Journal of Environmental Management 374 (2025) 124136

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Stakeholders' perspective on sustainable cement made with naturally occurring radioactive by-products: A cross-country comparison

Nazanin Love [a,b,*], Robbe Geysmans [b], Sara Leroi-Werelds [c], Nadja Železnik [d], Tanja Perko [b,e,f], Wouter Schroeyers [g], Robert Malina [a]

[a] Research Group Environmental Economics, Centre of Environmental Sciences, Hasselt University, 3590, Diepenbeek, Belgium
[b] Belgian Nuclear Research Centre SCK CEN, 2400, Mol, Belgium
[c] Department of Marketing and Strategy, Hasselt University, 3590, Diepenbeek, Belgium
[d] EIMV, Hajdrihova ulica 2, Ljubljana, 1000, Slovenia
[e] Department of Political Science, University of Antwerp, 2000, Antwerp, Belgium
[f] Faculty of Social Sciences, University of Ljubljana, Slovenia
[g] NuTeC, Nuclear Technology, Centre of Environmental Sciences, Faculty of Engineering Technology, Hasselt University, 3590, Diepenbeek, Belgium

ARTICLE INFO

Keywords:
Sustainable solutions
Circular economy
CO_2
Alternative cement
Naturally occurring radioactive material
Stakeholder perceptions

ABSTRACT

The use of industrial by-products as substitutes for raw materials in cement production not only reduces raw material use, thereby contributing to the circular economy, but also offers an avenue for reducing greenhouse gas emissions. This study investigates the perceptions of industry representatives and end-users across Belgium, Czechia and Slovenia regarding alternative cement made with industrial by-products categorised as naturally occurring radioactive materials. Based on 66 interviews, three main concerns were discerned: health, performance, and economic. Health concerns varied across countries, whereas performance and economic concerns were consistent. Health concerns can be mitigated by fostering trust in authorities. Performance concerns can be addressed through certification and practical examples. Economic concerns arising from the perceived higher costs connected to sustainability and lack of urgency for immediate change can be mitigated through incentives and regulations. This study informs communication and policy strategies tailored to address stakeholders' specific concerns in each country.

1. Introduction

Innovative solutions for energy and material efficiency in the cement sector are key to reducing the 7% of the global GHG emissions for which the cement industry is responsible (Marmier, 2023). The predominant source of GHG emissions in cement production comes from the manufacturing of clinker, which is the main component of cement. These emissions result from the chemical reactions and fuel combustion during the production process. Reducing the clinker-to-cement ratio by increasing clinker substitution could make the greatest contribution to reducing emissions in the cement industry (IEA, 2023). Commonly used substitutes for clinker include fly ash from coal-fired power plants (Vargas and Halog, 2015), granulated blast furnace slag from steel blast furnaces (Oge et al., 2019), and calcined clays, which are natural clays subjected to thermal treatment (Scrivener et al., 2018). However, a reduction in the supply of some commonly used by-products is expected due to major changes in their respective industries (GCCA, 2023). Consequently, alternative industrial by-products with the potential to substitute clinker have been investigated extensively (Duchesne, 2021; Juenger et al., 2019; Miller, 2018; Snellings et al., 2023; Yang et al., 2015).

Among potential clinker substitutions, by-products such as copper slag from copper production and red mud from aluminium production can, in specific cases, be classified as naturally occurring radioactive material (NORM) due to their elevated radionuclide concentrations. NORM is a radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides (i.e., uranium (^{238}U), thorium (^{232}Th) and their decay products, and potassium (^{40}K)) (Popic et al., 2023b). Although the activity concentrations of these radionuclides are typically low in natural rocks and soils, industrial extraction and processing can cause radionuclides to become unevenly distributed between various products, by-products, and residues. In

* Corresponding author. Research Group Environmental Economics, Centre of Environmental Sciences, Hasselt University, 3590, Diepenbeek, Belgium.
E-mail address: nazanin.love@uhasselt.be (N. Love).

https://doi.org/10.1016/j.jenvman.2025.124136
Received 24 June 2024; Received in revised form 17 December 2024; Accepted 11 January 2025
Available online 17 January 2025

some cases, radionuclide concentrations may increase by several orders of magnitude, surpassing legislative limits that vary by country, classifying the material as NORM (IAEA, 2024). For example, commercially exploited minerals may contain 238U, 232Th, their decay products, or potassium at elevated concentrations, raising radiological safety concerns (IAEA, 2022). For a detailed methodology on the systematic identification of NORM and data collection practices, readers may refer to studies such as Michalik et al. (2023), which outline a comprehensive approach to identifying NORM, and Popic et al. (2023a, 2023b), which discuss harmonised data collection and exposure assessments across European countries (Michalik et al., 2023; Popic et al., 2023a, 2023b).

NORM-containing by-products, such as copper slag and red mud, also present significant environmental challenges. For every tonne of aluminium produced, approximately 1.5 tonnes of red mud are generated, while copper slag is produced at a rate of 2.2 tonnes per tonne of copper. Much of this waste is disposed of in landfills, contributing to environmental degradation through the leaching of heavy metals and radionuclides (Wang et al., 2020). The International Atomic Energy Agency (IAEA, 2013) recommends recycling these by-products in industrial applications, including cement production, to align with circular economy principles. This approach reduces waste while promoting sustainability by shifting the perception of NORM from waste to a valuable resource, enabling its safe and productive use.

The use of NORM-containing by-products as clinker substitutions provides dual benefits: reducing the clinker-to-cement ratio—and thus greenhouse gas emissions during cement production—and repurposing industrial by-products that would otherwise accumulate as waste. This integration minimises the demand for virgin raw materials while addressing waste disposal issues, showcasing the potential of NORM as a supplementary material in cementitious binders (de Brito and Kurda, 2021; Juenger et al., 2019). Nevertheless, building materials containing NORM may expose individuals to gamma radiation or radon (^{222}Rn) and thoron (220Rn) gases released into indoor air (ICRP, 2019).

The European Union's Basic Safety Standards (EU-BSS) Directive (Council Directive, 2013/59/Euratom) mandates strict regulations for NORM-containing building materials, including monitoring and assessing radiation exposure. The Directive sets a reference level of 1 mSv per year for indoor gamma radiation from building materials. It employs an activity concentration index (I-index) as a screening tool, requiring further assessment if the index exceeds a value of 1. Member states may enforce stricter national regulations where local conditions necessitate. Furthermore, National Radon Action Plans under the EU-BSS Directive ensure comprehensive management of radon (^{222}Rn) emissions from NORM-containing building materials, soil, and water, thereby addressing long-term radon (^{222}Rn) exposure risks (HERCA, 2016).

The radioactivity concentration of building materials incorporating NORM-contained by-products depends on several factors, including the geological origin of the raw materials, the specific industrial processes involved, and the extent of their use in construction applications. For example, red mud, a by-product of bauxite processing, exhibits activity concentrations ranging from 97 to 1700 Bq/kg for ^{226}Ra, 45–1800 Bq/kg for ^{232}Th, and 15–583 Bq/kg for ^{40}K, depending on its origin and treatment process. The incorporation of such materials into construction products can sometimes lead to exceeding regulatory screening levels, as indicated by the EU-BSS standards. Consequently, a detailed radiological assessment is critical before these materials are used in building applications. Such assessments not only provide insights into potential radiological risks but also inform regulatory compliance and public perception of their use as sustainable alternatives in construction (Schroeyers et al., 2018).

While this regulatory framework ensures the safe use of NORM in construction, aligning with sustainability goals such as waste reduction and resource reuse, its effectiveness depends heavily on public trust. Addressing societal concerns about potential radiological risks is vital for fostering acceptance and facilitating the broader adoption of these materials in construction, contributing to the advancement of a circular economy and sustainable practices.

A significant body of research has explored the technical feasibility and environmental impact of using NORM-contained by-products as clinker substitutes (see Kumar et al., 2021; Phiri et al., 2021; Wang et al., 2021). However, the successful development and deployment of emerging technologies also depends on understanding and addressing stakeholders' concerns (Siegrist and Hartmann, 2020). Kirchherr et al. (2018) classified a lack of consumer interest and awareness as one of the main barriers to a circular economy in the EU context. Their findings indicate that while technological advancements are necessary, they are not sufficient to adopt sustainable practices. The importance of societal acceptance has been highlighted for other disruptive technologies such as hydrogen (Emodi et al., 2021), low-carbon technologies (Arning et al., 2020), and renewable energy (Batel, 2020). In the context of alternative cement made with NORM-contained by-products, societal acceptance is critical, especially due to potential concerns about radioactivity.

To our knowledge, the societal aspects of using alternative cement made with NORM-contained by-products have, to date, been explored solely in the context of the Belgian concrete industry (Love et al., 2023). Our study broadens this scope by extending the investigation to include end-users'[1] perceptions beyond industry insiders, as well as expanding the geographical context to the Czech Republic (Czechia) and Slovenia. This allows us to assess whether previous findings are context-specific or generalisable to other national contexts. We pose the following research questions to further explore the complexities of the transition to alternative cements[2]

RQ1: What key factors influence industry representatives' and end-users' perceptions of alternative cements in Belgium, Czechia and Slovenia?

RQ2: To what extent do country-specific factors in the three countries shape industry representatives' and end-users' perceptions of alternative cement?

Thus, this study identifies the challenges in transitioning to alternative cement, contributing to the ongoing discourse on sustainable replacements for traditional cement. By investigating societal aspects, we extend the analysis scope of the literature, which is currently strongly focused on technical and environmental issues as previously outlined. Insights into stakeholders' perceptions of alternative cement provide a foundation for strategies that can inform the design of public policies and communication strategies.

2. Methods

To explore perceptions of industry representatives and end-users of alternative cement, we adopted a qualitative research method that provided comprehensive insights into uncharted research areas, enabling a detailed understanding of the topic without predefined variables (Creswell and Creswell, 2017; Knott et al., 2022). Among the different qualitative techniques, we conducted semi-structured interviews because this format strikes a balance between structured and flexible discussions, guided by key questions, while allowing for the emergence of new relevant topics during the interviews (Gibson and Brown, 2009). This approach was particularly effective in our study, owing to its exploratory nature. Appendix 1 provides the interview protocol and design steps.

[1] End-users influence the cement industry more than heavy industries such as iron, steel, and chemicals, due to the direct use of cement in everyday construction materials (Griffiths et al., 2023).

[2] In this paper, we refer to 'alternative cement made with NORM-contained by-products' simply as 'alternative cement'.

2.1. Sampling and data collection

To extend the previous research conducted in the Belgian context (Love et al., 2023), our study compares perceptions in Belgium with two other countries within the EU: Czechia and Slovenia. This ensured consistency across evaluations, leveraging the fact that all EU Member States adhere to European climate law, which mandates significant reductions in greenhouse gas emissions to achieve the 2050 net-zero target (European Council, 2024). Czechia and Slovenia were chosen for their distinct socio-historical contexts which we will discuss further in section 3.1.

Building on our comparative framework, participant recruitment involved tailored sampling strategies for end-users and industry representatives, detailed in Table 1.

In line with ethical research practices, ethical approval was obtained from the Social-Societal Ethics Committee at Hasselt University. Informed consent was obtained from all participants before the interviews, highlighting the principles of voluntary participation, autonomy, and confidentiality. These interviews, conducted online between September 2021 and April 2023, had an average duration of 45 min. Each interview was audio-recorded and later transcribed and translated to English. Table 2 presents the number of participants in each category. We relied on the concept of data saturation to determine when data collection was sufficient, which meant that no new insights emerged, while ensuring the richness and comprehensiveness of the collected data (Gerson and Damaske, 2020).

2.2. Analysis of interview data

In line with the recommendations of Knott et al. (2022), we initiated our analysis concurrently with data collection, allowing early findings to shape the direction and focus of the subsequent interviews. Employing this iterative approach ensures a cohesive alignment between the collected data and the findings that emerge (Spencer et al., 2014).

Thematic analysis was chosen for its ability to explore data in depth and utilised to scrutinise commonalities, relationships, and differences within our dataset. This method, ideal for our study's iterative approach, facilitated the identification and interpretation of emerging patterns and themes, offering in-depth insights into the data collected (Gibson and Brown, 2009). Informed by Braun and Clarke (2021, 2006) guidelines, this approach enabled us to extract meaningful insights, particularly into understanding the nuances and perspectives revealed in the interviews. The first author engaged in an initial round of open coding by labelling sections of data with each code to encapsulate a single idea from the data. The coding process was iterative, involving reading and rereading the interview transcripts, and applying and refining the codes. This process continued until we ensured that the coding frame was consistently applied across the dataset. This allowed us to create a new understanding by identifying thematic patterns that convey significant meanings across the dataset (Knott et al., 2022). Our analysis alternated between closely examining the data for detailed insights and stepping back to synthesise and articulate broader analytical findings. We ensured that our interpretations remained firmly grounded in the data, reflecting a deep understanding of participants' perspectives (Glaser and Strauss, 2017). Throughout this iterative process, we combined deductive and inductive logic, which is often referred to as an abductive approach, a hallmark of thematic analysis (Fereday and Muir-Cochrane, 2006). Our approach was attentive to the emergence and comparison of themes and patterns across different stakeholders and across countries. NVivo software was used to manage interview data and facilitate the coding process.

Table 1
Sampling strategies for both stakeholder groups.

z	End-users	Industry representatives
Definition	Individuals in the process of building or renovating their houses.	Professionals involved in their company or organisation's decision-making processes regarding the type of cement used. This includes roles within concrete companies, construction companies, and related federations that represent industry perspective.
Sampling strategy	**Purposive sampling**: End-users who have recently built or renovated their houses were targeted due to their recent involvement in choosing building materials for their construction projects **Convenience sampling**: Participants were selected based on their accessibility and availability to the researcher, optimising research efficiency, and resource utilisation.	**Snowball sampling**: Networks of initial participants were used to identify additional relevant individuals from other companies, ensuring that those selected could offer detailed insights into our research questions.
	Quota sampling: To ensure representation from each of the three countries under study, the above strategies were combined with quota sampling, balancing the input from both stakeholder groups across geographical locations.	

Table 2
Distribution of participants.

	Belgium	Slovenia	Czechia	
End-users	12	11	10	
Industry	14	9	10	**66**
Total	26	20	20	

3. Results and discussion

Three main themes emerged, representing key concerns associated with the use of alternative cement: (i) health, (ii) performance, and (iii) economic. Each theme represents a fundamental aspect of the decision-making process on both the supply (industry representatives) and demand (end-users) sides of the market. For each theme, we highlight key sub-themes to shed light on the specific aspects that influence these concerns.

3.1. Health concerns

This theme entails stakeholders' concerns about the potential health impacts of alternative cement, which is a key factor because of the widespread use of cement in buildings and hence potential long-term exposure risks. Our analysis highlighted a divergence in health-related concerns among participant groups. The greatest concern emerged among end-users in Czechia, who demanded long-term evidence regarding the *"non-toxicity" [3.E.C]*[3] of alternative cement, stating: *"My decision depends on whether buildings or apartments have already been constructed with this material. Otherwise, I would likely be hesitant and choose to wait. It could take years to establish the non-existence of negative health effects of such materials" [10.E.C]*. This heightened concern may be partly attributed to Czechia's historical use of concrete containing industrial by-products with elevated levels of natural radioactivity, which has led to increased indoor radon (^{222}Rn)[4] levels. These incidents, in

[3] Each quote is coded to identify the participant: the number is their sequence within their stakeholder group and country; the first letter denotes stakeholder type (I=Industry, E = End-user), and the second letter their country (B=Belgium, S=Slovenia, C= Czechia).

[4] Radon (^{222}Rn): A radioactive noble gas formed from the decay of uranium in soil, rock, and water. It tends to accumulate indoors, especially in lower areas such as basements.

some cases, necessitated the demolition or remediation of affected dwellings (Hulka and Thomas, 1999; SURO, 2024). This historical context likely shapes end-users' heightened awareness and demand for safety assurances in Czechia, providing a unique dimension to our comparative analysis. Conversely, industry representatives in Czechia demonstrated less concern but emphasised the need to guarantee its safety *"for the occupants and users of the building as well as for the construction workers" [6.I.C]*.

Both industry and end-users in Slovenia were among the groups with elevated health concerns. An industry representative said: *"Yes, of course, I would be worried. The average citizen does not initially measure it, know about it, or feel its effects, only after becoming ill. What is the reason they became ill? They don't know. […][5] Consumer safety is paramount. If we work with residential construction, this cement must be medically indisputable and safe" [8.I.S]*. Participants in Slovenia and end-users in Czechia believed that alternative cement *"should not be used for a house" [7.E.S]* because *"health effects only manifest over years" [9.E.S]*. Echoing this, one end-user in Slovenia stated: *"If I were to do it, I would begin with certain construction examples, such as garages that no one lives in. I would conduct measurements there and, with assistance from independent institutions, demonstrate that radiation is essentially non-existent. This could pave the way for its application in ordinary constructions. I would certainly not start with residential buildings" [2.E.S]*. In Czechia, the elevated health concerns among end-users prompted additional caution, even with non-residential applications: *"I don't know if I would want that in my immediate proximity. I'd rather have it quietly in that fence. I don't think I'd mind that, but still I'd want to get that painted, or I'd like to treat it somehow so the radiation wouldn't leak out" [2.E.C]*.

Our analysis indicates the least pronounced concerns in Belgium. Both stakeholder groups had broad concerns. For example, they mentioned that alternative cement should be *"safe for use in production" [13.I.B],* and *"within limits" [3.E.B]*.

3.1.1. Perceived trustworthiness of certifications

This sub-theme emerged as one of the main factors shaping perceptions of health risks, with a notable contrast between Belgium and Slovenia. In Belgium, the lower health risk perception among both stakeholder groups was linked to their higher trust in certification. End-users in Belgium exhibited trust in the safety of products in the market. As one participant said: *"If that is extreme, then it will not be allowed to be put on the market" [9.E.B]*. Another participant explained: *"If it is really too radioactive, then it should never be used. I trust the inspection authorities on that" [8.E.B]*. Through certification, companies can guarantee the safety of their product:

> "I think we, as an industry, if the product is approved and certified, then we will agree, and then we will be ready to use the product." [5.I.B]

In Slovenia, scepticism towards certification underscores a more cautious approach. Both stakeholder groups' higher perceived risk is linked to lower trust in certification. Despite acknowledging its necessity, certification did not equate to the safety of the product, primarily because of an underlying mistrust in certifying authorities: *"As soon as you hear radioactive, you lose interest, right? I mean, that's quite a problem, even though it's low. No, it's low now, but then in 10 years, they'll figure out that it's not that low" [11.E.S]*. Slovenia's high recycling rate, as reported by the European Environment Agency (2023), underscores a societal inclination towards resource eff iciency, which could translate into a positive reception of alternative cement solutions that promote sustainability. However, recent criticism of Slovenia's largest cement plant regarding air pollution (CIPRA, 2022) provides context that enriches our comparative study: a robust recycling ethos in Slovenia coexists with the health challenges related to cement production. To alleviate their health concerns, both stakeholder groups sought additional assurances such as detailed information and explanations, as well as approval from other trusted entities:

> "If experts unanimously agree that it's safe and poses no harm, then I have no problem with it." [6.E.S]

This theme was less pronounced in Czechia, particularly among end-users. Despite the link between certification and health concerns, due to negative past experiences in the country (see Section 2.1), some participants stated that these materials would not be allowed in the market:

> "It is not allowed, and we have standards for that. Radon is monitored here and people are sensitive to that. Lung cancer and radon have been dealt with a lot in the country, even among us – some houses were demolished or so-called undercut to shield them" [4.I.C].

3.1.2. Experience with similar materials

Stakeholders' health concerns were also influenced by their past experiences with similar materials. This theme emerged most frequently during the interviews in Czechia. Some of the end-users recounted past experiences, with one noting, *"Due to historical reasons in Czechia, especially from those who lived in houses constructed with radioactive fly ash[6]; I know many who developed lymph node cancer" [5.E.C]*. Another added: *"So it could cause cancer over time" [9.E.C]*. Awareness of previous negative incidents has led to elevated health concerns regarding the use of alternative cement. In line with this, industry representatives stated that customers would not accept the use of alternative cement: *"But that risk seems familiar and, if the public knows, I believe the majority of people would not want it" [3.I.C]*. This sentiment is echoed in concerns that switching to alternative cement will not be justifiable: *"It wouldn't be worthwhile. […] We have radioactivity linked to cancer, and even a lower price would not solve that if it was written there or people had that information" [4.I.C]*. To address the current negative connotation of these materials, one participant suggested *"using them in government contracts" [6.I.C], implying that the government prescribes the use of alternative cement in their construction projects. This strategy would enhance public trust by associating the materials with governmental approval and incorporating them into public infrastructure, such as state buildings, thereby normalising their application and demonstrating their safety and reliability.*

Similar patterns were observed in Belgium and Slovenia, even though participants there were mostly unaware of the prior use of NORM-containing by-products. Participants raised health concerns when they associated the use of NORM-contained by-products with previous problematic use of hazardous materials in the market. For example, in Belgium, although most participants were receptive to using alternative cement, one expressed scepticism about its use, even with certification. This participant referred to a building material initially regarded as safe, but later discovered it to pose harmful health risks: *"For example, asbestos used to be a good building material. […] But something will probably come up at some point where people will say, 'ah well, we shouldn't have used that either'." [11.E.B]*

Participants with a history of successfully managing hazardous materials tended to feel more confident about the use of alternative cement. Previous experience helped them overcome potential obstacles associated with the use of by-products containing NORMs; thus, they expressed fewer health concerns: *"We have conducted leaching tests for years, so there is sufficient experience there to say that it is safe. Frankly, I don't have any experience with radioactivity. I don't know. But, of course,*

[5] […] is used when a quote is given as an example, but the middle words or sentence(s) have been omitted because they are not relevant to the study or the example given.

[6] The use of fly ash, by-product of the local coal power station, in porous concrete production resulted in exceeding the radon (^{222}Rn) concentration in some dwellings.

let's say this will have to be handled appropriately" [8.I.B]. This is also evident in the following quote from an end-user:

> "I would primarily research that. I had a similar issue with my kitchen countertop made of granite or stone, which is also supposed to be radioactive, but I looked into it and found that the levels are so low that they're insignificant. I would make a similar decision here." [6.E.S]

This response highlights the importance of providing clear, comparative information on the radioactive levels of sustainable cement and the raw materials used in its production relative to conventional cement. Communicating this information comprehensively yet simply, in a way that end-users can easily understand, is crucial for building trust and addressing perceived health risks associated with its use. Future research should focus on systematically comparing the radiological properties of sustainable and conventional cements, as well as exploring effective ways to communicate these findings to diverse stakeholders.

Health concerns related to disruptive technologies have been highlighted in several studies. Arning et al. (2020) identified health concerns as a key factor in public scepticism towards carbon capture and utilisation. Etale et al.'s (2020) study on the willingness to use recycled water in Australia and South Africa indicated that greater trust in institutions leads to lower perceived health risks. Our findings also align with Scovell's (2022), in which positive experiences with similar technologies were identified as the contributing factors to acceptance. Similarly, negative personal experiences have been shown to increase risk perceptions (Siegrist and Árvai, 2020; Xie et al., 2019).

3.2. Performance concerns

This theme emerged among all participant groups. There were no major differences in their concerns regarding the workability and performance of alternative cement. Validation of long-term durability and resilience emerged as key factors that reduce the participants' performance concerns. Performance-related durability and resilience are essential for materials such as cement, because they ensure that buildings can maintain stability over time. One participant stated: *"It must have the same properties, which perhaps won't change over time, and won't be affected by weather and such" [5.E.C].* A flaw in the product can endanger human life: *"Construction is about safety. If you construct something that ultimately lacks strength, resilience, or durability, you create potential danger" [9.I.B].* Therefore, *"introducing a revolutionary binder into the market [...] may be a bit riskier than other products where there are no such [safety] concerns" [3.I.S].*

Furthermore, some participants perceive "*environmentally friendly options as slightly more complicated" [5.E.S]*, which often led them to favour traditional cement. Participants stressed that alternative cement must be convenient to work with. One participant from the construction companies emphasised: *"In construction, there is a saying that paper can handle everything. I mean, it's nice to say that this is such and such a cement and that it has such and such properties when it was worked with it in the lab, but when this is actually used on construction sites, things can vary a bit and it may be, for example, that some cement types are less popular because it causes certain inconveniences on the site" [1.I.S].* Workability concerns were particularly pronounced among end-users in Belgium, who were more actively involved in the construction of their houses. Participants emphasised the need for alternative cement to be *"easy to use" [9.E.B]* and not require *"any specialised protective equipment" [1.E.S].* A common sentiment among these participants was the need for the cement to be straightforward to work with:

> "We do some of the construction work on our house ourselves. We should be able to easily work with that material, not fight with it." [5.E.C]

3.2.1. Validation of long-term durability and resilience

To address participants' performance concerns, validation and guarantee of the long-term durability of alternative cement is required. Participants emphasised that alternative cement must *"align with specifications" [8.E.C]* and *"comply fully with established standards and regulations" [6.I.C].* While compliance with standards lowers participants' performance concerns, some industry representatives highlighted that *"sometimes, the regulation itself is the main problem" [2.I.S].* They pointed out that *"various bureaucratic hurdles and lengthy processes" [3.I.S]* often dissuades the adoption of sustainable practices, as "*most people don't even find it worthwhile" [6.I.C].* Participants urged streamlined and effective regulations that do not themselves become barriers.

End-users, typically those less experienced with cement, place their trust beyond certifications, valuing *"the opinions of those who use it to determine whether the product is good or not" [4.E.S].* This is evident in the following statement: *"This isn't where you rely on the government or even scientists, as they can't-test it! The experience of those builders is what matters" [5.E.C].* In addition to contractors, other frequently mentioned trusted entities include architects, reputable institutions, building shops, and acquaintances.

End-users generally expect the house they build to *"be functional for the rest of [their] life" [5.E.C].* Given the novelty of alternative cement and their structural importance, the above-mentioned enablers should be accompanied with practical examples of the use of alternative cement in other buildings: *"So this is a novelty. I think I'd wait first to see what the results and references would be" [1.E.C].* A prevalent concern among participants was *"the absence of references" [5.E.S].* They emphasised the need for it to be *"historically proven" [5.E.C] "to see if it actually does what it claims" [2.E.B].* One industry representative articulated:

> "So, with these cements, we are not sure because they are so new. [...] I wouldn't recommend them because we don't know what they mean in the long run." [4.I.S]

Our findings align with those of previous studies investigating barriers to the circular economy, which suggested revising existing restrictive product regulations. These were identified as significant impediments, owing to their misalignment with the principles of sustainable production. They recommended the introduction of new regulations to promote sustainable production (Geissdoerfer et al., 2023; Gue et al., 2020; Kirchherr et al., 2018).

3.3. Economic concerns

This theme highlights the economic challenges stakeholders encounter when shifting towards sustainable alternatives. Incentives and obligatory pathways emerged as sub-themes identified as key enablers for overcoming economic concerns. Economic concerns were consistent across countries and both stakeholder groups generally acknowledged that *"if nothing is done about environmental issues, they will only worsen" [9.E.B].* However, there was also a common perception that *"what is more environmentally friendly is more expensive" [5.E.S],* which prevents this recognition from translating into action. One participant outlined the dilemma, stating: *"We also want our children to have a better future. But for the moment, changing would lead me to bankruptcy" [9.I.B].* There was a conspicuous *"lack of urgency" [12.I.B]* among participants to adopt environmental actions. This hesitancy stems from viewing sustainability as a long-term goal, rather than an immediate priority. For instance, one participant remarked: *"Over a horizon of 30 to 50 years, I believe changes will be necessary; maybe I will not be alive by then, but maybe I will" [3.I.C].* Immediate economic challenges overshadow the urgent need to address environmental issues. Participants emphasised that: *"It is an uncertain time for choosing even more expensive materials that might be ecologically better in the long run" [2.E.B].* Echoing this, one industry representative mentioned that: *"Currently, there is a slight decline in this [opt for sustainable alternatives] due to the economic crisis, high inflation, a problem with the supply of materials, and the Ukrainian War. I don't think* *any big ecological turbulence in traditional construction can happen now" [4.I.C].*

Furthermore, industry representatives noted a lack of demand for sustainable materials, explaining that customers are generally positive about sustainable options "until they have to pay for it" [8.I.C]. During the interviews with end-users, this lack of demand was linked to the fact that "When building a house, funds are usually limited, making it difficult to focus on every detail, including environmental impact" [6.E.S]. Another underlying reason was that construction of the house is "primarily the biggest expense we [end-users] have in life" [10.E.S]. Hence, opting for a novel, yet unverified product introduces considerable financial uncertainty: "You always have to take out a mortgage on it, and then with this new thing, to find out that somehow it's a problem with the construction, I would just be concerned" [5.E.C]. Industries find a shift towards sustainable alternative cement, which is impractical without guaranteed customer demand:

> "We cannot use cement that is much more expensive as it would make us non-competitive with our colleagues." [8.I.S]

3.3.1. Incentives

Both stakeholder groups mentioned that they opt for sustainable solutions only *"if it yields a profit for them elsewhere" [3.E.B]*. In the absence of financial motives, they were less inclined to invest in sustainable cement. One end-user stated: *"I'll go for solar power because then you have some financial benefits or savings. At the same time, you do something good for the environment, so it's a win-win. The question is, if it was only about the environment, you pay three times more, and do something good for the environment, there would be fewer decisions made in that direction" [11.E.S].*

Both stakeholder groups mentioned government incentives as a form of encouragement, but also that *"currently, there is no leverage or stimulation" [5.E.C]*. One participant said: *"If you want to do it, you have to pay for it without receiving something. There is no impulse from the government" [11.I.B]*. Some industry representatives pointed out that incentives can also take the form of *"company image" [2.I.B]* or *"PR* [Public Relations]*" [6.I.S]*. However, the absence of standardised parameters complicates the process of making credible sustainability claims. As one participant explained: *"Everyone interprets sustainability differently, and even I am uncertain about how to understand and declare it in the context of our company" [6.I.C]*. This ambiguity often leads to greenwashing: *"Customers no longer know whom to believe" [9.I.B]*. This was also pointed out during the interviews with end-users: *"It's challenging to be a judge here, and very difficult to process all the different information coming from all sides. There's a lot of deception and misleading people as a result" [7.E.B].*

Participants repeatedly mentioned that: *"It is essential to maintain consistency in how environmental product declarations are expressed'' [4.I.C]*. The lack of *"a universally recognised calculation method" [6.I.B]* demotivates companies to invest in sustainable solutions: *"It often feels like a matter of saying something that sounds good, the use of alternative fuels, and alternative materials in order to increase or maintain profits. We know that is the case in every company. My personal opinion is that everything has too much to do with these profits. This sometimes obscures the truth about our motives and whether there is genuine commitment to sustainability. Where is this boundary, and where is this truth, or are these just some nice words?" [6.I.S].*

3.3.2. Obligatory pathways

This sub-theme was mentioned more frequently during the interviews with industry representatives. The participants highlighted that, without direct benefits from using alternative cement, regulatory measures are essential to facilitate a transition. One participant stated: *"Clearly, the industry will not adapt unless there is a necessity or advantage to do so. Why should we torture one another? [...] Regulation and standardisation are absolutely necessary. Without them, change is not possible" [6.I.S]*. Echoing industry's perspective, an end-user mentioned that: *"People are unlikely to significantly reduce consumption unless faced with a shortage or a ban" [7.E.S]*. Participants indicated that the most effective way to switch to sustainable cement is through obligations, particularly due to higher associated costs: *"Clear rules are necessary, and who better to set them than politicians, since it is unpopular and currently also expensive" [3.E.C]*. Some industry representatives stated that there is no significant mandate for enforcing the use of sustainable cement in concrete production: *"In other areas, there are even requirements, not just desires [...], whereas for concrete, this trend is very low or almost non-existent" [7.I.S]*. To render the use of traditional cement financially unviable, representatives advocated for increasing CO_2 taxes and emission allowances: *"Should the emission allowances increase so high that it will stop being profitable to use natural cement" [9.I.C]*. They argued that legal obligations would *"guarantee the same rules of the game for everyone" [3.I.S]* and establish *"a single and fair market" [6.I.C]* within which *"no one could abuse them" [3.I.C]*.

Moreover, participants highlighted that: *"The sustainability aspect is not yet a requirement in public procurement" [9.I.C]*. This situation further discourages companies from adopting sustainable solutions, as, currently, *"the government needs to sign contracts with the cheapest contractor" [6.I.B]*. Participants suggested that authorities need to *"put an environmental criterion into their tender" [5.I.S]*.

Our findings confirm those of Sáez-Martínez et al. (2016), who highlighted the central role of regulations in driving sustainable solutions, while Tokbolat et al. (2020) indicated the role of perceived benefits of sustainable investments. Niaki et al. (2019) even found financial motives to be the primary motivators for adopting sustainability practices. Furthermore, prior studies (Adams et al., 2017; Guerra and Leite, 2021) confirmed the role of consistent and clear environmental regulations.

4. Concluding remarks

This study investigated the perceptions of industry representatives and end-users across Belgium, Czechia, and Slovenia, regarding the use of alternative cement made with NORM-contained by-products. It also sought to identify country-specific factors that affect these perceptions. Through our analysis, we identified three key concerns among both industry and end-users that influence their perception of alternative cement: health, performance, economic. Notably, while health concerns varied, performance and economic concerns were expressed consistently across the countries. Country-specific differences related to health concerns underscore the need for tailored approaches when promoting alternative cement in different contexts.

In Czechia, reassuring end-users about the safety of alternative cement requires transparency and careful communication that addresses the historical context and its impact on current perceptions. While the industry's apprehension largely reflects end-users' negative attitudes, there is a prevailing belief that certifying authorities will not approve the use of NORM-contained by-products in alternative cement in Czechia. A strategic response is required to alter this perception, potentially through using alternative cement in government projects and implementing additional safety measures, such as radon (^{222}Rn) testing. Such measures are required to gradually change negative perceptions and assure both the industry and end-users of its safety. Similarly, in Slovenia, perceived health concerns were high, although they resulted from low trust in regulatory authorities. Effectively addressing these concerns requires engaging with trusted institutions and leveraging the best practices of countries with stringent safety regulations. Conversely, in Belgium, a high level of trust in the safety of certified products underscores the need for communication strategies that emphasise regulatory approval. However, over-emphasising certification might lead consumers to question its necessity, especially if risks are perceived as low (see Siegrist and Hartmann's (2020) study on novel food technologies). Therefore, a nuanced approach is needed to avoid the inadvertent signalling of potential risks.

Performance concerns were consistent across the countries. Addressing these concerns requires going beyond merely complying with the established standards. Communication strategies should focus on highlighting endorsements from trusted institutions specialising in building materials, such as reputable construction companies, to enhance end-user trust in the reliability of alternative cement. Additionally, demonstrating practical real-world examples that showcase the durability and resilience of buildings constructed with alternative cement is critical in their decision-making process. The practicality and ease of use of alternative cement should also be emphasised in communications.

Finally, to effectively address the economic concerns of stakeholders regarding the transition to alternative cement, a comprehensive approach from governmental bodies is required. Authorities need to implement globally standardised sustainable parameters and employ stringent regulations, along with incentives, to ensure a balanced yet impactful approach. This combination of regulatory measures and incentives is necessary in order to encourage stakeholder participation and prevent greenwashing practices that can arise in the absence of clear guidelines. Such governmental actions can help ensure the fair and equitable adoption of sustainable practices across the industry. Furthermore, government involvement in public procurement can create economies of scale, serving as a catalyst for the successful implementation of alternative cement in major projects.

This study has highlighted the indispensable role of authorities in facilitating the transition to alternative cement. It calls for a concerted effort that includes customised communication, nuanced policy strategies, and strategic incentivisation, all of which are reflective of each country's unique context and stakeholder concerns. By exploring non-technical perspectives, this study enriches the existing body of literature on alternative cement and extends our understanding of sustainable practices within the construction industry.

To sum up, we derive four hypotheses from our work that could be tested in quantitative study as future work. H1: Trust in certifying authorities reduces perceived health risks. H2: Associating the use of alternative cement with previous health-related problems increases the perceived health risk. H3: Practical examples of the use of alternative cement in building materials reduce the perceived performance risk. H4: The absence of financial incentives hinders the adoption of alternative cement.

Due to the nature of qualitative research, it is not feasible to assign weights to the identified themes pertaining to their various concerns. We recommend conducting a quantitative study as future work. Such a study would test the hypotheses derived from this exploratory study, evaluate the relative significance of these themes, and potentially enable the generalisation of the findings. Furthermore, we suggest conducting a study in a non-European context.

CRediT authorship contribution statement

Nazanin Love: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Robbe Geysmans:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Sara Leroi-Werelds:** Writing – review & editing, Conceptualization. **Nadja Železnik:** Writing – review & editing, Data curation. **Tanja Perko:** Writing – review & editing, Funding acquisition, Conceptualization. **Wouter Schroeyers:** Writing – review & editing, Supervision, Funding acquisition. **Robert Malina:** Writing – review & editing, Supervision, Conceptualization.

Funding

This work was supported by the Euratom research and training programme 2019–2020 under grant [agreement No 900009].

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nazanin Love reports financial support was provided by Euratom Research and Training Programme. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to express their gratitude to the interviewees for their participation in this study and for providing valuable insights. Furthermore, we would like to express our gratitude to Ela Praznik, Matija Simon, Christophe Ruiters, Ivana Fojtíková, Zuzana Freitinger, and Peter Mihok for their invaluable help during the interviews, transcription, and translation processes.

Appendix 1

Interview Protocol Development

The initial interview protocol was crafted in English before translation into Dutch,[7] Slovenian, and Czech to accommodate the linguistic differences among the three countries. The development of the industry interview protocol [8] was shaped by an extensive review of the relevant literature and insights from both industry experts and academic researchers, ensuring its relevance and comprehensiveness. For end-users, we tailored the questions accordingly. For example, while we asked industry representatives about their decision-making process for buying cement, we posed more general questions to end-users about their choice of materials during the construction of their houses. We also simplified some of the terminologies, such as changing 'cementitious binders' to 'alternative cement'. We conducted five pilot studies with end-users and made necessary adjustments; for instance, we decided not to provide examples of the by-products used because they were perceived as too technical by the participants.

By adopting a semi-structured interview approach, we oriented the conversations around a topic guide. Each section contained a series of open-ended and potential probing questions designed to encourage detailed and reflective responses. To ease participants in the discussion, we started with more general questions about their decision-making process when choosing cement (for industry representatives) and building materials (for end-users). We then gradually transitioned to a discussion on sustainable building materials. Before delving into the participants' perceptions of cement made with NORM-contained by-products, we provided them with objective general information about the topic. This information was

[7] Interviews with representatives from industry in Belgium were conducted in English since participants expressed comfort to do the interview in English.

[8] Interview protocol is a structured framework that includes a list of questions and the sequence in which these questions are asked. It also encompasses guidelines for the interviewer on how to handle different types of responses, and manage the overall direction and flow of the conversation.

delivered in two steps. First, we explained the potential of using by-products in cement to reduce its environmental impact. In the second step, we informed them that some of these by-products are categorised as NORM. The flexibility inherent in our semi-structured format allowed for spontaneous exploration of emergent themes, which were not strictly confined to the initial guide. This adaptive nature of the protocol ensured that we could capitalise on the unforeseen, yet valuable, insights offered by participants during the interviews.

The researcher's role was not merely to administer questions, but to actively navigate the conversation, maintaining a balance between the intended topics and the dynamic flow of the dialogue. This approach facilitated a deep and comprehensive understanding of stakeholders' perceptions and attitudes towards the use of alternative cement.

Interview Protocol

Industry	End-users
General	
Please briefly introduce yourself and your company and explain your role & responsibilities in the company.	Please briefly introduce yourself. What type of property are you currently building or renovating? - Is it a place for yourself to live or rent out/sell? Who is and/or will be living in the house with you? - Children (number)? age? Parents?
Briefly explain the type of cement currently used in your production. And why is that? - Except for [their answer to the previous question], what other factors are taken into account when choosing the cement, you use? What is your company's decision-making process for choosing what cement to buy? If they struggle to answer, ask: - Who is usually involved in making this decision? (their role in the company) - Would this be a lengthy process if you would like to change the type of cement you use? @Do you take into account environmental sustainability in your decision making process?	What criteria did you take into account when choosing the house, you are currently living in? What are the most important factors that you consider in choosing the products when building/renovating your house? -Except for [their answer], what other factors do you take into account? Can you guide me through your decision-making process when deciding which products/materials you choose to use for the construction of your house? - Who is involved? (Was the architect involved? Contractor?) - Where or from whom would you seek information? - How long does it usually take you to make these decisions?
Environmental behaviour	
How do you define environmental sustainability? In what ways does your company affect or is affected by environmental issues? - How do you see your company's environmental impact? [if they don't mention the product (cement/concrete), ask them specifically about the impact of their products] - How do you see the environmental impacts of your company in comparison to other companies in your sector? - How do you see the environmental impacts of the entire concrete and cement industry? Do you see any changes in the demand for more environmentally sustainable products in the market? - Where do you see the role of price in this? In your opinion, what can be done to tackle or deal with [above-mentioned] impacts? @Are actions taken by your company to reduce its impact on the environment? Please explain. - Is it something that you do on your initiative or is it something that you are legally obliged to or feel the pressure to do so? [pressure by who?] E.g., change in legislation or CO_2 tax [If they mention the pressure from other actors, ask: - Is this a fair expectation? - Is it possible?] So far, is there anything holding you back from taking more environmentally sustainable actions? What encourages you to reduce your CO_2 emissions? Where do you see the government's role in this? @Currently, is there any help offered by authorities to become more environmentally sustainable? What kind of help? Is it helpful? How? @Do you have any plans in the future to become a more environmentally sustainable company? Why?	What comes to your mind when you hear the term 'environmental sustainability'? In your opinion, what are the major current environmental issues? Do you think you and your family are affected or might be affected in the future by any of these environmental issues? - Who is affected? - Who else? (You and/or your children/next generation) - When? (In the (far) future or right now?) - Why do you think that? Who do you see being as most responsible for the current environmental issues? - Are there other actors you think are responsible? - Try to understand their opinion on the magnitude of the impacts of different actors. @If they do not mention consumers, ask: How do you see consumers' role in environmental issues? Who do you consider responsible for tackling these environmental issues? - Do you think that enough action has been taken to solve environmental issues? To what extent do you believe that your purchase or consumption decisions negatively affect environmental issues? - Why is that? - Can you give me some examples of your actions/choices that negatively impact environmental issues? - Have you recently made a decision where considering environmental impacts was a part of your decision? If so, can you explain this in an example (your way of thinking and what product was it)? How often have you come across environmentally friendly options when looking for building materials? Do you consider environmental sustainability when choosing materials/products for building or renovating your house? ↓ Can you give an example? Explore their motivation (e.g., saving money, the planet, effects on human health?) - What has mostly held you back? - What has encouraged you? - What will encourage you more? How would you describe the environmental behaviour of the members of your household? @Some building materials are claimed to be more environmentally friendly; do you have any idea how/why they are environmentally friendly? - What do you think about these materials? [Just listen to what they say and if they are short ask them why that is?] If in the previous section they mentioned that they chose environmentally friendly products, ask: Do you know why … is more environmentally friendly than the traditional form? Have you ever purchased any cement yourself in the last 5 years? Are you aware of the environmental impact of cement production?
Briefly explaining the alternative cement	
My research aims to bridge industry and scientists who are working on new types of cementitious binders made with 70–90% industrial by-products. Because they have a flexible process and use different concentrations of various types of industrial by-	Now, I will talk about the product that is at the core of this research; namely, an alternative to traditional cement. This product is currently under development and has the potential to substitute traditional cement. To give you some background information

(continued on next page)

(*continued*)

Industry	End-users
products, the performance of these cements can be modified based on the specific applications and industry demands. This can entail new opportunities in the concrete industry. Because secondary raw materials are used instead of limestone, they preserve raw materials and contribute to the circular economy. In addition, they have the potential to reduce CO2 emissions during production. Before we go into details about the by-products, based on this brief information, we would like to hear your opinion about this type of alternative cement or, in general, about alternative cementitious binders. (Immediately ask the question below.)	about the production of cement, there are several points I want to highlight: - A lot of raw materials are used (for the production of 1 ton of cement clinker, 1.7 tons of raw materials such as clay and limestone are needed); - To produce cement, very high temperatures are needed to melt the raw materials (1500 °C), which require a significant amount of energy. This results in significant amounts of CO_2 emissions. In order to reduce emissions, this product will use less natural resources as it is made with 70–90% of by-products. These by-products replace natural resources to a certain extent and do not require these tremendous high temperatures; therefore, they contribute to reducing emissions during the production process. The by-products themselves come from different industries. The final result is a new type of cement that has a flexible process and uses different concentrations of various types of industrial by-products, resulting in the cement performance being modified according to its composition. Before we go into details about the by-products, we would like to hear your opinion about this type of alternative cement.
Perception of the product	
What are the main criteria that would affect your opinion to consider using these types of new binders in your production? -[Mechanical properties, Sustainability Regulation? Standards] -Whose approval of this product would matter to you? (Scientists, government, major companies, experts in your company, concrete federation, etc.) If they were negative towards this alternative cement, ask: Under what circumstances might it be worthwhile for your company to switch to cement? OR Do you think you may consider this in the future? What may change in the future? Do you think contractors and architects will be in favour of or against this product? - What about the public? What types of companies do you expect would buy/use this product? Will the actions of other companies influence yours?	What are your thoughts on this product? What criteria in this cement would matter to you if you were to consider it when building your house? -What other criteria will you consider in making this decision (price, quality, safety, etc.)? -What [else] might hold you back? [Why do you think … might be a problem?] -What [else] might encourage you? Whose approval of this product do you take into consideration? (Scientists, government, construction companies, producers, family/friends) - If they are unsure: If this type of cement is used in most newly built houses, will you be more open to this product? Why? - If they are negative: Do you think your opinion might change in the future? Why?
As mentioned earlier, this cement can be made with various industrial by-products, some of which you might be familiar with, such as metal slag (e.g., copper slag) and phosphogypsum (a by-product in the phosphorus fertiliser industry). Similar to some other by-products that are currently being used, such as fly ash, the enhanced level of natural radioactivity of these by-products adds to the importance of recycling them; for example, using them in cementitious binders. The goals in developing these new types of cementitious binders are to become closer to carbon neutrality and to improve the mechanical properties of these binders. Of course, it is not possible to have all beneficial properties at the same time. As previously mentioned, the properties and environmental profile would vary depending on the configuration.	As I mentioned earlier, this cement can be made with various industrial by-products; some have already been used in lower quantities in cement production. Similar to some other by-products that are currently being used in the cement/concrete production, the radioactivity of these by-products adds to the importance of recycling them. The goal of developing these new types of cement is not only the environmental aspects such as reducing CO_2 emissions, depletion of raw material and recycling by-products, but also improving the mechanical properties of cement. Of course, it is not possible to have all beneficial properties at the same time. As I mentioned, the mechanical properties and the environmental profile would vary depending on the configuration.
Ask the same questions in the previous section Given the information that you now have, what are your thoughts about this product?	
+ **Finally ask these:** @What do you think of the fact that the by-products used in these cementitious binders have enhanced levels of radioactivity? Who do you think will be most concerned about the radioactivity of the by-products used in this alternative binder? (Contractors, home-owners, government, workers, producers?)	+ **Finally, ask these:** What is your opinion on radiation? What comes to mind if you hear the word 'radiation'? Are you aware of being exposed to radiation in your everyday life? - Can you give me examples of types of radiation? Do you expect any risks related to the radioactivity of the residues used to produce this cement? Can you explain this further? - If yes: Who will be the most at risk? Can you explain this further, with an example?
If there are questions that you didn't have a chance to cover, ask: This covers most of what we needed to know, but there are a couple of specific questions that I want to ask before we finish.	
We have covered everything. We are just at the beginning of this research and would be interested in hearing if you have any thoughts about what you think would be interesting for us to pursue, kind of angles, or questions. It can be challenging to find the right company and the right person in that company to talk to. I was wondering if there is anyone specific that you think it would be beneficial for us to talk to? Thank you again for your time. I ensure that your data will be kept strictly confidential.	We have covered everything. We are just at the beginning of this research and would be really interested to hear if you have any thoughts about what you think would be interesting for me to pursue, kind of angles, or questions. Thank you again for participating. I ensure that your data will be kept strictly confidential.

@: This symbol means that this question might have been covered in the previous answer.

Data availability

Data will be made available on request.

References

Adams, K.T., Osmani, M., Thorpe, T., Thornback, J., 2017. Circular economy in construction: current awareness, challenges and enablers. In: Proceedings of the Institution of Civil Engineers-Waste and Resource Management, vol. 170. Thomas Telford Ltd, pp. 15–24. https://doi.org/10.1680/jwarm.16.00011, 1.

Arning, K., Offermann-van Heek, J., Sternberg, A., Bardow, A., Ziefle, M., 2020. Risk-benefit perceptions and public acceptance of carbon capture and utilization. Environ. Innov. Soc. Transit. 35, 292–308. https://doi.org/10.1016/j.eist.2019.05.003.

Batel, S., 2020. Research on the social acceptance of renewable energy technologies: past, present and future. Energy Res. Social Sci. 68, 101544. https://doi.org/10.1016/j.erss.2020.101544.

Braun, V., Clarke, V., 2021. Thematic Analysis: A Practical Guide. Sage Publication Ltd.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3 (2), 77–101. https://doi.org/10.1191/1478088706qp063oa.
CIPRA, 2022. Bad atmosphere soča valley. https://www.cipra.org/en/news/bad-atmosphere-in-the-soca-valley. (Accessed 3 May 2024).
Creswell, J.W., Creswell, J.D., 2017. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. Sage Publications.
de Brito, J., Kurda, R., 2021. The past and future of sustainable concrete: a critical review and new strategies on cement-based materials. Construct. Build. Mater. 310, 125123. https://doi.org/10.1016/j.conbuildmat.2021.125123.
Duchesne, J., 2021. Alternative supplementary cementitious materials for sustainable concrete structures: a review on characterization and properties. Waste and Biomass Valorization 12, 1219–1236. https://doi.org/10.1007/s12649-020-01068-4.
Emodi, N.V., Lovell, H., Levitt, C., Franklin, E., 2021. A systematic literature review of societal acceptance and stakeholders' perception of hydrogen technologies. Int. J. Hydrogen Energy 46 (60), 30669–30697. https://doi.org/10.1016/j.ijhydene.2021.06.212.
Etale, A., Fielding, K., Schäfer, A.I., Siegrist, M., 2020. Recycled and desalinated water: consumers' associations, and the influence of affect and disgust on willingness to use. J. Environ. Manag. 261, 110217. https://doi.org/10.1016/j.jenvman.2020.110217.
European Council, 2024. Climate change: what the EU is doing. https://www.consilium.europa.eu/en/policies/climate-change/. (Accessed 3 May 2024).
European Environment Agency, 2023. Waste recycling in europe. https://www.eea.europa.eu/en/analysis/indicators/waste-recycling-in-europe. (Accessed 5 May 2024).
Fereday, J., Muir-Cochrane, E., 2006. Demonstrating rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. Int. J. Qual. Methods 5 (1), 80–92. https://doi.org/10.1177/160940690600500107.
GCCA, 2023. Cement Industry Net Zero Progress Report. London. https://gccassociation.org/wp-content/uploads/2023/11/GCCA_Cement_Industry_Progress_Report_2023.pdf. (Accessed 5 May 2024).
Geissdoerfer, M., Santa-Maria, T., Kirchherr, J., Pelzeter, C., 2023. Drivers and barriers for circular business model innovation. Bus. Strat. Environ. 32 (6), 3814–3832. https://doi.org/10.1002/bse.3339.
Gerson, K., Damaske, S., 2020. The Science and Art of Interviewing. Oxford University Press.
Gibson, W., Brown, A., 2009. Working with Qualitative Data. Sage Publication Ltd. https://doi.org/10.4135/9780857029041.
Glaser, B., Strauss, A., 2017. Discovery of Grounded Theory: Strategies for Qualitative Research. Routledge. https://doi.org/10.4324/9780203793206.
Griffiths, S., Sovacool, B.K., Del Rio, D.D.F., Foley, A.M., Bazilian, M.D., Kim, J., Uratani, J.M., 2023. Decarbonizing the cement and concrete industry: a systematic review of socio-technical systems, technological innovations, and policy options. Renew. Sustain. Energy Rev. 180, 113291. https://doi.org/10.1016/j.rser.2023.113291.
Gue, I.H.V., Promentilla, M.A.B., Tan, R.R., Ubando, A.T., 2020. Sector perception of circular economy driver interrelationships. J. Clean. Prod. 276, 123204. https://doi.org/10.1016/j.jclepro.2020.123204.
Guerra, B.C., Leite, F., 2021. Circular economy in the construction industry: an overview of United States stakeholders' awareness, major challenges, and enablers. Resour. Conserv. Recycl. 170, 105617. https://doi.org/10.1016/j.resconrec.2021.105617.
HERCA, 2016. Common understanding and recommendations related of the BSS requirements on radon in workplaces. Available at:https://www.herca.org . (Accessed 20 November 2024).
Hulka, J., Thomas, J., 1999. Remedial Measures in Czech Houses with High Radium Content in Building Material. International Atomic Energy Agency (IAEA).
IAEA, 2024. ENVIRONET NORM Project. Available at: https://nucleus.iaea.org/sites/connect/ENVIRONETpublic/SitePages/Home.aspx. (Accessed 20 November 2024).
IAEA, 2022. Safety and Security Glossary: Definitions and Explanations of Safety Terms. International Atomic Energy Agency, Vienna. Available at:https://www.iaea.org/publications/15236/iaea-nuclear-safety-and-security-glossary.
IAEA, 2013. The Management of Radioactive Residues from NORM Industries. International Atomic Energy Agency. Available at:https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1712_web.pdf.
ICRP, 2019. Radiological protection from naturally occurring radioactive material (NORM) in industrial processes. ICRP Publication 142. Ann. ICRP 48 (4).
IEA, 2023. Net zero roadmap A global pathway to keep the 1.5 °C goal in reach. Available at: https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach. (Accessed 1 February 2024).
Juenger, M.C., Snellings, R., Bernal, S.A., 2019. Supplementary cementitious materials: new sources, characterization, and performance insights. Cement Concr. Res. 122, 257–273. https://doi.org/10.1016/j.cemconres.2019.05.008.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the circular economy: evidence from the European union (EU). Ecol. Econ. 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028.
Knott, E., Rao, A.H., Summers, K., Teeger, C., 2022. Interviews in the social sciences. Nature Reviews Methods Primers 2 (1), 73. https://doi.org/10.1038/s43586-022-00150-6.
Kumar, A., Saravanan, T.J., Bisht, K., Kabeer, K.S.A., 2021. A review on the utilization of red mud for the production of geopolymer and alkali activated concrete. Construct. Build. Mater. 302, 124170. https://doi.org/10.1016/j.conbuildmat.2021.124170.
Love, N., Geysmans, R., Leroi-Werelds, S., Perko, T., Malina, R., Schroeyers, W., 2023. Usage of alternative cementitious binders containing naturally occurring radioactive by-products: the industry's perspective. J. Clean. Prod. 387, 135903. https://doi.org/10.1016/j.jclepro.2023.135903.
Marmier, A., 2023. Decarbonisation Options for the Cement Industry (No. EUR 31378 EN). Publications Office of the European Union, Luxembourg.
Michalik, B., Dvorzhak, A., Pereira, R., Lourenço, J., Haanes, H., Di Carlo, C., Nuccetelli, C., Venoso, G., Leonardi, F., Trevisi, R., Trotti, F., Ugolini, R., Pannecoucke, L., Blanchart, P., Perez-Sanchez, D., Real, A., Escribano, A., Fevrier, L., Kallio, A., Skipperud, L., Mrdakovic Popic, J., 2023. A methodology for the systematic identification of naturally occurring radioactive materials (NORM). Sci. Total Environ. 881, 163324. https://doi.org/10.1016/j.scitotenv.2023.163324.
Miller, S.A., 2018. Supplementary cementitious materials to mitigate greenhouse gas emissions from concrete: can there be too much of a good thing? J. Clean. Prod. 178, 587–598. https://doi.org/10.1016/j.jclepro.2018.01.008.
Niaki, M.K., Torabi, S.A., Nonino, F., 2019. Why manufacturers adopt additive manufacturing technologies: the role of sustainability. J. Clean. Prod. 222, 381–392. https://doi.org/10.1016/j.jclepro.2019.03.019.
Oge, M., Ozkan, D., Celik, M.B., Gok, M.S., Karaoglanli, A.C., 2019. An overview of utilization of blast furnace and steelmaking slag in various applications. Mater. Today: Proc. 11, 516–525. https://doi.org/10.1016/j.matpr.2019.01.023.
Phiri, T.C., Singh, P., Nikoloski, A.N., 2021. The potential for copper slag waste as a resource for a circular economy: a review – Part II. Miner. Eng. 172, 107150. https://doi.org/10.1016/j.mineng.2021.107150.
Popic, J.M., Haanes, H., Di Carlo, C., Nuccetelli, C., Venoso, G., Leonardi, F., Trevisi, R., Trotti, F., Ugolini, R., Dvorzhak, A., Escribano, A., Perez Sanchez, D., Real, A., Michalik, B., Pannecoucke, L., Blanchart, P., Kallio, A., Pereira, R., Lourenço, J., Skipperud, L., Fevrier, L., 2023a. Tools for harmonized data collection at exposure situations with naturally occurring radioactive materials (NORM). Environ. Int. 175, 107954. https://doi.org/10.1016/j.envint.2023.107954.
Popic, J.M., Urso, L., Michalik, B., 2023b. Assessing the exposure situations with naturally occurring radioactive materials across European countries by means of the e-NORM survey. Sci. Total Environ. 905, 167065. https://doi.org/10.1016/j.scitotenv.2023.167065.
Sáez-Martínez, F.J., Lefebvre, G., Hernández, J.J., Clark, J.H., 2016. Drivers of sustainable cleaner production and sustainable energy options. J. Clean. Prod. 138, 1–7. https://doi.org/10.1016/j.jclepro.2016.08.094.
Scovell, M.D., 2022. Explaining hydrogen energy technology acceptance: a critical review. Int. J. Hydrogen Energy 47 (19), 10441–10459. https://doi.org/10.1016/j.ijhydene.2022.01.099.
Schroeyers, W., Sas, Z., Bator, G., Trevisi, R., Nuccetelli, C., Leonardi, F., Schreurs, S., Kovacs, T., 2018. The NORM4Building database, a tool for radiological assessment when using by-products in building materials. Construct. Build. Mater. 159, 755–767. https://doi.org/10.1016/j.conbuildmat.2017.11.037.
Scrivener, K., Martirena, F., Bishnoi, S., Maity, S., 2018. Calcined clay limestone cements (LC^3). Cement Concr. Res. 114, 49–56. https://doi.org/10.1016/j.cemconres.2017.08.017.
Siegrist, M., Árvai, J., 2020. Risk perception: reflections on 40 years of research. Risk Anal. 40 (S1), 2191–2206. https://doi.org/10.1111/risa.13599.
Siegrist, M., Hartmann, C., 2020. Consumer acceptance of novel food technologies. Nature Food 1 (6), 343–350. https://doi.org/10.1038/s43016-020-0094-x.
Snellings, R., Suraneni, P., Skibsted, J., 2023. Future and emerging supplementary cementitious materials. Cement Concr. Res. 171, 107199. https://doi.org/10.1016/j.cemconres.2023.107199.
Spencer, L., Ritchie, J., O'Connor, W., Ormston, R., Morrell, G., 2014. Analysis in practice. In: Qualitative Research Practice: A Guide for Social Science Students and Researchers. Sage Publication Ltd., pp. 295–346
SURO, 2024. Radon history. Natl. Radiat. Prot. Inst. Available at: https://www.suro.cz/en/prirodnioz/rnprogram/radon-history. (Accessed 12 March 2024).
Tokbolat, S., Karaca, F., Durdyev, S., Calay, R.K., 2020. Construction professionals' perspectives on drivers and barriers of sustainable construction. Environ. Dev. Sustain. 22, 4361–4378. https://doi.org/10.1007/s10668-019-00388-3, 22, 4361–4378.
Vargas, J., Halog, A., 2015. Effective carbon emission reductions from using upgraded fly ash in the cement industry. J. Clean. Prod. 103, 948–959. https://doi.org/10.1016/j.jclepro.2015.04.136.
Wang, D., Wang, Q., Huang, Z., 2020. Reuse of copper slag as a supplementary cementitious material: reactivity and safety. Resour. Conserv. Recycl. 162, 105037. https://doi.org/10.1016/j.resconrec.2020.105037.
Wang, R., Shi, Q., Li, Y., Cao, Z., Si, Z., 2021. A critical review on the use of copper slag (CS) as a substitute constituent in concrete. Construct. Build. Mater. 292, 123371. https://doi.org/10.1016/j.conbuildmat.2021.123371.
Xie, B., Brewer, M.B., Hayes, B.K., McDonald, R.I., Newell, B.R., 2019. Predicting climate change risk perception and willingness to act. J. Environ. Psychol. 65, 101331. https://doi.org/10.1016/j.jenvp.2019.101331.
Yang, K.H., Jung, Y.B., Cho, M.S., Tae, S.H., 2015. Effect of supplementary cementitious materials on reduction of CO2 emissions from concrete. J. Clean. Prod. 103, 774–783. https://doi.org/10.1016/j.jclepro.2014.03.018.