



Original research article

What is nuclear cultural heritage? Developing an analytical framework

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ARTICLE INFO

Keywords:

Nuclear cultural heritage
 Energy culture
 Imaginaries
 Place attachment
 Remembrance

ABSTRACT

Nuclear cultural heritage (NCH) is a relatively new approach. It was introduced by Rindzevičiūtė (2019) and is being discussed internationally with reference to its contribution to knowledge preservation of nuclear objects and practices as well as safety aspects, especially in the context of nuclear waste governance. The latter includes knowledge transfer to future generations in the sense that knowledge of nuclear objects and practices might be further developed and could be applied as well in future. This is particularly relevant as nuclear technology is hazardous to the living environment and endures for very long periods of time. The great impacts on landscapes and the living environment are demonstrated by experiences with nuclear accidents, nuclear weapon tests, the storage and disposal of nuclear wastes, and uranium mining. One reason for the upcoming interest in NCH is the decommissioning of nuclear power plants and siting and construction of nuclear waste repositories. With this article, we aim to provide an analytical framework for understanding, identifying and studying NCH. Firstly, we discuss the specificities of NCH in reference to cultural heritage and overlaps with or added values of related approaches. This includes energy cultures, sociotechnical and spatial imaginaries as well as concepts related to place and remembrance. We then specify four key elements as part of a broader conceptualization of NCH: temporality, spatiality, (im)materiality, and institutionalization. These are central to the analytical framework that is presented, in a final step, with notes on possible methodological approaches.

1. Introduction: The issue of nuclear cultural heritage

Broadly conceived, cultural heritage relates to those places, objects, and knowledge from the past that warrant protection and conservation. While initially there was a particular interest in the preservation of monuments and specific sites (e.g., UNESCO world heritage sites such as the Aachen cathedral or the historic centre of Krakow¹), cultural heritage is now understood as a heterogeneous collection of 'objects, people, places, practices, pronouncements, bureaucratic apparatuses' as well as 'various people, institutions, apparatuses (dispositifs) and the relations between them' [2]. Ashley and Stone [3] also add 'arts, popular culture, media' to the scope of cultural heritage. It therefore includes material

artefacts,² and what is referred to as 'intangible cultural heritages,' defined by UNESCO as 'the practices, representations, expressions, knowledge, skills [that are] recognize[d] as part of ... cultural heritage' [6–8]. While there are many varying definitions of cultural heritage both in academic and policy contexts, there are overarching similarities in the definitions, including the fact that so-called 'heritage values' are constantly evolving based on social perception, they are consistently produced and reproduced, and can have both tangible and intangible as well as natural and man-made attributes i.e., artefacts. In the development of a cultural heritage, various actors³ identify that which is at risk of loss and assign value to certain material and immaterial elements that are hence in need of protection and conservation. Cultural heritage does

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E-mail addresses: m.mbah@oeko.de (M. Mbah), v.noka@oeko.de (V. Noka), a.lampke@oeko.de (A. Lampke), r.kelly@oeko.de (R. Kelly), sophie.kuppler@kit.edu (S. Kuppler).¹ Both received world heritage status at the 2nd annual session of the World Heritage Committee in 1978 [1].² Artefacts are, in a narrow sense, all artificial (material) objects produced by humans [4]. In a broader sense it is understood as every result of human actions including meanings [5]. We understand artefacts in this paper rather narrowly such that they include all material objects produced in social debates referring to nuclear technologies, e.g., museums, archives, symbols, memorials as well as texts, films, etc.³ These various actors involved in the development and construction of cultural heritage include political institutions, civil society, scientists, and activists, amongst others.

not simply exist but is rather an ongoing value-producing process that actors 'do' and through which these actors continuously negotiate their power to interpret the past [9,10]. Cultural heritage is, therefore, both a technical and managerial practice as well as a cultural and political one [11]. It is an ongoing process rather than an 'end product' [12] that includes continuous categorising, curating, conserving, and communicating.

Although Heritage Studies has engaged specifically with (nuclear) waste on occasion [13,14], 'the nuclear' is not necessarily or obviously related to cultural heritage. The only UNESCO World Heritage Site currently listed with an explicit connection to the nuclear is the Bikini Atoll, a coral reef in the Marshall Islands used as nuclear weapons testing sites between 1946 and 1958 [6]. This does not mean, however, that the heritagization of other (and more diverse) nuclear sites is not taking place. The Erzgebirge/Krušnohoří Mining Region in Germany and Czechia, for example, was inscribed as a UNESCO World Heritage Site in 2019 and includes the uranium mine shaft 'Schacht 371'. It is managed by the Wismut Foundation which is responsible for preserving the history and heritage of the uranium mining activities in the region.⁴ This is just one of many examples in which nuclear cultural heritage (NCH) is already being put into practice, even if it is not explicitly named as such.

In comparison to cultural heritage, *nuclear* cultural heritage (NCH) is a relatively new term and defined by Rindzevičiūtė [15] as the practice of 'collecting, storing, archiving, preserving and caring for representative artefacts of nuclear material culture, mapping and safeguarding sites, preparing and selecting documentation, recording intangible practices, and establishing and keeping new archives'. It includes the preservation of objects and practices 'that are significant for not only the history of nuclear science and technology, but also for the history of industry, the military, and anti-nuclear social movements' [16,17]. The aim of this paper is to further establish NCH as an analytical concept and highlight the merits of this conceptualization in the context of nuclear energy production and nuclear waste governance. We argue that there are many implicit links to other related approaches that should be explored further, in order to provide a more comprehensive understanding of NCH. We focus on making explicit the added value of integrating these related approaches into NCH to strengthen the definition and understanding of it. We argue that this is relevant to developing a framework of analysis for NCH, which contributes to strengthening long-term safety (culture) [18,19].

We aim to further solidify the merits of an explicit NCH, arguing that the specificities of the nuclear, particularly in relation the longevity and often invisibility of its dangerous materialities, need to be differentiated from other cultural heritages. This is because 'the nuclear' is, on the one hand, both abstract and intangible, particularly when thought of as the presence of radiation and how it is constantly evolving as radioactivity decays and, for example, the nuclear inventory underground changes. It is, however, also bound to specific sites, architectures, and natural landscapes, as well as alive in the knowledge and practices of workers, activists, and political discourses. Moreover, nuclear energy is characterized by multiscale networks due to the different sites of uranium mining, energy production, reprocessing and final disposal; NCH is also characterized in this way because of the involvement of multiple actors at different scales and the importance of local, regional, national and international discourses and events [20]. This duality of the nuclear means that any form of management or remembrance must be able to bridge these modalities. At the same time, Alexis-Martin et al. [21] have argued that spaces are produced as nuclear through more than the mere presence of radioactivity or nuclear infrastructure. They draw on Hecht's [22] term 'nuclearity' to highlight how spaces are constructed as nuclear – they are nuclear not only because one or several object(s) of the nuclear industry, but also actors and agency (e.g., via debates and discourses) are present. Nuclearity is something that 'is revealed during

negotiations and tensions or frictions between actors' [23]. This coincides with the unique long-term governance issue of 'the nuclear,' whereby knowledge of nuclearity is required to remain capable of acting. Since nuclearity is also culturally, socially, and politically charged nuclear waste governance benefits from the heterogenous and holistic approach of cultural heritage. Cultural heritage is uniquely positioned to deal with the future-orientedness necessary for the knowledge preservation of nuclearity.

Indeed, in research on heritage futures, Harrison [2] has argued that nuclear waste has a certain 'material and discursive legacy, the governance of which is, like heritage, oriented towards the construction of particular kinds of actual and imagined futures' [2,13,14]. In making decisions about preservation, heritage practices articulate an imaginary of the future. In the context of the civil use of nuclear energy as a source of energy, this includes visions of and for future waste governance and energy systems. Nuclear waste governance in particular is confronted with the issue of long-term knowledge preservation and transfer to guarantee the safety of nuclear wastes, i.e., by having the ability to make informed decisions in case an unintended event occurs [10,19]. Pescatore and Palm [24] offer strategies in this context for preserving records, knowledge and memory of nuclear energy (RK&M), which includes an active cultural heritage. This characteristic of future-orientedness shows that heritage work is just as much about conserving the past (and the present) as it is about making futures [24]. Harrison [13] describes heritage as a 'future-assembling practice' in the sense that work is put into assembling and caring for the future.

However, clearly identifying what nuclear objects, sites, practices, and knowledge are part of a nuclear heritage, how it develops and who has the right to interpret and declare it as such is particularly difficult as many different actors are involved against the background of controversial societal debates. The NCH approach brings together cultural, political, societal, industrial, and technological aspects which can help identify interdependencies [25,26]. It includes material cultures, pop-cultural representations, art, and other practices that are understood as 'culture' such as organization, architecture, landscapes and seascapes, social movements, and politics [27]. It is important that NCH reflects these complexities and not just reframes these 'as a sign of past national glory, for example by labelling it as 'heritage' with positive 'connotations' [28]. Therefore, we define NCH as a practice which is temporal and dynamic, an active process, not (necessarily) a product and can be perceived as both positive and negative. Hereby, social perceptions and actors play an important role in maintaining cultural heritage, but also in creating, recreating, and discarding it.

In the following section, we first introduce our methodological approach before examining the related concepts that support our conceptualization of NCH: energy cultures together with socio-technical and spatial imaginaries, as well as place attachment and remembrance. In section four, we present our understanding of NCH which integrates these related approaches and an analytical framework for studying NCH.

2. Methodological approach and conceptualization

Since NCH is still an emerging field, the aim of our approach is to focus on a 'meta-frame' that could capture the analysis of developing heritages. This was particularly important because NCH is discussed in a wide field of disciplines from different angles. Contributions range from the disciplines of heritage studies, history, geography, architecture, political sciences, and art, focusing on aspects such as architecture as a monument, landscape transformations, narratives and the role of civil society. By widening the scope of literature examined in the context of NCH, we aim to present this very particular heritage in its heterogeneity. These conceptual approaches are then distilled into an analytical framework, the aim of which is to help the study and analysis of NCH (see Fig. 4). We acknowledge that frameworks generally can be limiting when applied too rigidly and therefore provide this as a tool which enables the emphasis to be placed on chosen aspects. These aspects can

⁴ <https://www.wismut-stiftung.de/>, last accessed February 7, 2025.

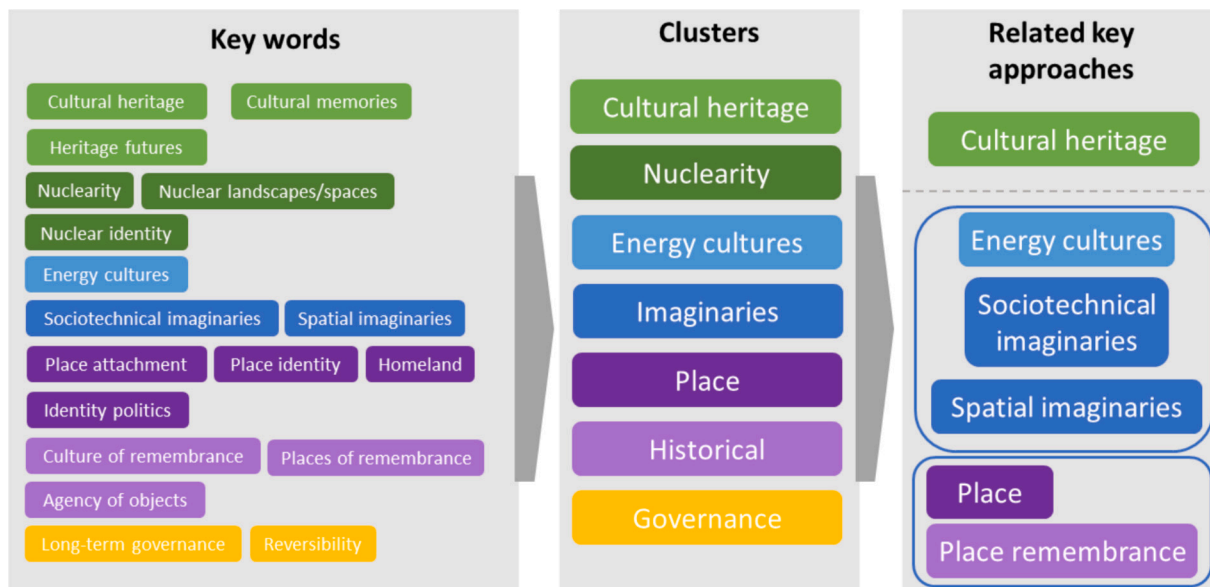


Fig. 1. Process of the literature review.
(Source: Own depiction.)

be amended or expanded as necessary, not limiting the methods that can be applied to study it. It needs to be taken into account that several studies working with this framework will not be comparable with each other as methods being used might vary.

To further conceptualize and develop a framework for analysis of NCH, an extensive literature review was therefore conducted. Firstly, a small number of key papers referring explicitly to NCH were identified based on a keyword search on Scopus and Google Scholar. Secondly, based on this literature, a range of related approaches were identified and grouped into seven clusters (see Fig. 1). In this process, we put an emphasis on identifying recent publications (from 2017 to 2023) and the search results were filtered based on their relevance to NCH by means of a scan of the titles, keywords, and abstracts.

Literature from the cultural heritage and nuclearity clusters on the one hand provided a basis for understanding what constitutes cultural heritage, but also helped to draw out the specificities of a *nuclear* cultural heritage. This was the basis from which we further conceptualised NCH. Approaches related to energy cultures, imaginaries, and place were identified to be particularly helpful in this regard. Additionally, work on places of remembrance was included to bridge the clusters place and history. Other identified literature in the history cluster was either already covered by cultural heritage or was too broad for the scope of this review.⁵ While making connections between governance and NCH, we argue that this is primarily related to the potential policy application of NCH and goes beyond the scope of a conceptualisation of the concept NCH.

It should be noted, however, that although the literature reviewed was extensive, there are limits to the method. Non-English language publications, with the exception of German publications, were not considered, for example, and our respective research backgrounds inevitably guided the keyword search. Nonetheless, the variety of literature that we consider provides valuable insights into the further development of NCH.

As there are several overlaps between the identified approaches, we discuss first energy cultures and spatial and socio-technical imaginaries together before moving on to the role of place and remembrance. We

will discuss the relevance and potential contribution to analyzing NCH of these approaches in the next section.

3. Linking the past with the future: Further conceptualizing nuclear cultural heritage

Energy cultures and socio-technical and spatial imaginaries are introduced as distinct yet interconnected approaches that help bridge developments from the past to the future through NCH. These perspectives enable a deeper understanding of the processes of institutionalization through narrative construction while also incorporating place-specific aspects of energy cultures. By disentangling these approaches, we emphasize their respective contributions: energy cultures foreground the social, material, and behavioural dimensions of energy systems, while socio-technical and spatial imaginaries provide insights into the ways in which visions of ‘the nuclear’ shape policies, discourses, and governance structures. Additionally, place and remembrance are considered to provide insights into the different scales involved, particularly the local and regional scales, but also to better understand the relationality⁶ of NCH as well as the role of landscape transformations, perceptions of infrastructures and identities.

3.1. The role of energy cultures and imaginaries

Energy cultures refer to the co-evolution of material infrastructures, social behavior patterns, and interpretations in relation to energy production, all of which influence one another and co-constitute specific ‘energy cultures’ [30,31]. These cultures are ‘both practiced and imagined’ [32], meaning that they are shaped by tangible energy systems and the discursive framings surrounding them.

With energy cultures the entanglement of social and technical aspects in the energy system is meant. They are described as the ‘social relations in the energy system’ which are expressed spatially through physical expressions of the energy system (artefacts) at different scales, rely on power relations and are transformative [33,34]. A focus on

⁵ Work on the cultures of remembrance, for example, were in the German context exclusively related to World War II, the Nazi regime, or related historical events.

⁶ Here, relationality means that, with regard to nuclear energy, different spatial references and scales are addressed, i.e., both material objects in specific places and social practices related to them sometimes far away, which open up a relational space [21,30].

energy cultures (rather than energy systems) extends beyond technological configurations and includes how energy is collectively understood, discussed, and debated, revealing fundamental societal values regarding power, control, and agency [33,35].

Part of these understandings are imaginaries—both socio-technical and spatial—which are widely referenced in the context of energy technologies. Socio-technical imaginaries refer to collectively held visions of desirable futures that are intertwined with technological advancements and governance structures [36,37]. These imaginaries shape policy decisions, public expectations, and institutional trajectories, thereby influencing the long-term governance of energy infrastructures. In contrast, spatial imaginaries focus on localized visions of the future [38], emphasizing how communities conceptualize and negotiate transformations in their energy landscapes, for example.

Nuclear culture represents a specific category of the energy culture concept that is uniquely shaped by the political, ideological, and technological frameworks as well as imaginaries surrounding nuclear energy (futures). Unlike other energy cultures that develop primarily through economic and infrastructural factors, nuclear culture is deeply entwined with broader geopolitical narratives, public perceptions of risk, and the long-term implications of radioactive waste governance [19,39].

Historically, nuclear power served as a symbol of modernity, national progress, and economic development. Such imaginaries have historically justified the expansion of nuclear energy infrastructures, embedding them within broader societal narratives of technological advancement [36,40] particularly during the Cold War era [41]. The Geneva Conference in 1955 was the starting point for introducing nuclear power as the only option for meeting the growing energy demands as a requirement for economic and social prosperity [42]. In the USA nuclear power was narrated as ‘electricity too cheap to meter’ and as ‘atoms for peace’⁷ [43]. The Soviet Union, for instance, framed nuclear power as central to its vision of ‘Atomic-Powered Communism,’ which positioned scientific advancements as a means of achieving socialist superiority [44]. However, catastrophic events like Chernobyl and Fukushima have disrupted these imaginaries, especially in the Western nuclear culture, with Cold War iconography—including the mushroom cloud—serving as a persistent reminder of nuclear danger [45]. This led to alternative visions that challenge the nuclear paradigm and emphasize the need for post-nuclear energy transitions. More so than other energy cultures, nuclear energy cultures are characterized by these contrasting and oppositional imaginaries of ‘the nuclear.’

Furthermore, nuclear culture is characterized by its emphasis on secrecy and control. Unlike other energy cultures, in which technological developments are often openly debated and contested, nuclear energy has historically been managed within highly regulated and securitized environments. At the same time, it is characterized by uncertainty because of the invisibility of radioactivity and its dangers [20]. This secrecy has contributed to both the mystification of nuclear technology and the proliferation of public distrust, reinforcing cycles of opposition and advocacy that define nuclear discourse.

Energy culture also encompasses the ways in which societies integrate energy technologies into their collective identities. Hogg [46] highlights how nuclear heritage is embedded in everyday experiences, from education systems that normalize nuclear energy to cultural representations that influence public attitudes. This cultural embedding plays a crucial role in shaping the governance of nuclear legacies, as societies must negotiate between the preservation of nuclear infrastructure and the long-term risks associated with radioactive materials in addition to negotiating the necessity of nuclear waste disposal.

This nuclear waste governance is also shaped by socio-technical imaginaries that frame repository solutions as either responsible stewardship or hazardous burdens for future generations. For instance, the

development of deep geological repositories—such as the Onkalo spent nuclear fuel repository in Finland—rests upon imaginaries that conceptualize underground storage as a permanent and secure solution despite uncertainties about its long-term viability [24,47–49]. These imaginative practices are considered socio-technical imaginaries when they refer to a technology and become part of and are developed through political actions and social discourses, for example nuclear power in relation to narratives of cheap and endless energy supply [36]. Such imaginaries are socially and politically constructed visions of desirable futures as cultural systems of ‘meaning-making’ that help to create collective and institutionalized visions, influence public perceptions of, for example, an energy form or its burdens, such as nuclear waste management, and determine which governance models are considered acceptable [38,50]. This nuclear waste governance is also shaped by socio-technical imaginaries that frame repository solutions as either responsible stewardship or hazardous burdens for future generations. For instance, the development of deep geological repositories—such as the Onkalo spent nuclear fuel repository in Finland—rests upon imaginaries that conceptualize underground storage as a permanent and secure solution despite uncertainties about its long-term viability [25,47–49]. These imaginative practices are considered socio-technical imaginaries when they refer to a technology and become part of and are developed through political actions and social discourses, e.g., nuclear power in relation to narratives of cheap and endless energy supply [36]. Such imaginaries are socially and politically constructed visions of desirable futures as cultural systems of ‘meaning-making’ that help to create collective and institutionalized visions, influence public perceptions of, for example, an energy form or its burdens, such as nuclear waste management, and determine which governance models are considered acceptable [38,50].

In the nuclear context, energy cultures are particularly relevant as they shape how communities engage with nuclear energy and its infrastructures over time. Nuclear energy cultures do not emerge solely from the presence of reactors or waste disposal sites; they are also constituted by narratives of technological optimism, resistance, and risk. This is particularly evident in Germany, where strong anti-nuclear movements have coalesced around a distinct cultural identity shaped by the opposition to nuclear power. Additionally, nuclear waste governance plays a pivotal role in shaping energy cultures as the long-term management of hazardous waste challenges conventional temporal frameworks and demands continuous cultural engagement with the nuclear past and future [14]. By drawing on national policies and imaginations as well as energy cultures, a distinct spatial dimension also emerges. The spatial dimension encompasses not only international or national levels, but also regional and local scales on which energy cultures are contested and negotiated. Particularly when addressing future scenarios, socio-technical and spatial imaginaries need to be integrated into the NCH framework in order to gain a deeper understanding of how nuclear heritage is not merely inherited but continuously negotiated through societal visions of the past and the future. These imaginaries influence which aspects of the nuclear legacy are preserved, how they are framed in public discourse, and what role they play in shaping long-term governance strategies.

By integrating energy cultures and imaginaries into the NCH framework, we underscore the need to consider how nuclear practices, artefacts, and memories are not just preserved but actively co-produced through societal engagements with nuclearity. This approach highlights the lived experiences and cultural expressions of nuclear communities, helping to reveal how nuclear heritage is actively shaped by both material infrastructures and the socio-political contestations surrounding them. In this context, place-sensitive approaches offer deeper insights into how local perceptions and practices come into existence and shape energy cultures and imaginaries.

⁷ See also here: <https://www.iaea.org/about/history/atoms-for-peace-speech>, last accessed February 7, 2025.

3.2. The role of place and remembrance

In thinking spatially about nuclear cultural heritage, place and place attachment are important concepts that emphasize the geographies of transformation through material objects as well as non-material aspects such as emotions, perceptions, and meanings of material objects in space [51,52].

In this paper, place is understood as a location that holds meaning for individuals and groups [53] and is the product of social relations [54]. Places are continuously produced through the 'social, political, and material processes by which people iteratively create and recreate the experienced geographies in which they live' [55]. Within this framing of place, as produced through a particular set of social relations at a particular location, 'the singularity of any individual place is formed in part out of the specificity of the interactions which occur at that location (nowhere else does this precise mixture occur) and in part out of the fact that the meeting of those social relations at that location (their partly happenstance juxtaposition) will in turn produce new social effects' [54]. This means that place is relational and not restricted by administrative or political boundaries. Events in one place—e.g., another country like the Chernobyl accident in Ukraine or the Fukushima accident in Japan—can influence debates and perceptions in (or even the production of) another place, e.g., the societal debates regarding nuclear energy in Germany and elsewhere [56,57].

Despite this relationality of place, distinct place attachments in the form of 'emotional bonds with a place' are formed and articulated by memories, wishes, emotions, and personal relations [58,59]. Place attachment and associated identity formations are shaped, on the one hand, by combinations of structural societal patterns (demography, economy, history) [60] and, on the other hand, through collective constructions of interpretations and attributions of places [61,62]. Therefore, place attachment shapes the personal significance of a place which influences the extent to which people feel threatened if a place is transformed, for example. This might lead to actions in favour or against infrastructural projects [61,63,64], e.g., waste disposal infrastructure or energy plants. Osborne et al. [65] therefore argue that governments need to integrate place-based aspects of society into decision-making processes, e.g., through participatory or collaborative knowledge production processes.

Processes of place- and meaning-making intertwine with the curation and re-production of the past. Through such processes, places of remembrance begin to evolve. They provide insights into how society culturally, socially, and spatially engages with and (re)produces the past [66]. They are 'crystallisation points of collective memory and identity' [67], which are the product of both material and immaterial elements, i. e., geographical places, but also social constructs, like events or rituals [68]. As such, places of remembrance do not (exclusively) refer to physical spaces (within a national context) but must also be understood as relational places that are discursively constructed elements of identity formation which may transcend borders and influence national politics and narratives [66]. Therefore, Chernobyl and Fukushima can be understood as German places of (ecological) remembrance [69] as they exerted a lasting impact on national environmental and energy policy [70,71]. However, the 'spatial proximity' factor enables citizens to experience places of remembrance more frequently and intensively compared to the nation and Europe' [68]. This further emphasizes the importance of foregrounding place-based experiences of the past for remembrance, memory conservation⁸ or heritage practices.

We argue that place attachment and remembrance strengthen insights into the development of existing heritages and heritage processes. They influence what is assigned value and meaning, resulting in bottom-up heritage practices that are deeply embedded within the social and material entanglements in place. Material objects in specific places gain

collective importance only when shared memories, meanings, perceptions are attached to them and prompt action and routine [23]. In the context of local nuclear energy contestation, for example, Otto and Leibenath [73] argue that in order to perform such collective action triggered by place attachments, it is important to form discourse coalitions between different actors.

At the same time, the implementation of cultural heritages also has the potential to influence and transform place. Place attachments and memories as practices of remembrance are important aspects of institutionalization processes, activating networks and fostering social cohesion across individuals, collectives, and communities [61,65,73]. Through these, new social relations emerge which further transform and produce particular places.

3.3. Insights for NCH: An interim summary

All the approaches discussed above have clear connections to aspects of the nuclear and/or heritage practices. Approaches to energy cultures and imaginaries provide complementary insights into the ways in which nuclear heritage is produced, contested, and institutionalized. While energy cultures emphasize the social and material interactions shaping nuclear legacies, socio-technical and spatial imaginaries reveal how collective visions influence the governance and perception of nuclear sites. This is further strengthened by insights from place attachment and remembrance through a strong focus on social relations, particular identities, and associated actions in relation to material objects—natural landscapes as well as man-made artefacts—in specific places. These can be influenced by events and discourses happening in other places and at the same time the narratives and discourses from a particular place can influence discourses and politics on regional, national, or even international levels.

By thinking about these fields in conjunction, it becomes clear how specific narratives and imaginations are produced by policies and social discourses, and thus become materialized and institutionalized over time [36,74–76].

When arguing for, or working with, a heritage approach in the context of nuclear waste, it is essential to appreciate the interconnections between past, present and future in order to envisage a future-oriented archaeology of nuclear waste [77,78]. This involves both historical and future awareness, which is important for the safety of nuclear disposal and the long-term governance of the same [19,79].

The study of those additional approaches in their relationality thus contributes to a more comprehensive understanding of NCH. They demonstrate the ways in which nuclear artefacts, practices, and memories are dynamically shaped by cultural, political, and technological processes and vice versa; in the sense of Anthony Giddens' 'duality of structure' [80]. Moreover, the concept of NCH can be further differentiated by revealing the role of place and place remembrance as part of identity processes at the local and regional level, also culminating in cultural narratives and imaginaries at the national level or even spreading at the international level. These processes play an important role in the institutionalization of symbols, narratives and memories, practices as well as material objects and artefacts to which they refer to or which have been developed through such processes.

The sound theoretical understanding of NCH developed above provides a basis for discussing its role in long-term nuclear waste governance. The 'preservation of records, knowledge and memory across generations' [81] is considered a key prerequisite for safe disposal in the long-term. Nuclear heritage is not simply a static legacy; it is continually shaped by socio-political contestation, technological imaginaries, community as well as individual engagements with the nuclear past, present and future and can thus contribute to keeping memory alive. Recognizing these dynamics is essential for developing a critical and forward-looking approach to NCH. As such it can contribute to a long-term governance of nuclear waste disposal like processes described above that are part of heritagization support not only the development of a

⁸ A deeper insight into nuclear memory is offered in Keating and Storm [73].

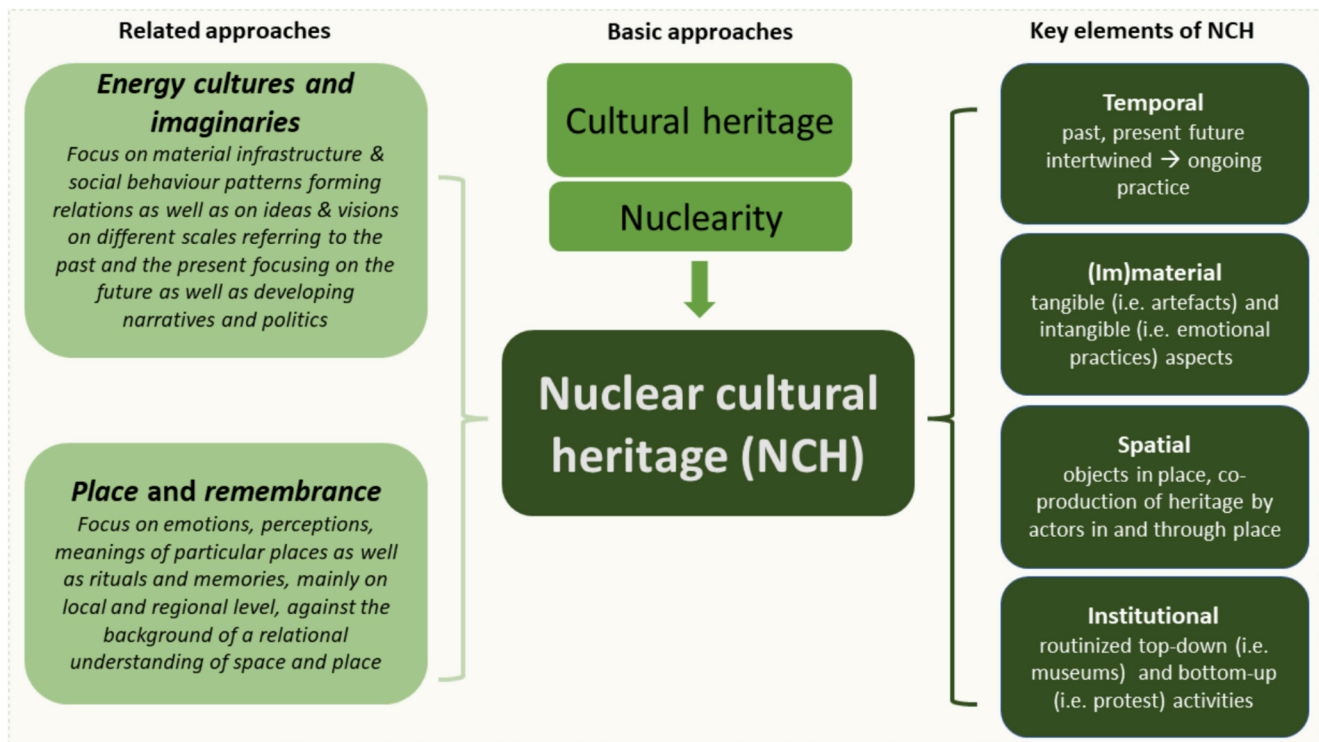


Fig. 2. Key elements of NCH.
(Source: Own depiction.)

nuclear cultural heritage, but also contribute to the safety of the disposal [19,39].

4. Discussion: Towards an analytical framework of nuclear cultural heritage

The related approaches described above – energy cultures and imaginaries as well as place and remembrance – are integrated in the cultural heritage approaches as basis for nuclear cultural heritage and form the basis of the framework for analysis of NCH. As such, NCH is defined along four key elements– temporality, (im)materiality, spatiality, institutionalization – as shown in Fig. 2. Below we set out this framework and discuss its suitability for analysis of NCH, especially in the context of Germany but also elsewhere and address how it can be operationalized (see Fig. 4).

Firstly, there is a clear temporal dimension to nuclear cultural heritage. As a practice, nuclear cultural heritage is a constant negotiation between the relevance of knowledge, practices, and artefacts of the past and for the future. Therefore, it is also an ongoing engagement with ‘the nuclear’ by various actors across multiple generations. In many countries the decommissioning of nuclear power plants and/or nuclear accidents have been triggers for the discussion of nuclear heritage [15,26,82]. Tourism practices in Poland [83] related to uranium mining, of cold war bunkers in Montenegro [84], or in the Chernobyl [85] exclusion zone are examples of an already practiced NCH that link past events with desired memory preservation practices. In Germany, there is a notable absence of both academic and popular literature on NCH. Recent nuclear heritage discussions seem to have been triggered largely by nuclear waste management and governance as part of a long-term knowledge preservation strategy to guarantee safety. This goes back until the anti-nuclear movements against nuclear power plants, e.g. Wyhl [86], or the plans for a nuclear waste management facility in Gorleben [87].

Secondly, nuclear cultural heritage encompasses both material and immaterial elements. Nuclearity itself is characterized by the tensions

between the tangible and intangible. Objects of a nuclear cultural heritage can be infrastructures associated with nuclear technology. For example, the ‘Atom Ei’—the first German nuclear research reactor—has preservation status in Germany. Although decommissioned, it still remains part of a larger research campus and acts as a symbol of German advancements in the field of nuclear energy research.⁹ However, nuclear heritage practices are not just related to specific sites and infrastructures, such as museums, archives, decommissioned reactors, and storage sites, but also to more diffuse cultural practices and artefacts. Actors produce nuclear cultural heritage in both emotional-affective ways (e.g., storytelling, arts, interpersonal exchange) and through more rational expressions (scientific data on, for example, risks) and the care for material elements. Particularly immaterial elements such as oral histories are identity-forming [60,72]. This can be observed in the social movements in Germany that have their roots in the anti-nuclear and peace movement in the 1970s and became an inherent part of the political culture of Germany [88,89]. Wyhl, a small municipality in south-western Germany, was the starting point of the anti-nuclear movements in Germany. Grassroot initiatives mounted civilian protests there against plans to build a nuclear power plant in the region. This protest movement grew even stronger when Gorleben, a municipality in the north of Germany, was made a possible site for high-radioactive waste disposal. Over the course of many decades of protest, several symbolic artefacts and practices were developed, e.g., the Beluga Boat (see Fig. 3) which Greenpeace used for demonstrations and water sampling, e.g., in front of the reprocessing plant in Sellafield in the UK and at the plutonium factories in La Hague, France [90]. Today, it stands in the Gorleben district and is the starting point for Sunday walks and Gorleben prayers which remind of the protest movement and the need to ensure the safety of a final repository.

Thirdly, nuclear cultural heritage practices are always spatially

⁹ <https://www.frm2.tum.de/en/frm2/about-us/from-atomic-egg-to-frm-ii/>, accessed February 2, 2025.



Fig. 3. The Beluga memorial in Gorleben.
(Source: Noka 2024.)

determined. All knowledge and practices of the nuclear, regardless of whether these are material or immaterial, are either already grounded in place, for example through infrastructures of nuclear industry, or they emerge out of and are deeply intertwined with situated knowledge, for example stemming from place-based activism [91,92]. Any engagement with nuclear cultural heritage must, therefore, contextualize all knowledge, practices, and artefacts by being sensitive to where these heritages emerge from. In turn, this facilitates cultural learning through place-based social interactions in formal and informal peer groups, contributing to the social construction of a sense of place [33,93]. Indeed, Ross [82] argues that ‘communities are the locations of nuclear cultural heritage, which perhaps have the greatest bearing on how it is interpreted and experienced,’ and where meanings are continuously ‘negotiated and renegotiated’. Additionally, everyday spaces within nuclear communities become coded by ‘the nuclear’; these include town squares during protests, train stations, and roads during waste transports, or town halls and local pubs in which discussions and informational exchanges occur(ed) [94]. The heterogeneity of nuclear cultural

heritage practices means that multiple places, sites, and actors of the nuclear can become enrolled in these heritage practices. A nuclear cultural heritage must reflect this multiplicity of nuclear spaces, taking into account that places are relational.

Finally, we argue that an nuclear cultural heritage practice needs to be ‘exposed’ to institutionalization [95]. A German example for that is the above mentioned Wismut foundation which preserves knowledge about the uranium mining.¹⁰ We take a broad view of institutionalization that not only encompasses top-down activities and mechanisms which order and govern society, but also bottom-up processes that establish structures such as models, rules, and routines in everyday social realities [96]. Another German example for such routinized practices referring to NCH is the Gorleben Prayer which takes place every

¹⁰ <https://www.wismut-stiftung.de/>, last accessed February 7, 2025.

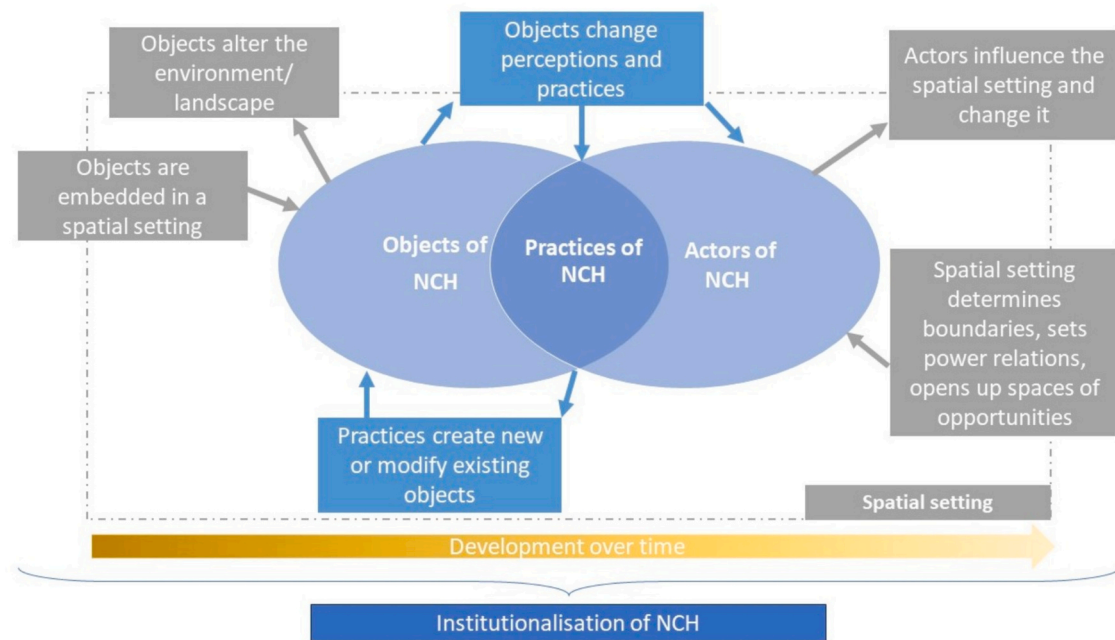


Fig. 4. Framework for analysis of NCH.
Source: Own depiction.

Sunday since 1989.¹¹ Essentially, these practices need to be routinized in some way, particularly those related to the social aspects of nuclear heritage as these ‘will to a large extent be lost or, rather, their disappearance transformed into a continuation of the nuclear industry’s self-proclaimed identity of cleanness and control’ [95]. The diversity of actors, practices, and knowledge of the nuclear needs to be reflected in nuclear heritage, to include positive-affirmative achievements associated with ‘the nuclear’ as well as nuclear disasters and atrocities [95].

In summary, a nuclear cultural heritage consists, on the one hand, of material objects that are created by people and are related to the everyday actions and activities of actors (see Fig. 3). This link between actors and material objects in the form of actions and perceptions gives rise, on the other hand, to immaterial practices. There are various interactions between objects and practices. For example, objects can change the perception of actors and thus may also influence their actions, which can manifest themselves in different practices. In addition, practices can also create new material objects (e.g., an archive through the collection of material artefacts of remembrance or a memorial) or change existing material objects (e.g., through the conversion of a nuclear facility as a place of remembrance). Material objects and actors as well as the immaterial practices associated with them exist and take place in a specific spatial setting that defines certain framework conditions, contains power relations and opens up spaces of opportunities. To an extent, this spatial setting is determined by landscape features as well as administrative-political borders and frameworks; however, external events, international politics and discourses also influence this setting, foregrounding a relational understanding of the spatial setting. In addition to the spatial dimensions, temporality also plays a significant role. Institutions, legal regulations and the relationships between the various political and administrative levels as well as the actors involved play a central role in the development of NCH over time. Through these interactions and links, institutionalization processes and different degrees of institutionalization become visible.

Since the analytical framework is very broad and covers multiple

dimensions, a variety of methods should be used to operationalize the analysis of an NCH based on the framework. When aiming to record the various objects of NCH, for example, a mapping can be useful to gain a broad overview or even to draw out relationships between places and actors [97]. To capture and identify the actors involved in NCH practices, an actor network analysis could be carried out using desk research and interviews [98]. In this way, relationships between the actors and to the objects can also be uncovered. The spatial dimension and temporal progression can be recorded via discourses, e.g., media analysis or archival work. In any case, on-site visits in the form of walk-alongs [99] or similar are useful to gain impressions of relevant objects and their embedding in the landscape, to get in touch with actors, and can also be a starting point for ethnographic research, e.g., ethnographic films or oral history research [94]. NCH is a heterogeneous phenomenon that draws from multiple disciplines. This intersectional nature of NCH should also be reflected in the methods to study it.

5. Conclusion: Analysis of nuclear cultural heritage as a complex task

The literature review demonstrated different approaches to the heritagization processes, foregrounding the importance of material objects but also related practices both of which are equally influenced by past (external) events, past as well as current (societal and political) discourses, and visions of the future. The four dimensions of NCH highlight the importance of history, rooted in energy cultures, past and current local actions, and perceptions influenced by place attachments and (future) imaginaries which come into practice by social and political actions both at the nation-state level by top-down processes and locally by shaping places of remembrance and fostering bottom-up institutionalization processes. Based on the literature review, we understand NCH as practices and artefacts of the nuclear past and present that are considered relevant and important for the future. The practices include identifying, collecting, preserving, and communicating about nuclear artefacts and related social debates. NCH is temporal, meaning that these practices have their roots in the past, have an effect in the present, and are important in the future. NCH encompasses material and immaterial elements; actors play a crucial role in this regard. In addition

¹¹ <https://www.gorleben-gebiet.de/wir-ueber-uns/>, last accessed February 7, 2025.

to nuclear objects, discourses referring to these objects as well as related narratives and perceptions can contribute to a place being constructed as nuclear. NCH is spatial as practices are linked to place attachments that are characterized by actors and their specific networks, socio-historical traditions, and energy cultures in one place which influence how localities react to certain developments, e.g., cleared landfill sites [23]. Finally, NCH requires institutionalization, which includes bottom-up processes as social processes of institutionalization.

Analyzing NCH in any given country or region is a complex task in which all these dimensions need to be taken into account. The introduced framework helps to operationalize a thorough analysis of NCH by pointing out the main dimensions of NCH, showing the relevance and interconnections between them, and providing guidance on how an analysis can be set out methodologically. The complexity and interrelationships of different actors involved in producing NCH in a particular place play an especially important role when defining a bundle of places and practices as NCH. This means that negotiations must take place to define objects and practices in a particular place as a NCH, in which questions of sovereignty of interpretation, self-efficacy in terms of place attachment and competing interests arise. In conceptualizing NCH in Germany, for example, different processes, especially bottom-up processes of protest movements, but also nuclear objects like phased-out nuclear power plants, nuclear disposal sites, interim storage sites or the diverse archives, symbols, memorials and museums, both produced by the nuclear industry and those emerging by social construction and activities from bottom-up need to be considered. This includes a wide range of actors, e.g., from the government, energy companies, politics, NGOs, and civil society. As such there is already a whole range of NCH practices at work in Germany that are not explicitly framed as such [100,101]. Further comprehensive and ideally case-study based research is needed, therefore, to uncover NCH as well as to study its incorporation into long-term governance with regard to safety of nuclear waste in an effort to better understand the role it does and could play in long-term safety.

CRedit authorship contribution statement

Melanie Mbah: Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Viktoria Noka:** Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Alexandra Lampke:** Writing – original draft, Investigation. **Ryan Kelly:** Writing – original draft, Investigation. **Sophie Kuppler:** Writing – original draft, Investigation.

Declaration of competing interest

The authors report there are no competing interests to declare.

Data availability

No data was used for the research described in the article.

Acknowledgements

This article was written as part of the project entitled “Nuclear Cultural Heritage approaches and methods and their applicability in the context of the site selection procedure” (NuCultAge), funded by the German Federal Office for the Safety of Nuclear Waste Management (BASE), grant number 4723F90101. The article reflects the views and opinions of the authors and is not necessarily the opinion of the funding institution. The authors thank Bettina Brohmann: Writing – Reviewing; Vanessa Cook: Writing – Language editing; Sarah Glück: Writing – Reviewing; Rosa Reising: Writing – Reviewing.

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