Nuclear Power is Not Sustainable' (*SAPL*) <https://saplnh.org/about-nuclear/why-nuclear-power-is-not-sustainable/> accessed 25 August 2022.
[57] (n 50).
[58] Ibid.
[59] J. Bruggink, B. der van Zwaan, 'The role of nuclear energy in establishing sustainable energy paths' (2002) 18(2-4) International Journal of Global Energy Issues 151.

Scholars have recognised that the Principles can guide the transition to greener energy sources in connection to renewable energy sources, such as solar and wind.[60] This can and should also be applied to nuclear energy. Currently, the life cycles of nuclear power plants are a linear process where waste must be "stored, treated and disposed".[61] Incorporating the Principles into the life cycles would ensure the minimisation of waste and pollution, efficient resource consumption, and reduce environmental impacts during the process of energy production. It would increase the sustainability of nuclear energy, protect future generations, mitigate climate change, and minimise resource depletion, and consequently, promote the circular economy goals. Hence, nuclear energy's role in the circular economy transition is strengthened, which can mitigate some of the arguments against its sustainability. This demonstrates the importance of applying the Principles in nuclear energy production, which has been neglected in academic literature and by regulators so far. The extent to which the Principles can enhance the sustainability of nuclear energy is discussed subsequently.

3. Circularity in Nuclear Back-End Management

Life cycles have six stages: siting, design, construction, operation, decommissioning, and release from regulatory control.[62] The back-end stages have never been the focus of nuclear energy policies. Instead, attention is given to the first

[60] G. Mutezo, J. Mulopo, 'A review of Afrcia's transition from fossil fuel to renewable energy using circular economy principles' (2021) 137 Renewable and Sustainable Energy Reviews.
[61] Kristina Gillin, 'How can nuclear decommissioning be adapted to support a circular economy?' (*VysusGroup*, 7 April 2022) <https://www.vysusgroup.com/articles/how-can-nuclear-decommissioning-be-adapted-to-support-a-circular-economy> accessed 1 July 2022.
[62] IAEA, *Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning of Nuclear Facilities* (Technical Report, 2001) 1.

stages.[63] Some countries, including the Netherlands, started to actively incorporate the Principles in the decommissioning stage of other energy sources, but such steps have not been taken in the nuclear sector.[64] Similarly, academic literature on nuclear back-end management, especially from the circular economy perspective, is non-existent. However, the back-end management of nuclear power plants is of high importance, as this stage can significantly impact the sustainability of nuclear energy generation, which is demonstrated subsequently. It is important to understand how the Principles can be incorporated into nuclear back-end management to improve the sustainability of nuclear energy and strengthen its role in the circular economy transition. This chapter provides an overview of circular back-end strategies advanced by experts in the field by following the waste hierarchy approach.

3.1. The Waste Hierarchy

Reduce, reuse and recycle are the main concepts for waste management pursuing the waste hierarchy. They have descending priority pursuant to their level of sustainability.[65] First, the amount of waste produced should be reduced to the lowest amount achievable before reusing materials as often as possible. When materials cannot be reused, they should be recycled. Waste should only be disposed of when reusing and recycling is not possible. This is the so-called waste hierarchy.[66] This concept is insufficient to eliminate waste in the economy, [67] which is the same limitation as the

[63] Diletta Invernizzi and others 'Developing policies for the end-of-life of energy infrastructure: Coming to terms with the challenges of decommissioning' (2020) 144 Energy Policy 1.
[64] Ibid 5.
[65] Gillin (n 61).
[66] Andrew Waite, 'Waste and the Waste Hierarchy in Europe' (2011) 26(1) Natural Resources & Environment 54.
[67] S. Van Ewijk, J. Stegemann, 'Limitations of the waste hierarchy for achieving absolute reductions in material throughput' (2016) 132 Journal of Cleaner Production 122, 127.

circular economy concept. It does not impact the discussion of the thesis, as it aims to demonstrate how the loop can be closed *as much as possible*.

Other parallels can be drawn to the circular economy concept, which has been observed by Chunbo Zhang. The three strategies aim to reduce the amount of waste that must be disposed of to reduce adverse environmental impacts, hence reflecting the goals of the circular economy concept.[68] However, he fails to identify the connection between the hierarchy and the individual Principles, which is important to understand how applying the waste hierarchy approach to nuclear back-end strategies can enhance the circular economy transition. The Principle to minimise waste and pollution is reflected in the overall goal of the hierarchy and the circular economy. The Principle to extend the useful life of materials can be incorporated when minimising the initial amount of waste by using and reusing the materials as long and often as. Natural systems are regenerated as a consequence of the three strategies, because the natural environment has more space to recover when waste is minimised.

Following this, the circular economy and waste hierarchy both strive for new waste management strategies which reduce waste and raw material extraction with the goal to protect humans, the environment and the earth's resources.[69] Consequently, reduce, reuse and recycle are the overall strategies to integrate the Principles in practice. This approach is used to discuss how circularity can be achieved in nuclear back-end management, and to what extend this would enhance the sustainability of nuclear energy. The methods by which each Principle can be incorporated into nuclear back-end management are discussed in turn in the following sections according to their descending level of sustainability in conformity with the waste hierarchy. Thus, first

[68] Chunbo Zhang and others, 'An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe' (2022) 803 Science of The Total Environment 11.
[69] Ibid.

measures to extend the useful life of materials, then to minimise waste and pollution, and, finally, to regenerate natural systems are discussed.

3.2. Extending the Useful Life of Materials

This Principle maximises the efficiency of materials used. In nuclear back-end management such materials can include buildings, structures, components, equipment and other materials. The Principle reduces the generation of waste and raw material consumption by reusing materials already in circulation which do not need to be thrown away. Consequently, new raw materials are not needed. The first method to achieve this is to keep nuclear power plants operating as long as reasonably safe. Extending plants' lives reduces the need to build new nuclear power plants or resort to other, less sustainable, sources of energy.[70] If the plants must shut down, decontamination, meaning the removing of contamination from surfaces of materials, should be the first step.[71] The more is decontaminated, the more materials can be reused (or recycled).[72] Generally, for nuclear facilities, reinstating the original use of the site by reusing buildings and structures for the same purpose is the best option.[73] Alternatives could include the redevelopment to, *inter alia*, waste storage and processing facilities, research and educational centres, and office buildings.[74] Components of reactors may be reused in other nuclear power plants which are still operating.[75] If the infrastructure

[70] Gillin (n 61).
[71] IAEA (n 62) 14.
[72] Ibid.
[73] IAEA, *Redevelopment and Reuse of Nuclear Facilities and Sites: Case Histories and Lessons Learned* (Nuclear Energy Series, No. NW-T-2.2) 18, 19.
[74] Gillin (n 61); and IAEA, *Selection of decommissioning strategies: Issues and factors* (Report, 2005) 8.
[75] Gillin (n 61).

must be demolished, the concrete can be used as foundations for new infrastructure, such as roads and buildings.[76]

Once the materials are decontaminated, the concept of clearance, by which regulatory control is lifted, can allow the release of materials.[77] These can then be reused or go through conventional recycling routes.[78] From a circular economy perspective, it is desirable to classify as much waste as possible as conventional waste rather than radioactive waste, as this increases reuse and recycling options. It improves the efficient use of materials and minimises the waste that must be stored and disposed of.[79] When unrestricted clearance is not possible, restricted release could be an alternative, which allows for the use of the materials under certain conditions and for restricted activities.[80]

Nevertheless, attention must be paid to the treatment of the conventional waste. Waste that is released from regulatory control through the use of these methods cannot only be reused and recycled, but can also be disposed of in landfills, [81] which is not compatible with the Principles. It does not attempt to minimise the amount of waste and resource extraction, and is harmful to the environment, which is not given the possibility to regenerate. Therefore, while clearance of waste can enhance the circular economy, it can also have the opposite effect.

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[76] Giorgia Marino, 'International Atomic Energy Agency: This is how nuclear decommissioning becomes circular' (*Renewable Matter*, 11 March 2021) <https://www.renewablematter.eu/articles/article/international-atomic-energy-agency-this-is-how-nuclear-decommissioning-becomes-circular> accessed 16 August 2022.

[77] IAEA (n 28) 6.

[78] Ibid 30.

[79] J. Devgun and others, 'Clearance of Bulk Materials From Decommissioning Projects: Regulatory and Cost Issues' (*The American Society of Mechanical Engineers*, 18 November 2014) <https://asmedigitalcollection.asme.org/PVP/proceedings-abstract/PVP2014/V007T07A029/283237> accessed 23 August 2022; and IAEA, *Predisposal Management of Radioactive Waste* (Safety Standards, No. GSR Part 5) 16; and IAEA (n 28) 30.

[80] IAEA (n 28) 6.

[81] Jo Van Caneghem and others. 'Waste-to-energy is compatible and complementary with recycling in the circular economy' (2019) 21 Clean Technologies and Environmental Policy 925.

These circular methods extend the useful life of materials. Applying them in practice would reduce the waste generated and the new raw materials needed. Adverse environmental impacts and the extraction of new raw materials would be minimised, which directly protects the environment, resources and well-being of future generations. Hence, integrating these methods into nuclear back-end management would significantly enhance the sustainability of nuclear energy and contribute to the circular economy transition. However, the management of conventional waste may mitigate the positive contributions of the circular methods, if materials are disposed of in landfills rather than being reused or recycled.

3.3. Minimising Waste and Pollution

When measures to extend the useful life of materials to avoid waste generation have been exploited, strategies to minimise the volume of waste and pollution are the next most circular solution.

Spent nuclear fuel can either be disposed of directly, or can be reprocessed.[82] The former does not reflect the Principles, as no actions are taken to reduce, reuse or recycle the waste. Reprocessing can recycle around 97% of the spent fuel, which can be used again as new fuel in reactors.[83] Radioactive waste remaining from the procedure is reduced in volume, and other parts are decontaminated and treated as conventional waste.[84] Furthermore, the radioactive waste that must be stored has a much lower

[82] Pagano (n 17).
[83] Martin Leafe, 'End in sight for reprocessing nuclear fuel at Sellafield' (*Gov.uk*, 24 January 2017) <https://nda.blog.gov.uk/end-in-sight-for-reprocessing-nuclear-fuel-at-sellafield/> accessed 17 August 2022.
[84] Pagano (n 17).

radioactive life than spent fuel that was not reprocessed.[85] Nuclear power plants with 'breeder fuel cycles' can reduce the amount of spent fuel further, by allowing the immediate reprocessing of spent fuel for up to five times.[86] This makes recycling more effective and minimises secondary pollution by not needing to transport the spent fuel to reprocessing facilities. Hence, reprocessing enhances circularity in the management of spent fuel. Nevertheless, some radioactive waste remains and new raw materials are still needed.[87] Considerations must also be given to the secondary waste generated by reprocessing facilities, and their use of raw materials. This process itself must be managed in a circular manner.[88]

The remaining radioactive waste from the decontamination of the materials and reprocessing is radioactive due to unstable nuclei which release energy in the form of radiation to become more stable. This process of nuclei losing radiation with time is called radioactive decay.[89] Radioactive waste loses its radioactivity over time. Hence, there are strong incentives to store the waste for decay before disposal for around 50 years, which is called decay storage.[90] Once the waste is less radioactive, a larger amount of non-radioactive substances can be separated and recycled, thereby reducing the overall amount of waste that must be put into long-term storage. Consequently, decay storage is a strategy to minimise waste in the circular economy, although the effectiveness of this method also depends on the management strategies for conventional waste.

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85 Guillermo DelCul, Barry Spencer, 'Reprocessing and recycling' (2020) Advances in Nuclear Fuel Chemistry 469.
86 Pagano (n 17).
87 Ibid.
88 Gillin (n 61).
89 Gopal Saha, *Fundamentals of Nuclear Pharmacy* (6th edn, Springer 2010) 11.
90 'Storage and Disposal of Radioactive Waste' (*World Nuclear Association*, May 2021) <https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste.aspx> accessed 17 August 2022.

New technologies may emerge, which would significantly benefit the circularity of radioactive waste management. Partitioning and Transmutation (P&T), which aims to convert long-lived radioactive substances into substances with a shorter life, may be one of them.[91] Radioactive waste could be taken out of storage sooner and further recycled. An underground repository remains necessary for the long-lived radioactive substances that do not qualify for P&T and for the long-lived by-products of transmutation.[92]

This does not mean that radioactive waste management is per se in conflict with the Principles. Due to the lack of current technologies to eliminate radioactivity in waste, long-term storage solutions are still required. Deep geological disposal, meaning the isolation of radioactive waste in deep underground repositories, is the most favoured option in most countries.[93] It includes the possibility to reverse the storage and retrieve the waste.[94] Thus, it allows for the recycling and reuse of radioactive waste once the necessary technology has been invented. This solution provides a pathway to adopt more sustainable solutions in the future, and close the loop in the circular economy further.[95] Nevertheless, future generations are burdened with the radioactive waste in storage and finding better management solutions.

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[91] M. Salvatores, G. Palmiotti, 'Radioactive waste partitioning and transmutation within advanced fuel cycles: Achievements and challenges' (2011) 66(1) Progress in Particle and Nuclear Physics 144.
[92] Ibid 165.
[93] 'Deep Geological Repository' (*NuclearPower*) <https://www.nuclear-power.com/nuclear-power-plant/radioactive-waste/deep-geological-repository/> accessed 29 August 2022.
[94] IenW, *Het nationale programma voor het beheer van radioactief afval en verbruikte splijtstoffen* (National Program, 2016) 29.
[95] IenW, *Joint convention on the safety of spent fuel management and on the safety of radioactive waste management: National Report of the Kingdom of the Netherlands for the Seventh Review Meeting* (Report, October 2020) 101.

With regard to conventional waste, if the reuse of materials is not possible, 90% of materials in the structure of nuclear power plants can be recycled after decontamination.[96] The steam generator of a nuclear power plant in Sweden, for example, was recycled by decontamination and melting, and was then released from regulatory control.[97] The more materials are recycled, the smaller the amount of final waste that must be disposed of. Here too the effectiveness of the method depends on the conventional waste management regulations and policies, as conventional waste can also be disposed of in landfills.

This demonstrates that the application of these circular methods does not reduce the initial waste generated, but can significantly reduce the amount of waste that needs to be disposed of in the long-term. The lower the amount of waste in storage, the smaller the burden on future generations to manage the waste later, and the more space the environment has to regenerate. Additionally, by recycling materials, new secondary raw materials are created, thereby addressing resource depletion by requiring less raw materials to be extracted from the earth. This implies less pollution from extraction processes, which helps mitigate climate change and to regenerate natural systems. It also secures resources and a healthier environment for future generations. Consequently, by incorporating this Principle into nuclear back-end management, the sustainability of nuclear can be improved, and the circular economy transition enhanced. The extent of the positive effects can be mitigated by inadequate conventional waste management strategies.

[96] Gillin (n 61); and Pagano (n 17).
[97] IAEA (n 28) 32.

3.4. Regenerating Natural Systems

Techniques directly aimed at regenerating natural systems are the last step in which circularity in nuclear energy production can be enhanced. The Principle implies that practices in the circular economy should aim to restore environmental damage.[98] In nuclear back-end management this means that, once the facility is fully decommissioned, the site should be restored to its initial state. The restoration of soil is of particular importance, since healthy soil is necessary for social, economic, sanitary and environmental reasons.[99] Restorative measures allow the natural system in and around the site to regenerate, and future generations are not burdened with a contaminated and unhealthy environment. However, this method does not provide an avenue to address resource depletion, which is an integral part of the circular economy goal. Thus, this back-end strategy does not enhance the sustainability of nuclear energy as much as the other methods, and its contributing role in the circular economy transition is limited. It should not be the preliminary decommissioning solution, since it entails the demolition of reusable buildings and structures, thereby not extending the useful life of materials which is higher in the waste hierarchy.

3.5. Concluding Observations

The previous chapter highlighted the importance of nuclear energy in the circular economy transition. Increased sustainability may strengthen nuclear energy's role in the circular economy transition. This chapter demonstrates that the waste

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[98] Morseletto (n 42) 767, 768.
[99] Claudio Bini, 'Soil Restoration: Remediation and Valorization of Contaminated Soils' (2009) Environmental Sciences.

hierarchy approach in integrating the Principles in nuclear back-end management has the potential to significantly enhance the sustainability of nuclear energy by reducing the need of new raw materials and waste generation, and giving natural systems space to regenerate. The incorporation of the Principles allows states to take full advantage of nuclear energy's potential to contribute to the minimisation of resource depletion, mitigation of climate change, and protection of future generations. Nevertheless, waste cannot be eliminated completely. Emerging technologies may reduce the amount of radioactive waste even further, but deep geological disposal remains necessary and a fully closed loop of raw material consumption will never exist. This reflects the general criticism of the circular economy concept. It follows that the Principles can enhance the sustainability of nuclear energy to a considerable extent, although cannot create a waste-free economy.

Whether each of the discussed circular practices in nuclear back-end management are viable options must be evaluated on a case-by-case basis. For instance, the location of the facility may play a role. Commercial and social land values vary, communities have different political motivations and legal requirements, and sites can have distinct environmental characteristics.[100] The unique design and operation characteristics of reactors, as well as economic factors, can also influence case-by-case analysis.[101]

To experience the full potential of these circular methods, a supporting regulatory framework is necessary. Kristina Gillin identified that regulatory

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[100] IAEA (n 73) 92.
[101] Ibid 18, 19.

requirements influence the capability to enhance nuclear energy's and the economy's circularity.[102] Many scholars come to similar conclusions when examining how the circular economy transition can be achieved.[103] Gillin further found that different approaches and criteria can influence whether the methods can be used in practice. It must be ensured that regulatory requirements do not hinder the integration of circular economy practices in nuclear energy production.[104] This is correct, but she fails to identify the influencing role that the general structure of the regulatory framework can have in promoting nuclear energy's role in the circular economy transition, and hence, to encourage the incorporation of the Principles into nuclear back-end management. Chris Bakers, for instance, has acknowledged the need to consider the overall system when researching the circular economy, rather than analysing a single sector.[105] A combination of his broader and Gillin's narrower approach to the legal analysis is necessary to establish the extent to which the Dutch regulatory framework for nuclear back-end management allows for the transition to a circular economy. This is the subject of the following chapter.

4. <u>The Regulatory Framework as Basis for a Circular Economy</u>

First, the relevant regulatory framework is explained and its role in enhancing the circular economy transition discussed. Then, specific provisions are analysed to determine whether the Dutch legal framework for nuclear back-end management allows

[102] Gillin (n 27).
[103] Christina Ciliberto and others, 'Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0' (2021) 30 Business Strategy and the Environment 3255, 3261; and Patrizia Ghisellini, Sergio Ulgiati, 'Circular economy transition in Italy. Achievements, perspectives and contraints' (2020) 243 Journal of Cleaner Production 12.
[104] Gillin (n 27).
[105] Chris Backes, 'Law for a Circular Economy' (2017) Utrecht Centre for Water, Oceans and Sustainability Law 16.

for the circular economy transition by giving opportunities to adopt the previously explained circular methods.

4.1. Limitations of the General Framework

Nuclear back-end management is closely connected to environmental law and energy law, since nuclear law incorporates environmental protection concepts, nuclear activities are subject to international environmental law, and it is a form of energy production.[106] Hence, the connection between these laws and regulatory instruments for the circular economy transition must be discussed, to understand how they influence nuclear energy's role in the circular economy transition. First, the relevant international and national legal instruments are outlined.

4.1.1. The Circular Economy, Energy Law and Environmental Law

Article 191 of the Treaty on the Functioning of the European Union ('TFEU'), which states that resources must be used in a 'prudent and rational' manner, is the legal basis for the circular economy in the EU.[107] The circular economy package forms one of the main pillars for the transition to a resource-efficient circular economy together with other instruments, such as the Energy Roadmap 2050.[108] These are a mix of legally binding and non-binding regulatory instruments and supplement environmental and

[106] Sam Emmerechts, 'Environmental Law and Nuclear Law: A Growing Symbosis'(2008) OECD 109.
[107] Consolidated Version of the Treaty on the Functioning of the European Union [2012] OJ C326/47; and Teresa Domenech, Bettina Bahn-Walkowiak, 'Transition Towards a Resource Efficient Circular Economy in Europe: Policy Lessons From the EU and the Member States' (2019) 155 Ecological Economies 7, 10, 11.
[108] Commission, 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy Roadmap 2050' (Communication) COM (2011) 885 final.

energy law.[109] The CEAP, which is part of the circular economy package, can be described as a framework comprised of a collection of pre-existing EU instruments advancing certain circular economy aspects, which are supplemented by an understanding of the circular economy concept.[110] The EU commitment to the circular economy has largely introduced non-binding and some legally binding obligations for member states. For instance, there are no legally binding targets for resource efficiency, but the EU's Waste Framework Directive ('WFD') imposes binding provisions on conventional waste treatment and management.[111]

The Netherlands' regulatory instruments for the circular economy transition have formulated general targets, according to which primary resource consumption should be halved by 2030.[112] The Netherlands has adapted further commitments to 'realise the circular economy' by 2050.[113] The three strategies of the circular economy program called 'Circular Dutch economy by 2050' prescribe that (1) raw materials should be used efficiently to reduce their overall need; (2) where new raw materials are needed, unsustainable and exhaustible resources should be replaced with raw materials that are sustainably produced, renewable and commonly available; and (3) new production methods and products should be designed in a circular way.[114] The Dutch transition agendas cover five sectors, namely plastics, biomass and food, consumer

[109] Domenech (n 107) 10, 11.
[110] Thomas de Römph, Jacqueline M Cramer, 'How to improve the EU legal framework in view of the circular economy' (2020) 38(3) Journal of Energy & Natural Resources Law 245.
[111] Domenech (n 107) 14; and Directive (2008/98/EC) of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives [2008] OJ L312/3; and Commission, 'The role of waste-to-energy in the circular economy' (Opinion) COM (2017) 34 final 3; and 'Waste and recycling' (*European Commission*) <https://environment.ec.europa.eu/topics/waste-and-recycling_en> accessed 23 August 2022; and 'Waste Framework Directive' (*European Commission*) <https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en> accessed 23 August 2022.
[112] Backes (n 105) 11.
[113] Ibid.
[114] 'Circular Dutch economy by 2050' (*Government of the Netherlands*) <https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050> accessed 17 August 2022.

goods, manufacturing, and construction.[115] Agreements exist in which companies commit to adhere to the Dutch circular economy program. These, however, are not legally enforceable.[116]

This framework to enhance the circular economy transition in the Netherlands has significant limitations. First, the Netherlands does not have clear legally binding targets to achieve resource efficiency.[117] This would not only provide incentives encouraging the circular economy transition and efficient resource consumption, but also promoting nuclear energy as a low-carbon energy source. It would also endorse the application of circular methods in nuclear back-end management to maximise resource efficiency in the energy production process, and reduce the extraction of new raw materials. General targets exist, but details on how these should be achieved are missing. This is needed to ensure that the goal of responsible resource consumption is achieved.[118] Austria, for example, has adopted targets including timelines and figures to achieve resource efficiency in their national regulatory framework.[119] A similar approach could be adapted by the Netherlands. The introduction of legally binding obligations can have a much stronger effect than voluntary commitments of companies to support the circular economy transition, which has been highlighted by multiple scholars.[120] The mandatory obligation of member states to follow the waste hierarchy approach for conventional waste, imposed by the WFD, is one example where legally binding targets "have been a key driver to improve waste management practices,

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[115] (n 114).
[116] IenW, *Grondstoffenakkoord: Intentieovereenkomst om te komen tot transitieagenda's voor de Circulaire Economie* (Agreement, 2017).
[117] Domenech (n 107) 14.
[118] Backes (n 105) 11, 12.
[119] Domenech (n 107) 14.
[120] Ciliberto (n 103) 3261; and Sita Mishra and others, 'The anatomy of circular economy transition in the fashion industry' (2021) 17(4) Social Responsibility Journal 524, 534; and Ghisellini (n 103) 12.

stimulate innovation in recycling, limit the use of landfilling, and create incentives to change consumer behaviour"[121] according to the EC. Hence, such a legally binding approach could also enhance the integration of the Principles in nuclear back-end strategies, and the circular economy transition.

Furthermore, the lack of reference to energy production in circular economy instruments is a weakness of the regulatory framework. Sustainable energy production, including nuclear energy, is of high importance to achieve a circular economy, as explained in section 2.2. It can reduce raw material consumption, waste and pollution considerably, and should be specifically acknowledged as such in regulatory instruments for the circular economy transition. The EU circular economy package complements regulations and policies on energy efficiency, and the Energy Roadmap 2050 strives for resource-efficient energy production, but the link is weak.[122] The Energy Roadmap 2050 recognises the importance of nuclear energy as a decarbonisation option, but does not establish a clear link to the circular economy transition.[123] On the national level, energy is also not part of the transition agendas. Addressing this weakness would enhance the circular economy transition by making nuclear energy's role in the transition explicit. It would also make nuclear energy subject to circular economy policies and, thus, provide a legal basis to integrate the Principles into the energy generation process, including nuclear back-end management. Consequently, addressing this regulatory limitation would contribute to the reduction of raw material consumption and mitigation of climate change, as well as to the goal of the circular economy to protect future generations. This is because the principle not to

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[121] Commission, 'Proposal for a Directive of the European Parliament and the Council amending Directive 2008/98/EC on waste' (Proposal) COM (2015) 595 final 2.
[122] Domenech (n 107) 10.
[123] Commission (n 108) 13.

impose undue burdens on future generations is found in multiple relevant sources of law, including the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management ('Joint Convention')[124], the EU Council Directive 2011/70/EURATOM ('2011 Directive')[125], and the IAEA Safety Standards.[126] A connection between the circular economy instruments and nuclear law would deepen the integration of this principle in the circular economy transition. It would also give further guidance on how future generations can be protected, thereby addressing the criticism of the EC that the Dutch national framework does not sufficiently explain how this principle can be achieved in practice.[127]

Lastly, the Dutch circular economy framework does not establish a clear connection to environmental law, although the fundamental environmental principle in Article 191 TFEU is the legal basis for the circular economy on EU level.[128] The circular economy instruments complement environmental law, but environmental law does not play a role in the strategy to transition to the circular economy.[129] This, however, should be the case, as environmental law principle and the circular economy concept share the same goals.

International environmental law principles can be defined as "an amorphous group of policy ideas concerning how environmental protection and sustainable development ought to be pursued."[130] There is no clear list of international environmental law principles, but the most commonly used principles are found in the

[124] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (adopted 5 September 1997, entered into force 18 June 2001) INFCIRC/546.
[125] Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste [2011] OJ L199/48.
[126] For example, IAEA, *Fundamental Safety Principles* (Safety Standards, No. SF-1) Principle 7.
[127] André Oostdijk and others, *Evaluatie Radioactief afval* (Report 2022) 27; and RIVM (n 19) 30.
[128] Domenech (n 107) 10.
[129] Ibid 10, 11.
[130] Elizabeth Fisher and others, *Environmental Law* (2nd edn, Oxford 2019) 402.

1992 Rio Declaration on Environment and Development ('Rio Declaration').[131] The principle of sustainable development pursuant to Principle 4 of the Rio Declaration is relevant here. The 1987 Brundtland Report defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[132] This imposes an international obligation upon states to ensure sustainable development practices and natural resource consumption to protect future generations. This is the so-called principle of intergenerational equity, which is also connected to the principles of sustainable use, for which the exploitation of natural resources must be 'sustainable', 'prudent', 'rational', 'wise' or 'appropriate'.[133] Another relevant principle is the precautionary principle in Principle 15 of the Rio Declaration, which "provides guidance for early and proactive action to avoid future environmental and health impacts or to conserve natural resources for future generations, even if knowledge of the nature, extent and probability of the impacts and cause-effect relationships is incomplete or uncertain."[134] In the context of nuclear back-end management, reducing waste by following the waste hierarchy approach would be in accordance with the precautionary principle, since less waste in landfills likely results in less damage to human health and the environment.

These international environmental principles are directly linked to responsible resource consumption and the protection of future generations, which are also the aims of the circular economy concept. The goal of international environmental law and the circular economy concept is, therefore, to create an economy which follows sustainable

[131] Rio Declaration of Environment and Development (1992) UN Doc. A/CONF.151/26 (vol. I), 31 ILM 874 (1992).
[132] World Commission on Environmental and Development, *Our Common Future* (United Nations Report, 1987) Paragraph 27.
[133] Edith Brown Weiss, 'In Fairness to Future Generations and Sustainable Development' (1992) 8(1) American University Journal of International Law and Policy 19; and Philippe Sands, *Principles of International Environmental Law* (2nd edn, Cambridge 2003) 253.
[134] German Environment Agency, *9 Principles for a Circular Economy* (Communication, 2020) 16, 17.

development practices. Consequently, they share the same objectives and there should be a clear link in the regulatory framework. It would deepen the integration of the common principles into the regulatory framework for the circular economy transition, contribute to reducing resource depletion and protecting future generations. This is supported by Song Guohui and Li Yunfeng, who found that national legislation and regulations should establish a clear link between environmental law and circular economy principles to strengthen the circular economy transition.[135] It is also in accordance with the opinion of the National Institute for Health and Environment ('RIVM') that drafting a "description of the national framework, including legislation on environmental protection […], can help clarify objectives and emphasise interlinkages between elements of the national program and different policy areas."[136] It would also address the EC's criticism by providing more guidance on how future generations can be protected. Simultaneously, it would promote nuclear energy's role in the circular economy transition and the application of sustainable practices in nuclear back-end management. The current Dutch regulatory framework does not establish such a link, which may hinder the circular economy transition.

It follows that the current Dutch regulatory system has significant limitations, which do not support the circular economy transition generally, and influence the role of nuclear energy in the transition. They also do not encourage the integration of Principles in nuclear back-end management to enhance nuclear energy's sustainability. Introducing legally binding targets for resource efficiency, including energy production as a strategy in the transition agendas, and establishing a clear link between

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[135] Song Guohui, Li Yunfeng, 'The Effect of Reinforcing the Concept of Circular Economy in West China Environmental Protection and Economic Development' (2012) 12(B) Procedia Environmental Sciences 785, 792.
[136] RIVM (n 19) 30.

environmental law and circular economy instruments, may address these limitations by providing legal incentives to reduce resource consumption and adverse environmental impacts, and protect future generations. The extent to which the specific Dutch regulatory framework for nuclear back-end management provides a basis for the circular economy transition is discussed in the subsequent section. First, the framework is outlined, before discussing general issues impacting the incorporation of the Principles into nuclear back-end management. Then, the possibility to adopt the circular methods identified in chapter 3 is analysed.

4.1.2. Decommissioning, Radioactive Waste and Spent Fuel

Directly relevant for nuclear back-end management is the regulatory framework for the decommissioning of nuclear power plants and radioactive waste and spent fuel management. The international legal basis for the Dutch system includes conventions and EU law, as well as non-binding IAEA Safety Standards. The Safety Standards include principles, requirements and measures to ensure safety. Guides provide further support to comply with the requirements.[137] These are soft-laws, which help members to fulfil their international law obligations.[138] Members can voluntarily integrate them into the national legal framework, which is an ongoing project in the Netherlands.[139]

On the national level, the Nuclear Energy Act ('Kew')[140] forms the regulatory basis for nuclear safety and radiation protection.[141] Governmental decrees provide more

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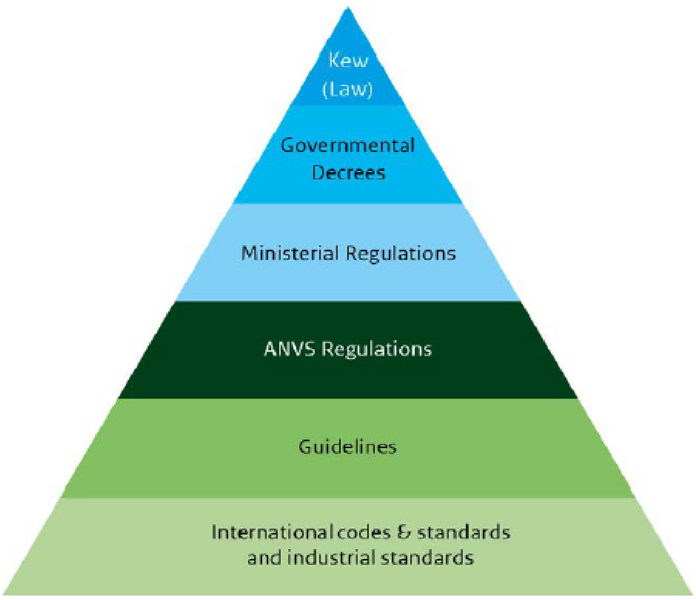
[137] IAEA, *Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities* (Safety Standards Guide, No. SSG-47) Background.
[138] Ibid.
[139] Ibid Foreword; and 'IAEA Mission Says the Netherlands Has Significantly Strengthened its Regulatory Framework' (IAEA, 26 November 2018) <https://www.iaea.org/newscenter/pressreleases/iaea-mission-says-the-netherlands-has-significantly-strengthened-its-regulatory-framework> accessed 23 August 2022.
[140] Kernenergiewet 1963.
[141] IenW (n 94) 33.

detailed regulations. Relevant are the Nuclear Installations, Fissionable Materials and Ores Decree ('Bkse'), and the Decree on Basic Safety Standards for Radiation Protection ('Bbs').[142] These include provisions on nuclear power plants, the handling of radioactive waste, and spent nuclear fuel.[143] Ministerial decrees provide further authoritative sources with even more detailed provisions. These are found in the licences for nuclear power plants issued by the Authority for Nuclear Safety and Radiation Protection ('ANVS').[144] The Safety Reports from nuclear installations are attached to their respective licences, and impose legally binding obligations upon operators.[145] The last two layers constitute the IAEA Safety Guidelines and further international codes and standards as illustrated in the figure 2 below, showing that the legal framework is based on the international documents.[146] The following figure visualises the hierarchy of the Dutch legal framework regulating nuclear activities.



The Hierarchy of the Dutch legal framework.[147]

[142] IenW (n 94) 33; and Besluit kerninstallaties, splijtstoffen en ertsen 1969 668/372 W.J.A.; and Besluit basisveiligheidsnormen stralingsbescherming 2017 IenM/BSK-2017/135624.
[143] IenW (n 94) 33.
[144] Ibid.
[145] EPZ, Veiligheidsrapport Kernenenergiecentrale Borssele VR15 (Safety Report, 2015) 1.1.
[146] IenW (n 94) 38.
[147] Ibid.

This framework has two general issues which may impact the incorporation of the Principles in nuclear back-end management and the circular economy transition. First, the regulations for the decommissioning of nuclear power plants give operators too much flexibility. On the international level, the only guidance is given by Requirement 8 in the IAEA Safety Standards for the Decommissioning of Nuclear Power Plants.[148] It leaves the choice of decommissioning strategy to the operator of nuclear power plants, but it must follow the national policies on nuclear waste management.[149] On the national level, the Bkse requires a detailed decommissioning strategy to be part of the licence, which must be reviewed and approved by the ANVS every five years during the lifetime of the nuclear power plant.[150] Rules on how the decommissioning should be conducted are not provided. Instead, Article 6 requires the decommissioning plan to reflect the 'most modern technologies'. This does not mean that the newest and most sustainable techniques should be used, but rather the most modern technologies for the specific decommissioning strategy. Vague provisions are included in the Safety Report for the Borssele nuclear power plant, which describe possible techniques that can be adopted in the decommissioning plan. These can include decontamination, dismantling, combustion, melting and evaporation pursuant to Paragraph 15.2.4.[151] This framework provides flexibility in the decision which decommissioning practices are adopted. It does not exclude the possibility of circular methods, and it even suggests techniques like decontamination and melting, which are compatible with the circular economy goals. However, it may give operators too much freedom in the decision, since the framework does not oblige nor encourage circular decommissioning practices. A certain, smaller degree of flexibility should remain.

[148] IAEA (n 137).
[149] Ibid 12.
[150] IenW (n 94) 18, 19.
[151] EPZ (n 145).

Nuclear power plants have unique characteristics which require detailed reviews of whether certain techniques would be possible. The best approach may be the establishment of a legally binding and, hence, according to Christina Ciliberto, Sita Mishra and Patrizia Ghisellini[152], stronger legal requirement obliging operators to adopt circular methods following the waste hierarchy approach which are most appropriate for their installations. The existing legal basis requiring the review and approval of the strategy by the ANVS every five years already provides an enforcement mechanism for such a new obligation. This would ensure the adoption of circular methods in practice and, hence, sustainable practices in nuclear energy generation, thereby enhancing the circular economy goals.

Second, with regard to radioactive waste, provisions are unclear and the authority's control is limited. International obligations rooted in the Joint Convention, the 2011 Directive, and the IAEA Safety Standards share the principle of minimising the generation of radioactive waste. This can be found, for instance, in Article 4(ii) and 11(ii) of the Joint Convention. On the national level, the 'national program on radioactive waste management' ('national program'), directly incorporates this principle of minimisation of radioactive waste in Article 10(2) Bbs and Article 40(a)(2)(a) Bkse.[153] The national program also includes the fundamental principle not to create undue burdens for future generations.[154] The integration of these two principles into the Dutch regulatory framework is a strong indicator for the presence of the circular economy Principles in radioactive waste management. It directly reflects

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[152] Ciliberto (n 103) 3261; and Mishra (n 120) 534; and Ghisellini (n 103) 12.
[153] 'Nationale programma radioactief afval' (Autoriteit Nucleaire Veiligheid en Stralingsbescherming) <https://www.autoriteitnvs.nl/onderwerpen/nationale-programma-radioactief-afval> accessed 17 August 2022; IenW (n 94) 3.
[154] IenW (n 94) 30, 31.

the Principle to minimise waste and pollution and the goal to protect future generations. Nevertheless, the legal instruments do not provide detailed policies, clear objectives, or outline good practices in preventing radioactive waste generation and protecting future generations. It must be clear how to apply the principles, to ensure the use of circular techniques in practice, which is not currently the case. This weakness in regulation has already been highlighted in different contexts by the EC and multiple reports.[155] France, for instance, explains how to implement the principle of minimising waste in practice, by emphasising the reuse and recycling as good practices.[156] Additionally, radioactive waste does not have to be managed following the waste hierarchy approach according to Article 2(1)(d) of the WFD. However, radioactive waste should also be managed pursuant to the waste hierarchy approach to limit the burden on future generations. Addressing these limitations would significantly aid the introduction of the Principles into the system of radioactive waste management regulation and enhance the transition to a circular economy by introducing further obligations for efficient resource consumption and protecting future generations. Furthermore, clear requirements to follow the waste hierarchy approach in radioactive waste disposal in the Dutch framework, as present for conventional waste according to the WFD and advised by Requirement 8 of the IAEA Safety Standards for the Predisposal Management of Radioactive Waste, would further enhance that goal.

Moreover, regulatory bodies lack control in enforcing radioactive waste management regulations. Currently, the ways in which this is achieved do not have to be approved by the authorities.[157] Paragraph 57 of the Borssele nuclear power plant licence ('EPZ licence') states that the progress on implementing waste prevention

[155] Oostdijk (n 127) 27; and RIVM (n 19) 30.
[156] RIVM (n 19) 30.
[157] Oostdijk (n 127) 26.

measures must be reported, but not approved, annually to the authorities. Hence, the government has limited control which must be addressed, as studies suggest that regulating authorities promote the circular economy transition.[158] The regulating body can ensure that the most circular methods for radioactive waste management are followed by operators, thereby promoting the circular economy transition, if they have the authority to approve or deny waste prevention measures. Additionally, such an obligation may also motivate operators to adapt more circular techniques from the outset. An obligation which would require operators to draft waste plans for the authority's approval was also suggested in a report evaluating the Dutch framework for radioactive waste management.[159] It follows that more control should be exercised by the regulators in how minimise radioactive waste is minimised. This would reduce the generation of waste as much as possible, protect the environment and future generations, and enhance the circular economy transition. This is especially important in light of recent ambitions to expand the nuclear energy sector in the Netherlands, as more sources of radioactive waste may be created.

The general limitations of the Dutch regulatory framework for nuclear back-end management allow for the adoption of voluntary practices reflecting the Principles, but significant improvements can be made to enhance the transition to a circular economy. Based on this legal framework, the following sections analyse to what extent specific provisions permit the application of the circular methods identified in chapter 3. From this, the extent to which the Dutch regulatory framework allows the circular economy transition can be established.

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[158] Ipek Kazancoglu and others, 'Circular economy and the policy: A framework for improving the corporate environmental management in supply chains' (2020) 30(1) Business Strategy and the Environment 590, 592.
[159] Oostdijk (n 127) 27.

4.2. Legal Options for Circular Practices in Nuclear Back-End Management

The methods identified in chapter 3 have the potential to enhance the sustainability of nuclear energy production and, ultimately, support the circular economy transition. The following analysis follows the waste hierarchy approach, as before, to identify whether the Dutch regulatory framework supports the incorporation of the three Principles.

4.2.1. Extending the Useful Life Materials

According to the findings in section 3.2.1, when nuclear power plants reach their planned decommissioning age, it should first be considered to extend the life of the plant. However, the Kew does not allow for such measures. Pursuant to Article 15(a)(1), the EPZ licence expires on 31st December 2033, and a licence application to extend operations of the nuclear power plant cannot be considered following Article 15(a)(2). By not allowing life extensions for nuclear power plants to maximise the useful life of materials, the current regulatory system does not enhance the transition to a circular economy. Discussions about a possible life extension of the Borssele nuclear power plant are ongoing, and a motion to amend the Kew in such a way as to allow life extensions if "the permit holder deems this technically and economically feasible" has been issued.[160] Such an amendment should be made to maximise resource efficiency and minimise the extraction of new raw materials. However, incorporating the economic feasibility of the life extension as a legal requirement may hinder the long-

[160] 'EPZ: Borssele kan langer in bedrijf, maar moet wel geld bij' (*Laka*, 15 September 2020) <https://www.laka.org/nieuws/2020/epz-borssele-kan-langer-in-bedrijf-maar-moet-wel-geld-bij-13869> accessed 17 August 2022; and Ministerie van Economische Zaken en Klimaat, *Brief over acties die zijn ingezet om uitvoering te geven aan het coalitieakkoord op het gebied van kernenergie* (Letter to Parliament, 2022).

term operation of nuclear power plants by establishing a compliance burden. It can be seen as a red tape, which was defined by B. Bozeman as a requirement with which compliance does not meet the objective of the rule.[161] The goal of a provision to allow for life extensions of nuclear power plants is to keep energy production running as long as reasonably safe. The technical feasibility requirement directly contributes to this aim, by ensuring that the technical components can provide the necessary safety. The economic feasibility requirement does not contribute to this goal. Other countries have not included economic requirements in their regulations for the life extension of nuclear power plants. For instance, in Canada, Subsection 24(4) of the Nuclear Safety and Control Act states that licences can only be renewed if the applicant "(a) is qualified to carry on the activity […]; and (b) will, in carrying on that activity, make adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security and measures required to implement international obligations to which Canada has agreed."[162] The US also allows life extension on the basis of 10 Code of Federal Regulations ('CFR') Part 51 and Part 54, according to which an infinite number of applications for the renewal of nuclear power plants' operating licences by up to 20 year can be made.[163] For a successful application, the operators must "prove that the effects of ageing on certain plant structures and components will be adequately managed."[164] The two examples demonstrate good practices which focus on the goal to allow operations as long as it is safe, and do not have economic requirements. Nuclear power plant operators must have the possibility

[161] B. Bozeman, 'A Theory of Government "Red Tape"' (1993) 3(3) Journal of Public Administration and Research Theory 273; and Izhar Che Mee, Haim Milman, 'A Visual Framework for Identifying Sources of Unnecessary Regulatory Burdens on Business' (2015) 12(1) Advances in Global Business Research 878, 879.
[162] Nuclear Safety and Control Act S.C. 1997, c. 9.
[163] Code of Federal Regulations (1995).
[164] May Fawaz-Huber, 'Going Long Term: US Nuclear Power Plants Could Extend Operating Life to 80 Years' (*IAEA*, 16 January 2018) <https://www.iaea.org/newscenter/news/going-long-term-us-nuclear-power-plants-could-extend-operating-life-to-80-years> accessed 17 August 2022.

to prolong the lifetime of the plants if considered safe to extent the useful life of materials. Hence, the current system does not allow for the most efficient use of resources. By allowing and promoting a high degree of decontamination and reusing, this limitation of the regulatory framework could be balanced out to some extent, since these are other methods to extent the useful life of materials, although lower in the waste hierarchy.

The analysis in chapter 3 demonstrates that as many buildings, structures, components, equipment, etc. must be decontaminated for an efficient use of materials. However, decontamination is not a subject in any acts or decrees. The Safety Report attached to the EPZ licence, introduces the operator's duty to decontaminate 'nuclear systems' in Section 15(1).[165] There is no clear definition of the term, but it suggests that only technical systems, such as the production and control system, are covered by this obligation. This is arguably too narrow, as it excludes the obligation to decontaminate materials to enable their reuse. Consequently, although operators can choose to adopt more circular practices, there are no legal incentives to do so. While this does not hinder the circular economy transition, more can be done from a legal perspective to advance the integration of the Principles. Mandatory obligations may be one solution as explained previously,[166] which other countries have introduced. For instance, US law 10 CFR 50.51 (b) (1) obliges operators to "decontaminate the *facility*". Another example is the definition of 'decommissioning' in Canada, which includes the "decontamination […] of *some or all structures, systems and components*."[167] Both

[165] EPZ (n 145).
[166] Ciliberto (n 103) 3261; and Mishra (n 120) 534; and Ghisellini (n 103) 12.
[167] Regulatory Document REGDOC-2.11.2, 'Decommissioning' Glossary <http://www.nuclearsafety.gc.ca/eng/acts-and-regulations/consultation/comment/regdoc2-11-2.cfm> accessed 17 August 2022.

jurisdictions offer a broader term of materials that must be decontaminated during the decommissioning of nuclear power plants. Following such a broader approach to decontamination obligations of operators in the Netherlands would significantly increase the materials that can be reused or recycled, thereby maximising resource efficiency and minimising the generation of waste.

The integration of the Principle to extent the useful life of materials is further hindered by the Bkse, which does not allow the reuse, repurposing, or redevelopment of buildings and structures of nuclear power plants. Pursuant to Article 30(a)(1), the decommissioning aims at removing all systems, structures and components from the site, to re-establish a 'green field' which can be suitable for any future use. This means that there cannot be any remains of the nuclear power plants left on the site. The authority may deviate from this provision in special circumstances according to Article 30(a)(2). It is, however, unclear what these special circumstances are.

On the one hand, it can be argued that the re-establishment to a green field allows the natural system to regenerate and is, therefore, coherent with the third circular economy Principle. On the other hand, this does not allow the buildings and structures to be used as efficiently as possible. Buildings and structures that can still be used must be demolished, which is in direct conflict with the Principles to extend the useful life of materials and minimise waste as much as possible. Following the waste hierarchy approach, the regulatory framework should opt for the most circular option. First, the useful life of materials should be extended before minimising waste and pollution and regenerating natural systems. Consequently, this provision hinders the adoption of the most circular method, and addressing this would enhance the circular economy transition more than the current framework.

Other countries allow the reuse and repurposing of nuclear power plants. For instance, the Pacific Northwest B Reactor in the US has been converted into a museum.[168] The turbine hall of the Bohunice nuclear power plants in Slovakia has been repurposed to a radioactive waste and metal treatment facility, and other buildings will be used as part of a waste management system.[169] Another EU example is the reuse of the R1 Reactor in Sweden, which is being used as a theatre and for other art and entertainment events.[170] The Netherlands should reconsider its regulation, since allowing the reuse, repurposing and redevelopment of nuclear power plants could significantly enhance the circularity in the construction sector, which consumes 50% of all raw materials in the Netherlands.[171] This should especially be considered since the decommissioning of the Dodewaard nuclear power plant has not started yet. It may be interesting for the redevelopment to a new nuclear power plant in line with the government's plans to expand nuclear power production in the country, as the best option for redevelopment is often to reinstate the original use of the site.

Furthermore, the regulatory framework should actively encourage the reuse of decontaminated or lightly contaminated materials pursuing IAEA recommendations.[172] Currently, this is not subject to regulation. Addressing this by introducing new policies would reduce manufacturing needs and waste and pollution generation, and influence the capability to enhance nuclear energy's and the economy's circularity.[173]

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[168] IAEA (n 73) 26.
[169] Ibid 27.
[170] Ibid 52.
[171] 'Accelerating the transition to a circular economy' (*Government of the Netherlands*) <https://www.government.nl/topics/circular-economy/accelerating-the-transition-to-a-circular-economy> accessed 17 August 2022.
[172] IAEA, *Policies and Strategies for the Decommissioning of Nuclear Radiological Facilities* (Nuclear Energy Series, No. NW-G-2.1) 11, 12.
[173] Gillin (n 27).

The prohibition to extend the life of nuclear power plants and to reuse buildings and structures of the facilities, in combination with weak decontamination provisions and no incentive to reuse other materials, can result in large amount of conventional and radioactive waste. To extend the useful life of materials and reduce the volume of waste, chapter 3 found that clearance may be a circular solution to incorporate both principles into the regulatory framework. The European Directive 2013/59/Euratom permits the use of the clearance concept if basic safety standards are met.[174] In line with this Directive, the Netherlands introduced a specific clearance mechanism for radioactive waste in 2018, with which exemptions from regulation can be granted for specific actions if there is low exposure to ionising radiation.[175] There is also an option in which materials with higher radiation than the set levels can still be classified as general waste, which is called specific clearance.[176]

The availability of the clearance concept in the Dutch regulatory framework suggests that the useful life of materials is extended, if cleared for restricted or unrestricted use, while also integrating the principle of minimising waste and pollution. However, a report from the RIVM suggests that issues in the distinction between conventional and radioactive waste and materials impact the release of such substances.[177] This may have an effect on the adoption of the clearance concept and limit the effectiveness of this circular method. A research study on how the clearance concept is used in practice is expected to be published in 2023, which could add important insights to this discussion.[178]

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[174] Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom [2013] OJ L13/1.
[175] Oostdijk (n 127) 13.
[176] IenW (n 94) 16.
[177] RIVM, *Regelgeving conventionele en radioactieve afvalstoffen: vergelijking van begrippen en voorschriften* (Report, 2018) 6.
[178] Personal communication from IenW to author (7 July 2022).

It follows that the regulatory framework mostly hinders the adoption of the Principle to extend the useful life of materials. The clearance mechanism is insufficient, and the regulatory system should provide more room for circular methods. It contributes to the combatting of resource depletion or environmental damage only to a small extent, by not preventing the generation of waste. Consequently, the amount of waste generated is larger than necessary, putting a burden on future generations to manage the long-lived waste. This is in direct conflict with the aim to protect future generations, which is a fundamental principle of the regulatory framework and must be better incorporated into the national framework according to the criticism of the EC.[179] To mitigate this weakness, the regulatory framework must have good mechanisms to minimise waste and pollution, to still enhance the sustainability of nuclear energy and the circular economy transition. While the clearance concept also minimises the amount of waste that must be stored, this is not enough to reduce waste to the largest extent possible.

4.2.2. Minimising Waste and Pollution

Recycling methods for radioactive waste exist and are practised in the Netherlands.[180] These include, for instance, smelting contaminated steel, which produces reusable steel and a residual radioactive product.[181] Conventional waste must be separated in accordance with Paragraph 58 of the EPZ licence to facilitate the recycling of the materials. It is then recycled through the conventional route pursuant to the WFD and the National Waste Management Plan, which is based on the waste

[179] Oostdijk (n 127) 27; and RIVM (n 19) 30.
[180] IenW (n 94) 23.
[181] Ibid.

hierarchy approach.[182] The use of recycling methods in practice constitutes a good step towards circular nuclear energy generation and the enhancement of the circular economy transition, as waste is minimised. However, authoritative sources do not include legally binding or non-binding obligations for the operator to recycle contaminated materials, nor are there requirements to decontaminate materials to allow for their recycling. The framework merely obliges the separation of contaminated and non-contaminated materials. An additional problem may be caused by the unclear distinction between radioactive and conventional waste and materials, which the RIVM identified.[183] The ambiguous definitions may result in waste and materials that are labelled as radioactive substances which do not have to be recycled, thereby limiting the effectiveness of the requirement to separate radioactive and conventional substances in practice.

This regulatory system does not follow the IAEA recommendation to recycle decontaminated or lightly contaminated materials.[184] Some recycling methods are used in practice, but mandatory provisions can have a much stronger effect than voluntary commitments to support the circular economy transition.[185] Legally binding obligations could ensure that the maximum amount of contaminated waste is recycled and would promote the generation of secondary raw materials, thereby reducing the volume of waste that must be disposed of. It would also ensure the continuation of this circular practice in the future.

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[182] 'National Waste Management Plan' (*Rijkswaterstaat*) <https://lap3.nl/service/english/> accessed 17 August 2022.
[183] RIVM (n 177) 3.
[184] IAEA (n 172) 11, 12.
[185] Ciliberto (n 103) 3261; and Mishra (n 120) 534; Ghisellini (n 103) 12.

Spent fuel can be recycled by reprocessing. Pursuant to Recital 20 of the 2011 Directive, the Netherlands has sovereignty in deciding whether to define spent fuel as a resource which may be reprocessed, or as nuclear waste which is directly disposed of. These two options are passed on to operators of nuclear power plants.[186] In practice, spent nuclear fuel from the Borssele nuclear power plants is sent to France for reprocessing.[187] This reflects the Principle to minimise waste, since 95% of the spent fuel is being reused instead of being disposed of directly.[188] As the components which are responsible for the long decay period have been separated from the final waste, the waste stored at COVRA has a shorter decay time.[189] It significantly reduces the volume of radioactive waste and creates secondary raw materials that can be used instead of new fuel.[190] Therefore, the current practice enhances the circular economy transition by maximising resource efficiency and minimising waste. Nevertheless, a legally binding obligation upon operators to reprocess spent fuel would ensure that this circular practice is also conducted in the future.

For radioactive waste and spent fuel that cannot be recycled, decay storage is the next best circular method, as found in chapter 3. The Netherlands has special decay storage regulations in place. First, the waste storage facility COVRA may store unprocessed radioactive waste for up to 50 years.[191] Within this time period, radioactive waste that decays below the clearance level may be reused. Second, Article 10.7(4) Bbs allows radioactive waste to be stored at the producing facility for a maximum of two years if the time it takes for the waste to half its radioactivity is less than 100 days.

[186] IenW (n 94) 33.
[187] Ibid 24.
[188] Ibid.
[189] Ibid.
[190] IenW (n 95) 84.
[191] Ibid 23.

Paragraph 45 of the EPZ licence extends the exemption, by stating that the two-year maximum storage can be deviated from when a report finds that a longer period is necessary. This is not referred to as decay storage, but it fulfils the same purpose. Similarly, although not called decay storage, before the planned final deep geological disposal, waste is stored for at least 100 years in long-term interim storage at COVRA, which has the same benefits as decay storage. During this time, some radioactive waste can decay to clearance levels, and may be reused instead of disposed of in the final repository.[192] These three legal instruments encourage the generation and reuse of secondary raw materials, which minimises the overall waste which must be permanently stored.[193] Hence, it aligns with the Principle to minimise waste and enhances the circular economy transition. However, there is no regulatory obligation to actually recycle materials that lost their radioactivity after decay storage. Such an obligation would ensure that circular waste management methods are used after decay storage.

It follows that the regulatory framework allows for the practice of circular methods in line with the principle to minimise waste and pollution. The circular methods are practiced mostly voluntarily which reduce the volume of radioactive waste generated. Decay storage is regulated, but there is no obligation to actually recycle materials after they decayed. Legally binding obligations could improve the system by imposing requirements to maximise resource efficiency as much as reasonably possible. The obligation can be incorporated into the regulatory framework as a mechanism to protect future generations, thereby addressing the EC's criticism, as explained

[192] IenW (n 95) 23; and IenW (n 94) 25.
[193] IenW (n 95) 23.

previously.[194] This would increase nuclear energy's sustainability and enhance the circular economy transition to a greater extent than the current regulatory framework. Before reaching a conclusion to what extent the Dutch regulatory framework allows for the circular economy transition, the incorporation of the last Principle to regenerate natural systems must be analysed.

4.2.3. *Regenerating Natural Systems*

As mentioned in section 3.4, the regenerating natural systems implies that practices in the circular economy should aim to restore environmental damage.[195] Contaminated soil remediation legislation has only been adopted in a few countries, of which the Netherlands is one.[196] The Soil Protection Act Sections 36 to 55 impose detailed obligations for the remediation of soil, and Sections 55(a) and (b) include special provisions for the decontamination of industrial sites.[197] Nuclear power plant sites are not excluded from the scope pursuant to Article 99. The system establishes target and intervention values for certain metals for soil, which are used to determine the soil quality and whether there the soil is compromised for humans, animals or plants.[198] This legislative basis shows the strong commitment of the Netherlands to restore contaminated soil to let the natural system regenerate. Therefore, the current regulatory framework for restoration already reflects the Principles, and promotes the circular economy transition.

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[194] Oostdijk (n 127) 27; and RIVM (n 19) 30.
[195] Morseletto (n 42) 767, 768.
[196] Bini (n 99) 1.
[197] Wet bodembescherming 1986.
[198] Bini (n 99) 3.

4.2.4. Concluding Observations

In conclusion, it can be observed that the regulatory framework mostly hinders the adoption of the Principle to extend the useful life of materials. Similarly, although not prohibited, circular methods to minimise waste and pollution are not legally required nor encouraged. Clearance and decay storage are specifically regulated, but these too have limitations. The effectiveness of the circular methods falling under these two principles that are practiced may be implicated by the recycling framework for conventional waste. For this, a separate in-depth analysis is necessary, which is outside the scope of this thesis. The restoration of contaminated soil to regenerate natural systems is the only circular economy method which fulfils its full potential. Consequently, although the Dutch regulatory framework allows the adoption of circular methods to a small extent, it does not maximise nuclear energy's sustainability as much as it could. Especially circular back-end strategies at the top of the waste hierarchy should be better supported by the regulatory framework. Hence, more can be done from a legal perspective to enhance the circular economy transition and achieve the government's goal of a circular economy by 2050. Interviews conducted by a consultancy company with stakeholders illustrate similar findings.[199] It was found that there are possibilities for adopting Principles in the management of radioactive waste. However, due to the strictness and inflexible framework, these methods are not further explored. [200]

Addressing the discussed limitations and following similar approaches to the good practices of other countries discussed can help to achieve the goal of a circular economy. However, research into innovative technologies is also important to drive the transition to a circular economy in areas where circular practices are not possible yet.

[199] Oostdijk (n 127) 26.
[200] Ibid.

The Dutch research programs are explained in Appendix E.2 of the national program.[201] These concern merely studies related to the disposal of radioactive waste, including national and multinational deep geological disposal. It is an important component of the radioactive waste regulation.[202] This reflects the most circular long-term disposal solution for radioactive waste that exists today as explained in section 3.3, since retrievability is included as a condition in the regulatory framework for radioactive waste management in final disposal methods.[203]

The Netherlands is also involved in European research for shortening the lifespan of radioactive waste, including transmutation and partition. This means that research into innovative technologies that could significantly enhance the transition to a circular economy where long-lived radioactive waste is minimised is being conducted.[204]

Nevertheless, research programs do not cover alternatives for radioactive waste management or the decommissioning of nuclear power plants.[205] There is no research being conducted into the potential to reuse or treat radioactive waste, which is essential for the circular economy transition. Other countries such as Finland and France cover these topics pursuant to Chapter 6 and Appendix 1 of the national programs respectively.[206] Additionally, there are no indications that the Netherlands is researching or considering the possibilities of reactors with breeder fuel cycles, which would significantly improve the efficient use of the fuel and reduce the consumption of uranium and plutonium as raw materials. Including these areas of research into the

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201 RIVM (n 19) 39, 40.

202 'Waste' (*NucleairNederland*) <https://www.nucleairnederland.nl/en/themes/waste/> accessed 17 August 2022; and 'Deep Geological Disposal' (*COVRA*) <https://www.covra.nl/en/radioactive-waste/deep-geological-disposal/> accessed 17 August 2022.

203 IenW (n 94) 29.

204 'Radioactief afval' (Autoriteit Nucleaire veiligheid en Stralingsbescherming) <https://www.autoriteitnvs.nl/onderwerpen/radioactief-afval> accessed 17 August 2022.

205 RIVM (n 19) 39, 40.

206 Ibid.

national program may result in new techniques to enhance nuclear energy's sustainability and the circular economy transition.

5. Conclusion

The circular economy concept has been introduced at the EU and national levels in response to the ongoing depletion of the earth's resources. Simultaneously, it is also a strategy to combat climate change. Implementing the circular economy Principles into regulatory systems can promote efficient resource consumption and mitigate adverse environmental effects, which protects the interests of future generations.

The literature review illustrated that academics recognise the important role the Principles can have in guiding the transition to greener energy sources in connection to renewable energy sources. However, such a connection is not established to nuclear energy, which can and should be done. Nuclear energy has the potential to enhance the circular economy transition and contribute to the circular economy goals by providing a sustainable energy source. Waste and pollution cannot be eliminated, and new raw materials are still required, but the incorporation of the Principles into nuclear back-end management can significantly minimise waste and pollution, extend the useful life of materials to allow more efficient resource consumption, and allow natural system to regenerate. Hence, the Principles can considerably improve the sustainability of nuclear energy production, which would enhance the circular economy transition. These findings offer a new strategy to address the issues of global concern.

To allow the theoretical benefits to be experienced in practice, supporting regulatory frameworks are necessary. The analysis demonstrates that the Dutch regulatory framework for nuclear back-end management only allows the practice of circular methods to a small extent. There are significant limitations to the framework's general structure and specific provisions, which do not encourage, and even hider, the application of the Principles in nuclear back-end management. Consequently, the Dutch regulatory framework does not provide an adequate basis for the transitioning to the circular economy. The Dutch authorities should review the regulatory framework in order to achieve the goal of a circular economy by 2050. This is especially important since the government announced the building of new nuclear power plants to help achieve decarbonisation goals.

These findings highlight the importance of introducing nuclear energy in academic and regulatory debates regarding strategies for the circular economy transition. This research is a starting point, by demonstrating how the application of the Principles in nuclear back-end management can enhance nuclear energy's sustainability and the circular economy transition. It provides a theoretical framework for other IAEA member countries on how circular strategies can be incorporated into legal systems to further the circular economy transition. This thesis should fuel further discussions and research to allow nuclear energy to be an enabler for the circular economy.

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