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Part A

7 Preparatory work for tailings pond decommissioning: Non-technical aspects

7.4 Social aspects

To analyze the socially-relevant aspects in the context of the extraction of valuable materials and raw materials from tailings ponds, we distinguish between two perception contexts: on the one hand, the perception of raw material extraction from tailings ponds by local actors (regional perception), and on the other hand, the perception of recycled raw materials from tailings ponds in the building materials industry (perception of the building materials industry). This section presents the theoretical basis of the empirical analyses in Part B. Part B presents the specific factors that influence the society's perception of the extraction of raw materials from tailings ponds at Bollrich in Goslar, Germany. In view of our qualitative sociological research approach, it is essential to include conceptual aspects in Part B.

Regional perception

In the late 1990s, the concept of the "Social License to Operate" (SLO) emerged in the mining industry as a response to increasing social criticism of the negative impacts of mining practices and the insufficient participation of mining-affected communities in mining revenues. By relying on this concept, mining operators recognize that there is value for the company, not least to better incorporate stakeholder expectations, particularly local community expectations, into mining projects (Hall et al. 2015; Prno 2013). The dominant understanding is that an SLO is a management tool that makes it possible to minimize entrepreneurial risks (in this case, resistance to mining). This concept is considered an elementary prerequisite for successful mining operations (Falck and Spangenberg 2014). This concept includes incorporating the perspectives of various local stakeholders outside the mining industry into the planning and implementation of mining projects, to meet the social obligations of mining companies. In the mining industry's perspective, an SLO is a type of license that the local population issues for a mining project, similar to other licenses that a mining project usually requires from government agencies. In contrast to the latter, however, an SLO is not legally binding, but rather an informal agreement between mining operators and local community actors (Hall et al. 2015; Owen 2016; Rooney et al. 2014). This is one of the central criticisms of the concept of the SLO (Boutilier 2021; Owen 2016). Nevertheless, a serious and practical SLO approach can lead to an awareness of the relevance of social demands (stakeholder interests) in the context of mining projects.

Since its introduction in the mining context, the concept has also been adopted in other industrial sectors, (see e.g. Rooney et al. 2014) and there are authors who suggest that scientific research should strive for a social license to operate in order to shape relationships with local communities (Gough et al. 2018; Raman and Mohr 2014;). Therefore, it makes sense to draw on the concept of an SLO in the context of research and technology development for the extraction of raw materials from mining residues to analyze the relationship between research projects and local communities and to develop proposals for their design on this basis.

Specifically, the social science research in the REMINTA project aims to understand how a possible future extraction of raw materials from the tailings ponds at Bollrich in Goslar, Germany, is perceived by the local community, what issues, hopes, concerns, and fears are associated with such a project, and what factors influence this social perception. The SLO for the extraction of raw materials from the tailings at this specific location should be based on these points.

Some of the factors presented in Part B of this guide correspond to the factors for gaining or losing an SLO already presented and confirmed in the literature. Measham et al. (2021) have shown that former miners and smelting workers see re-mining projects as a continuation of mining, which can have an impact on the perceptions of and attitudes towards these projects (Measham et al. 2021 revealed positive attitudes). Perceptions and expectations associated with mining legacies also influence the perception of whether mining is beneficial or detrimental to a region as Measham et al. (2021) Walton et al. (2017), and Mononen and Sairinen (2021) have shown. Therefore, perceptions and expectations are crucial in determining whether local actors and communities have positive or negative attitudes towards accepting or rejecting the extraction of mining legacies (Conde and Le Billon 2017; Measham et al. 2021; Walton et al. 2017). Conde and Le Billon (2017) and Moffat and Zhang (2014) reported the opportunities for public participation in mining projects that are perceived as too limited, increase resistance to these projects, and weaken local acceptance. Prno and Slocombe (2014) noted that one of the important factors influencing an SLO is the specific actors involved. For example, local media sometimes represents the interests of the local community, which can influence the achievement of an SLO (Prno & Slocombe 2014). It becomes particularly relevant as an actor when companies lose their legitimacy (Mononen & Sairinen 2021). Finally, trust is an important factor underlying an SLO extractive projects (Conde and Le Billon 2017; Moffat and Zhang 2014; Zhang et al. 2018). Trust in economic, administrative, and political actors has a particularly strong influence on the attitudes of the local population towards mining projects (Jijelava and Vanclay 2017; Zhang et al. 2018).

In Part B of this guide, we present the factors relevant to Goslar and Oker in terms of the social perception of raw material extraction projects around the tailings ponds at Bollrich, and provide information that may be useful for the social embedding of future raw material extraction at Bollrich. This information is based on various discussions regarding public participation. For example, in the field of science communication, the increasing relevance of online science communication is discussed, and the influence of laypeople's expectations of experts in dialog-oriented science communication formats is described (Schäfer 2017; Taddicken et al. 2020). For example, Taddicken et al.(2020) describe how meeting the expectations of comprehensibility, professionalism, and credibility of laypersons towards experts can increase the positive evaluation of dialog-oriented science formats. In the area of communication of and about uncertainties, it is emphasized how important it is to be aware of the specific information expectations of the target audience and to adapt information formats accordingly, whereby the fact that not everything can be known at any given time should also be recognized as a constant prerequisite in decision-making (Parviainen et al. 2021; Petersen et al. 2013). Individual and social factors, such as a person's cultural background or values, can influence risk perception (Renn and Benighaus 2013).

Perception in the building materials industry

Presently, the building materials industry faces the challenge of rethinking resource consumption and producing more environmentally-friendly building materials. In the context of a circular economy, reducing the use of primary raw materials and avoiding waste–for example, by increasing the use of secondary raw materials–is of central importance (Gandenberger 2021). In addition, it is expected that minimizing impact on nature through the extraction of primary raw materials is one of the major goals of the industry (Gandenberger 2021). As explained in the guideline at hand, it can be assumed that tailings ponds in Germany represent a considerable source of secondary raw materials, as they contain various waste materials from mining that can be used as raw materials in the building materials industry. So far, this potential has been exploited to a limited extent. Therefore, research projects such as REMINTA are investigating the processing of deposited flotation residues from sulfide ore deposits and their potential use in the building materials industry.

However, it is to be expected that even if the scientific and technical feasibility of processing and reusing tailings pond materials is proven, various social factors will influence the actual use of these materials in the building materials industry. As mineral materials from tailings ponds have not yet been used on a large scale in the building materials industry, no body of literature has identified barriers to the use of these specific materials in the building industry. To address this gap, in Part B of this guide we identify the factors that specifically inhibit the use of mineral residues from tailings ponds in Germany's building materials industry.

Various research exists on the (social) factors that influence the use of other recycled materials in the building materials industry. We conducted a systematic literature search to identify these studies and the factors they discuss. In the last quarter of 2021, Google Scholar and Ingenta Connect databases as well as the Journal of Material Cycles and Waste Management were systematically searched using relevant search terms[1]. All publications in the first 15 pages of the respective databases that took a social science approach and dealt with factors influencing the use of recycled materials in the building materials industry were included. The search revealed that international scientific research has thus far focused on obstacles to the reuse of construction and demolition waste (e.g., concrete, gravel, earth, sand, bricks, steel, or wood). Waste producers and their recycling goals have often been examined in detail. The particular question is why building materials are not recycled during the demolition of buildings and infrastructure or under what conditions they are recycled (Darof et al. 2021; da Rocha and Sattler 2009; Hosseini et al. 2015; International Council for Research and Innovation in Building and Construction (CIB) 2014; Mahpour 2018). The perspective of actors who reuse materials already in use, which is relevant to our research question, is taken less frequently. In the following section, we present the international state of research on this perspective and identify the factors that inhibit the use of demolition materials in the building materials industry (see also table 1).

Chileshe et al. (2018) described in their study in South Australia that it was primarily costs and economic expectations (with regard to certain time and quality targets) that determined whether materials were re-used in the construction industry. However, social factors (such as the perceived benefits of a socially-desirable image) had no significant influence (Chileshe et al. 2018). Park and Tucker (2017) used a systematic literature analysis in the Australian context to show that the main factors hindering the reuse of construction waste were a lack of customer demand, negative attitudes towards reuse practices, and Australian legislation.

Badraddin et al. (2021) determined, on the basis of a study in Malaysia, that 11 factors influenced the implementation of concrete recycling in the construction industry. For example, the low availability of specialized recycling factories and the unrestricted availability of primary materials inhibit the recycling of concrete and the use of recycled concrete (Badraddin et al. 2021). Similarly, the low or uncertain quality of recycled concrete, high costs (e.g., for processing and transporting the material), unclear or missing legal regulations and incentives, and few political incentives for the use of recycled concrete can inhibit its use in the building materials industry (Badraddin et al. 2021). Finally, the social

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1 The following search terms were used: *Circular Economy; building materials; recycling building materials; recycling building materials industry; recycled materials construction; construction materials; construction waste (management); mineral construction material; demolition waste; recycling construction industry; recycled materials building; reuse building components; building waste recycling; building materials recycling; reprocessing building materials; stockpile processing; built environment*. Furthermore, the terms *social; acceptance; social acceptance; barriers* were combined with some of the search terms mentioned.

acceptance of recycled concrete, management skills of construction managers, type of project planning, and availability of skilled labor were mentioned as relevant factors (Badraddin et al. 2021).

Ding et al. (2021) showed, based on the results of a survey in China, that the intention to buy recycled building material products from various stakeholders (e.g., government officials, building owners, or contractors) was mainly influenced by the perceived value of the material. Perceived environmental benefits had the greatest influence on this value, followed by social and economic added-value (Ding et al. 2021).

Based on two Canadian case studies, Gorgolewski (2008), reported that increased complexity compared to the use of primary raw materials was the main obstacle to the use of recycled building materials in construction, as they were associated with increased logistics, storage, time, and costs.

Working in the European context, Densley Tingley et al. (2017) found in a UK study that cost, availability, and storage of recycled steel, lack of customer demand, low-quality control options, low traceability, gaps in the supply chain, and difficult integration into supply chains have the greatest inhibiting influence on the reuse of steel in the construction industry. Low financial and political incentives, a general inertia in the construction industry to deviate from business-as-usual, the impact of using recycled materials on the design of structures, and a lack of knowledge on the possibility and potential environmental benefits of reusing steel were also described as barriers (Densley Tingley et al. 2017). Dunant et al. (2017) also showed in a UK study that the following factors inhibited the use of previously-used steel: the economics and costs of steel recycling, cooperation with more experts than with primary steel (and thus possible time delays, for example), quality, certification and traceability of the materials, availability and quantities, the negative perception of secondary raw materials, lack of a clear understanding of the importance of secondary raw materials, and the lack of a clear understanding of the importance of secondary raw materials. A lack of trust and communication between the various stakeholders (due to established working relationships that would have to be changed when recycling), limited experience with steel recycling, and the lack of consideration of subsequent recycling when the steel was originally installed were also considered. However, they also showed that different stakeholders in the building materials industry face different barriers to recycling steel. For example, for architects and clients, trust and the perception that recycled steel is inferior are the biggest barriers (Dunant et al. 2017). However, the main contractors tend to have low availability and lack of experience, which inhibits the use of previously-used steels (Dunant et al. 2017). A lack of government support and market-related factors, such as low demand and supply of recycled concrete, were identified as key barriers to the use of recycled concrete in a case study in Germany and Switzerland (Katerusha 2021).

Finally, Shooshtarian et al. (2020), based on a meta-analysis of six case studies conducted in China, the UK, the USA, Switzerland, and Australia, identified seven main factors that inhibit the use of recycled materials in the construction industry. These include increased costs for energy and transportation; lack of knowledge about recycled products; limited waste recovery technologies; low quality, contamination, and reduced performance; lack of market availability of products; restrictions due to specifications, standards, and approvals; and limited acceptance and negative perceptions (among the public and industry) (Shooshtarian et al. 2020).

Table 1 Overview of the barriers to the use of recycled materials in the building materials industry.

Material flow	**Building materials in general**	**Concrete**	**Steel**
Spatial context of the studies	Australia, Canada, China, USA, Great Britain, Switzerland	Malaysia, Switzerland, Germany	Great Britain
Obstacles	• High costs and low profitability • Poor quality of the material (e.g., impurities) • Negative perception of recycled material • Lack of knowledge about the material • Missing technologies for reprocessing • Increased time, storage and logistics costs • Low demand • Low availability and quantities • Inadequate legal framework	• High costs and low profitability • Lack of recycling infrastructure (e.g., recycling factories) • Negative perception of recycled material • Inadequate quality of the material • Unrestricted availability of primary material • Inadequate legal and political framework conditions • Low demand • Low availability and quantities • Inadequate legal and political framework conditions	• High costs and low profitability • Negative perception of recycled material • Inadequate quality of the material • Lack of quality control options (e.g., low traceability) • Lack of knowledge about and experience in handling the material • Effects on the design of buildings and infrastructures • Increased storage costs • Low demand • Supply chains not yet established and lack of knowledge of the players in the chain • Low availability and quantities (e.g., gaps in the supply chain) • Inadequate legal and political framework conditions
Authors	Chileshe et al. 2018; Park and Tucker 2017; Ding et al. 2021; Gorgolewski 2008; Shooshtarian et al. 2020	Badraddin et al. 2021; Katerusha 2021	Densley Tingley et al. 2017; Dunant et al. 2017

In summary, current research highlights cost and economic efficiency (e.g., through transport, processing, or logistics), legal framework conditions, availability and quantities, quality of the material, negative perceptions of recycled material, political policies, low demand, lack of knowledge potential application, low traceability, limited experience in working with recycled material, increased time expenditure, increased storage costs, and limited acceptance of recycled material as barriers to the use of previously-used materials in the building materials industry.

However, the exact influencing factors and barriers vary depending on the geographical location, specific material, and, in individual cases, the actors involved. Against this background, in Part B of this guideline, we present the perceived barriers to the use of materials from tailings ponds at Goslar Bollrich from the perspective of various stakeholders in the building materials industry and draw possible parallels with the barriers identified in the literature. In addition to identifying obstacles, their respective implications for the use of tailings pond materials in the building materials industry are discussed, and recommendations for action are provided.

Part B

3 Preparatory work for tailings pond decommissioning: Non-technical aspects

3.4 Social aspects - Methodological approach

Based on the theoretical foundations presented in Part A and our empirical analyses in the REMINTA project, we present the social structures that influence the social perception of the extraction of raw materials from tailings ponds at Goslar's Bollrich. We distinguish between two perceptions: first, the perception of raw material extraction from tailings ponds by local actors (Section 3.4.1), and second, the perception of obstacles to the use of raw materials from tailings ponds in the building materials industry (Section 3.4.2). The reconstruction was based on the following methodological approach:

To reconstruct the perception of raw material extraction from tailings ponds by local stakeholders, we conducted 14 guided, semi-structured expert interviews with selected people from Goslar and Oker in the fields of nature conservation, municipal administration, aftercare of the Rammelsberg ore mine, cultural reappraisal of the history of Rammelsberg and the region, and regional economic development and policy. Interviewees were selected through recommendations from project partners with a high level of local expertise, their own research, and snowball sampling (Bogner et al. 2014). In addition to the interviews, a local exchange and information workshop on the project was held with almost 100 participants, and discussions were included in the evaluation. Finally, we evaluated articles from the regional press and local election programs. The data were collected between May 2021 and April 2022. The analysis of the material was based on Kuckartz's qualitative content analysis approach, (2018b), whereby analysis categories were selected on the basis of relevant SLO literature, and new, regionally-specific analysis categories were developed from the material. The aim of the qualitative content analysis was not to draw conclusions regarding the quantitative distribution of perceptions in the local population from the data collected. Rather, the aim was to identify the relevant factors and explore the connections between them.

To reconstruct the perceived barriers to the use of raw materials from tailings ponds in the construction materials industry, we conducted a systematic literature review and compiled barriers to the use of construction and demolition waste in the construction materials industry in an international context (for a description of the methods and results, see Part A). Subsequently, perceived barriers to the reuse of raw materials from tailings ponds in Germany were identified based on six expert interviews and an online workshop with approximately 20 participants. It should be noted that we have not yet been able to examine the actual use of tailings pond materials in the construction materials industry and the obstacles that arise as these materials are not yet in use. We can only identify the expected obstacles discussed by experts from the building materials industry. In the REMINTA project, cement, brick, and clinker production were identified as possible areas of application for tailings pond minerals; therefore, experts and workshop participants were primarily acquired in these areas of expertise.

Between December 2021 and July 2022, we interviewed selected stakeholders from the building materials industry (primarily the cement industry): Representatives from building material companies, multipliers, and representatives of building material interest groups, as well as scientists from relevant research fields in natural sciences and engineering. The expert workshop took place online in March 2023 with 20 participants. Half of the participants came from various medium to large building material companies, particularly from internal product management and product development departments for secondary raw materials. Other participants came from research institutions, federal authorities, and interest groups in the building-materials industry. All the participants had a certain level of expertise in mineral building materials.

A qualitative content analysis was conducted (Kuckartz2018a). Categories were selected based on the barriers identified in the literature, and new categories specific to tailings pond materials were derived from the empirical material. The obstacles identified in the literature and confirmed in the material, as well as the newly-found obstacles, were then divided into more and less important obstacles based on the assessments of the experts interviewed.

In April 2023, we also took part in an expert workshop as part of the ReMin funding measure on the topic of "Impurities, contamination, and limit values: The bottlenecks in the usability of RC materials in the building materials sector" with 44 participants from industry, research, and interest groups. We were then able to incorporate the weightings of the various obstacles observed in our analysis in the final stage.

3.4.1 Regional perception

The following section presents the factors identified in the empirical research that influence the social perception of the extraction of raw materials from tailings ponds in Bollrich, Goslar. In addition to the factors already described in the literature on SLOs, additional factors were identified in the course of the analysis that were relevant to the relationship between the research project and the local community, and thus, for gaining or losing an SLO. With appropriate local contextualization, these factors could also be important in other resource extraction projects using re-mining.

These factors are:

- the regional reference to the mining and smelting past,
- the perception of the recycling industry,
- the perception of the tailings ponds,
- expectations related to the tailings ponds,
- special district specifics of Oker,
- the culture of citizen participation in Oker,
- the expectations of participation in local projects,
- the local stakeholder structure, and
- trust in procedural fairness, fair distribution of impacts and benefits, and organization and management of projects.

These factors were selected from the many factors that could contribute to gaining or losing an SLO, as they had a particularly strong influence on local perceptions during the qualitative analysis of the collected material. In addition to the explanation of these factors, their respective implications for the restoration of tailings ponds are discussed, and recommendations for action are provided. At the end of Section 3.4.1, the recommendations for action, which were developed specifically for the Oker context but can also be adapted for similar restoration and raw material extraction projects, are summarized in table 3)

1. Regional reference to the mining and smelting past

One factor that decisively influences the perception of the extraction of raw materials from tailings ponds in Goslar's Bollrich is the local population's connection to the region's mining and smelting past. There is evidence of mining in the region dating back to the Bronze Age, so it is assumed that various ores, silver, and barite from Rammelsberg in Goslar have been mined and smelted on site almost without interruption for almost three millennia. The last mine was closed in 1988 under the management of Preussag AG (Großewinkelmann and Schneider 2021).

This history, which stretches back to the recent past, has resulted in economic continuity, which is expressed in local industrial companies, such as Harz-Metall GmbH, whose tradition is linked to mining and processing. It can also be used to explain regional social specifics, which can have an impact on the perception of projects for recycling materials from tailings ponds in the region. International research on the recycling of mining legacies has shown that former miners and smelting workers perceive relining projects as part of mining continuity (Measham et al. 2021). We found similar patterns in the material collected and analyzed for a specific case in Oker. In Goslar, especially in the Oker district, local knowledge about mining, the perception of mining and smelting technologies, and the way in which mining and smelting are remembered are particularly constitutive of this factor. It can be assumed that both positive and negative references to former mining and smelting activities are all the more present in people's memory, the earlier and closer in time to past activities re-mining projects begin in a former mining region. Communication about planned projects must deal with the fact that such memories exist, and that social actors actively relate planned projects to the past.

In the former mining region, some sections of the population still have a wealth of knowledge regarding mining processes and techniques. Former Preussag employees, particularly those who still live in Oker, possess relevant specialist knowledge. As a result, there is a professional understanding of the scientific and technical applications in the field of raw material extraction, which is transferred to re-mining projects, as is clear from the analyzed material. This group is particularly interested in and open to these projects. However, there can also be disputes about knowledge, such as the processes and risks of (post-)mining methods. Experiential knowledge, which is constitutive of social identities, is juxtaposed with scientific knowledge, a phenomenon that has long been researched in the social sciences regarding its consequences for technical projects (Wynne 1992). From this situation, it can be concluded that it is advisable to pay particular attention to involving this group of people in events that accompany reining projects in the region. Researchers trained in scientific communication should be able to respond to detailed scientific and technical questions and, in particular, be able to explain the differences and innovations between conventional (in Oker, specifically in the 1980s) and currently-used methods in re-mining and processing in an understandable way.

It is the perception of some population groups that old mining and smelting technologies, such as the winding tower at Rammelsberg, are perceived as local heritage and as identity-forming features (Wirth et al. 2012; Osebik 2012; Measham et al. 2021). This could also be transferred associatively to re-mining technologies in the tailings ponds at Bollrich (Measham et al. 2021). However, the re-mining technologies that are large and visible could also be perceived as detracting from the current familiar landscape, as suspected by some local stakeholders. Among other things, this assumption is based on the fact that some old technological structures in the region are now barely recognizable because vegetation and new technologies are perceived as disruptive.

Another aspect of reference to the mining past is the positive memory of the mining and smelting industry as an employer. The jobs available until 1988 were well-paid, and there were also jobs for unskilled workers. Until the closure of the mines, mining work had a social reputation, and those employed in mining enjoyed a high level of social recognition. In one interviewee's words,

> "The *most important company or division was Preussag Unterharzer Berg- und Hüttenwerke. Anyone who worked there belonged to the working class."* (Interview 7, 2021).

The memory of the mining and smelting industry as an employer is also closely linked to the family history of individual local residents, some family members having been employed in this industry for several generations. The existing traditional associations and alumni reunions also point to a "*symbolic connection*" (Interview 4, 2021) with the mining and smelting industry that still exists today. However, there are also negative references to this industry as an employer, as the jobs could be life-threatening and were considered “dirty”, and ultimately the decline of the industry led to some losing their jobs without being able to find further employment.

The environmental, odor, and noise pollution associated with mining and smelting in the region is another point of reference. Soil pollution has had, and continues to have, an impact on flora and fauna as well as human health (Knolle 2009; Strieker et al. 2022). In the interviews, studies on lead exposure in schoolchildren were frequently mentioned, establishing links between lead exposure and learning disorders (Duhm et al. 1990). This indicates that local stakeholders take note of scientific findings. Environmental pollution was addressed with reference to daily life. For example, in one interview:

> "*And I think there is still a generation that still knows that and then also says, yes, we don't want to have anything like that anymore. We now live nice and quietly there, in Oker, and we take a critical view of industrial use with trucks and large machines*" (Interview 6, 2021).

Their own experiences with environmental pollution (or intergenerational stories of such experiences) still carry certain "emotional legacies" with them today. This leads to a greater sensitivity on the part of stakeholders towards projects that are expected to cause further environmental and health impacts, which is expressed, for example, in the form of skepticism and critical questions[2]. It is therefore advisable to address environmental impacts at an early stage when dismantling tailings ponds, allowing both queries and critical comments and taking local experiences seriously (Prospectors & Developers Association of Canada (PDAC) 2015). In particular, it should be clearly communicated when new and more environmentally-friendly technologies are used and to what extent their effects on people and the environment differ from those of technologies remembered locally.

Individual interviewees made connections between the local mining past and the social structure that still exists. In particular, it was assumed that the principle originating from mining, "*If the foreman of miners goes first, you go second,*" (Interview 2, 2021) characterizes social relations in the local society in such a way that they are exceptionally hierarchical but accepted in this form. In addition, some interviewees reported that there were local actors who were seen as particularly central and competent. This competence was justified by the fact that they have been on-site for a long time, have often commented on local issues during this time, have a high level of knowledge of local issues and problems and sometimes have special expertise. If one assumes that the observations about a particular hierarchical social structure are correct, care should be taken in a restoration project at the tailings ponds to ensure that stakeholders with high positions in the hierarchy (such as local political figures and certain environmental stakeholders) are not ignored if the acceptance of the project in Oker is to be strengthened. An evaluation of these stakeholders should be carried out regularly throughout the project period, with the involvement of stakeholders with a high level of local expertise (Prospectors & Developers Association of Canada (PDAC) 2015).

2. Local perception of the recycling industry

The Oker industrial estate, where smelting plants were located, is now home to several recycling companies. Even if these companies are, in exceptional cases, direct successors of the local smelting industry, they are still associated with the predecessor industry.

However, other parts of the analyzed material also indicated that the extraction of raw materials from the tailings ponds at Bollrich was generally perceived as a project of the current recycling industry.

[2] However, there was also one voice in the material that perceived the environmental impact as fundamentally positive, as the low economic usability of the soil means that it was now more likely to be left alone, which in turn was seen as good for nature.

Therefore, the associations and local perceptions linked to the recycling industry and the effects these associations could have on the dismantling of tailings ponds at Bollrich are briefly discussed.

The recycling industry is perceived as an important economic sector in the region and is recognized and promoted by the city, especially in the Oker district (Economic Development Region Goslar GmbH & Co. KG (WiReGo) 2023). The recycling industry is perceived by the interviewed experts as relevant and, above all, as sustainable employers in the region. A stable recycling industry was seen by some interviewees as an important factor in achieving regional and national raw material sovereignty and combating raw material shortages. The future viability of this industry was also often justified in the analyzed materials, with the perceived contribution of the recycling industry to national sustainability efforts. In particular, the potential of the recycling industry to use fewer primary raw materials and close raw material cycles was considered to be positive and forward-looking. Some interviewees also mentioned possible CO_2 and energy savings as factors promoting sustainability through recycling. However, other interviewees disagreed with this association and emphasized the high energy consumption and possible environmental pollution. Recycling by some companies in Oker has also caused pollution, some of which is still remembered locally. According to social science risk research, memory influences the perception of planned projects (Renn and Benighaus 2013).

The positive associations of the recycling industry as an important employer and promoter of sustainability and raw material sovereignty can be built in the communication of mining projects at the Bollrich tailings ponds. Negative factors related to recycling activities, such as high energy consumption or possible environmental impacts, should be communicated in a clear and open manner, and any concerns addressed.

Furthermore, the relevance attributed to the recycling industry in comparison with other industries also plays a role in the perception of projects assigned to the recycling industry. It was particularly evident that, although the recycling industry was rated as important for the economy, it was never rated as more important than regional tourism. The latter is largely based on the attraction of the landscape of Harz National Park and its towns with historic buildings, such as Goslar, which are perceived as picturesque. Local mining history also supports tourism. However, according to some interviewees, it is not the main driver of tourism. Therefore, if a tailings pond mining project at Bollrich is perceived as detrimental to local tourism efforts, such as through visible industrial techniques in areas used by tourists or environmental pollution perceived by tourists, local opposition from residents, city administrations, or the tourism industry is very likely (Measham et al. 2021).

3. Perception of tailings ponds

Another factor that has an impact on the social perception of raw material extraction from tailings ponds at the Bollrich in Goslar is the current perception of tailings ponds. The anticipated changes in the tailings pond landscape can trigger reactions that influence whether the extraction of tailings ponds at Bollrich is perceived as beneficial or detrimental. This ultimately affects acceptance of such projects (Measham et al. 2021; Walton et al. 2017; Conde and Le Billon 2017). To increase the social acceptance of a mining project for Bollrich tailings ponds, it makes sense to strengthen the perceptions of the tailings ponds that are useful for the project. The various perceptions reconstructed from the empirical data are described below, and their possible implications for raw material extraction projects are explained. Particular attention was paid to the perception of contaminated sites, as this has particularly relevant implications for projects.

Eight different perceptions of tailings ponds were found in the analyzed material, each shared by different stakeholder groups (Figure 1).

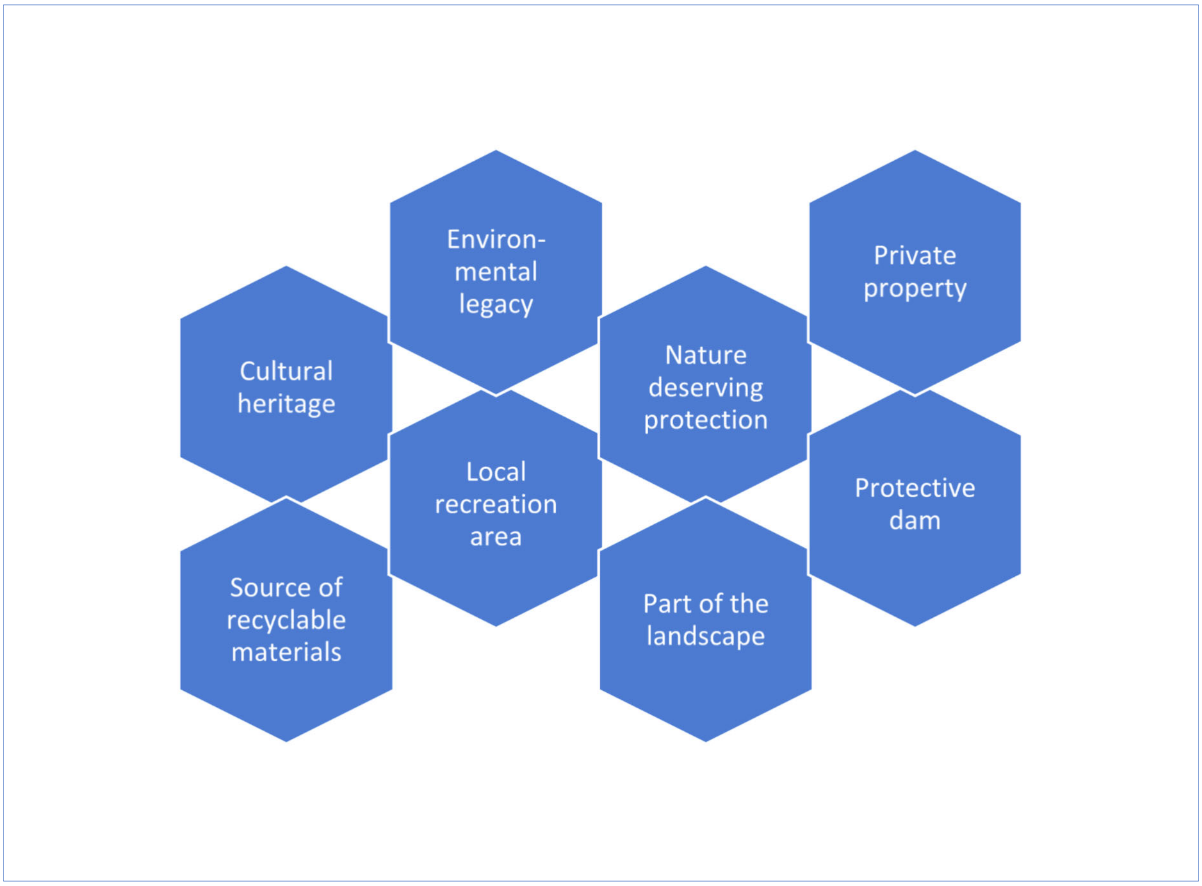

Figure 1: *Current perceptions of the tailings ponds*

The perception of the tailings ponds at Bollrich as contaminated sites was shared by all interviewees. The interviewees assumed that some local residents also shared this view (see below). However, the interviewees assessed the dangers and risks posed by tailings ponds as contaminated sites differently[3]. As has already been shown in various studies, different assessments of the risks posed by contaminated mining sites have a strong impact on the perceived advantages and disadvantages of mining. This has consequences for obtaining local SLOs (Measham et al. 2021; Walton et al. 2017).

The main difference in perception in the Bollrich-case was whether local stakeholders considered tailings ponds in their current form to pose relevant or negligible risks. Some stakeholders who classify tailings ponds as a relevant risk justify their perception of the danger of an overflow, a dam burst, or a creeping burden on humans and animals due to the drifting of tailings pond content during drought. In addition to these dangers, which are classified as future dangers, some Oker residents already consider heavy metal contamination of groundwater as a fact. Other stakeholders referred to more diffuse and unclearly identifiable dangers. Almost all interviewees shared the assessment that tailings ponds pose a certain risk in their current state, but some of them did not know exactly what the dangers that predispose these risks are. The interviewees estimated that these perceptions were widespread among local residents and caused fear. The fear of dam bursting was an issue that was strongly emotionalized during our data collection, especially by residents whose properties were located directly at the foot of the tailings ponds at Bollrich. There is a strong concern for personal

[3]It should be noted here that the terms hazard and risk are often not differentiated in public perception (Renn and Benighaus 2013). Here we follow the definition of the term according to Renn and Benighaus (2013), who define risks as the possibility of an adverse effect of an event or activity, while hazards are defined as events or activities that are already certain to have negative consequences, but which may differ in extent.

safety among some residents, which they perceive as not being addressed by the research to the extent they expect.

However, some local stakeholders also perceive tailings ponds as contaminated sites that pose no or only a very low and non-acute risk because the walls of the tailings ponds are very stable.

The various hazards associated with the tailings ponds at Bollrich as a contaminated site and the associated risk perceptions are not free of conflict, and are continuously negotiated by stakeholders (for similar negotiation processes in the context of technologies, see Nelkin, 1989). In some interviews, for example, the assumption was that the perception of high risk from tailings ponds is based on incorrect or outdated information. In other interviews, it was assumed that people who perceive tailings ponds as non-risky forget or suppress danger. These assumptions clarify that local actors have different perceptions of the dangers posed by tailings ponds at the Bollrich and the associated risks. Anthropological and sociological risk research explains these differences because risks are culturally constituted. Individual social integration and group membership(s), the values, experiences, and narratives shared within these groups, and tensions between social groups, institutional arrangements, and social situations are decisive for which danger is perceived as a risk and in what form (Douglas and Wildavsky 1982; Nelkin 1989; Douglas 1992). Research on contaminated regions has shown that the everyday experience of environmental pollution clearly influences what is perceived as a risk, and in what form (Edelstein 2004; Burningham and Thrush 2010). From the Oker context, it can therefore be assumed that the mining industry, the associated environmental impacts, experiences of how companies deal with accidents, and the individual's differing attachment to the industry (e.g., employee of Preussag or not) or the confrontation with environmental pollution (e.g., membership in an environmental group or not) also influence the perception of risks. The perception of risks is therefore culturally-shaped and is real for the individual, even if their probability of occurrence may be objectively low (in the sense of "based on scientific studies and probability calculations") (Nelkin 1989).

Various conclusions can be drawn these analyses. First, the fear of dam bursting should be taken seriously, and measures should be taken to avoid it. Second, the safety needs of local residents and fear of dam failure should be addressed in the public communication about a mining project. Information about the current state of the tailings ponds at Bollrich and possible dangers and risks identified based on technical expertise should be continuously prepared, made available, and explained to the public, even during the mining process. Care should be taken to ensure that the language used is sensitive to the fears communicated, and that safety-related aspects (positive and negative) that are likely to be associated with mining are presented in a comprehensible manner (Federal Ministry of the Interior 2014; Petersen et al. 2013; Taddicken et al. 2020). Care should also be taken to communicate existing dangers and risks early, value free, and transparently to avoid overemphasis and emotionalization. Known and (as yet) unknown hazards should be addressed (on communicating ignorance and unforeseeable events see Gross and Bleicher (2013) and Parviainen et al. (2021)). In addition, it should be clearly explained why, despite the risk of being perceived as acute, emergency response measures are not taken immediately; instead, dismantling is sought that does not immediately avert danger and may even be associated with additional, possibly still unknown, dangers. It must be expected that the associated risks will be perceived differently by different groups in the population and that there will be disputes about the "correct" perceptions.

The *tailings ponds* are also perceived *as a kind of nature.* These perceptions are divided according to the functions ascribed to nature: as usable for humans (*recreational area*), valuable in its function as a biotope (*nature worthy of protection*), and as nature with no function worth mentioning (*part of the landscape*).

The perception of tailings ponds and their surroundings as *local recreation area* was described by the interviewees as predominant among local residents. It is a local recreational area that tends to be used by Oker residents, for example, for jogging, walking a dog, or going for a stroll; however, it is an area with very little tourist development. The proximity of the area to the fairground, sailing course, sports grounds, and dog training areas also promoted its perception as a local recreational area. If the materials in the tailings ponds are removed, it should be noted that the area becomes temporarily unavailable as a local recreational area. It may be advisable to address any frustration on the project side, for example, by cooperatively developing plans to deal with the site and its surroundings during and after dismantling.

As part of the analysis, it was identified that individual stakeholders also perceived the area as *nature worthy of protection*. The tailings ponds and the surrounding landscape are described as biotopes, places of biodiversity and special vegetation, and natural features worthy of protection. This perception was found among some local residents and a certain group of environmentalists. The reason given by local residents for this perception was that the impact on the site was not visible and that the flora concealed the technical facilities on the site. This can be addressed by highlighting the impact of the dismantling project in an understandable manner. Some environmentalists have argued that the particular heavy metal flora and fauna around tailings ponds (Ernst et al. 2004) should be protected. It is likely that there will be a debate regarding the appropriateness of mining tailings ponds in the context of mining projects with representatives of such a position.

However, many interviewees also emphasized that many local residents and outsiders simply perceive tailings ponds as *part of the landscape* without assigning them a special role as a contaminated site or local recreation area. This perception can be used in the context of dismantling projects to strengthen the perceptions that justify the need for dismantling (e.g., as a contaminated site and source of recyclables).

The two perceptions conducive to a mining project are those of the tailings ponds at Bollrich as a *source of recyclable materials* and *private land*. The perception as a source of recyclable materials was found both in the form of "dormant wealth" and as a "subsidized business.” Both are based on the perception that money can be generated through the extraction and sale of materials from tailings ponds, either as economic profit or as partial financing for the removal of contaminated sites. The perception of the Bollrich site as private land is conducive to a mining project, as the de jure ownership situation is recognized and not de facto appropriation for local recreational use. This perception could hardly be found in the material, especially among local residents, as tailings ponds are rarely perceived as private property. Therefore, this perception could be (further) strengthened from a project perspective.

Another perception is that the Bollrich tailings ponds serve as *protective dam* against heavy rainfall events, which some interviewees expect to continue in the future. When planning a dismantling project, the continued protective function of the rebuilt Bollrich Site should be addressed, discussed, planned, and communicated.

Finally, the tailings ponds at Bollrich are perceived as a part of *the region's cultural heritage.* Unlike other spatial contexts, (e.g. Wirth et al. 2012; Harfst 2015; Measham et al. 2021) this aspect of Oker's perception does not seem to play a major role. Only rarely did interviewees point out that tailings ponds and associated technical facilities are part of the cultural mining heritage of the region. They are culturally unworthy of protection. This is justified by the fact that Goslar and Oker have many other visually impressive memorials of the mining and smelting past.

Expectations in relation to the tailings ponds

Just as important as the perception of tailings ponds in their current state are the expectations of local stakeholders and stakeholder groups regarding the future management of tailings ponds. These factors also influence the perception of mining as beneficial or detrimental to the region, and thus the attitude towards the corresponding projects (Measham et al. 2021; Walton et al. 2017). According to Mononen and Sairinen (2021), realistic expectations of the effects of a mining project in terms of increasing local acceptance of mining projects are particularly important. For this reason, the following section presents how local stakeholders currently wish to deal with tailings ponds in general and specifically in relation to mining.

a) Current expectations

Expectations related to tailings ponds can be divided into two main categories: leaving the tailings ponds untouched or changing their current state completely or partially. There are also stakeholders who have no idea what should happen to tailings ponds.

The desire to leave the tailings ponds untouched is justified on the one hand by the protection of the flora and fauna at Bollrich and on the other hand by the fact that some stakeholders do not need to change the tailings ponds, as they pose little or no risk. Furthermore, there are stakeholders who favor leaving tailings ponds untouched, at least as long as it is unclear what will happen to the residual materials of a mining operation, or if there are still stability concerns during a mining operation. It is therefore advisable to provide information on these issues in the course of a mining project.

The expectations to change the current state of tailings ponds are expressed either as a desire to secure or restore them, whereby there are different expectations regarding the objectives of restoration. Securing means minimizing the risk of water seepage and dam failure; otherwise, it does not change the tailings pond.

b) Expectations related to dismantling

There are various hopes and fears regarding dismantling. Not all hopes and fears are shared by all stakeholders; however, they can be relevant to various stakeholders.

Table 2: *Hopes and fears regarding the extraction of the tailing ponds at Bollrich*

	Hopes	Fears
economic	• Potential to generate revenue (such as profit opportunity through high-quality materials in the tailings ponds, correct timing of sale on the raw materials market) • Covering the renovation costs	• Question of whether dismantling is economically feasible → fears that it will become a subsidized business • Concerns that the substances contained are not recyclable due to excessive contamination and must be disposed of at cost (e.g. expensive hazardous waste) • Fewer tourists due to environmental pollution
social	• Creating jobs in the region • Strengthen local recycling expertise and export this expertise	• Endangered stability during dismantling • Exposure of citizens to noise, odor, or dust

	• Strengthening recognition of the region • Recovery of raw materials as an ideal goal (circular economy) • Elimination of the risk of dam failure • Continuation of flood protection • Subsequent use of the area that is beneficial to the public (possibly as a local recreation area or leisure area)	• Elimination of a local recreation area • Damage to the image of the area in the event of pollution or similar (major impact on the landscape) • possibly not enough qualified workers in the region, so that no jobs are created
ecological	• Remediation of a contaminated site (minimization of ecological risks) • Renaturation of the area	• Destruction of nature at Bollrich • Environmental pollution from mining • Concerns as to whether renaturation is possible/planned

Where possible, a positive reference can be made to the expectations outlined in the preparation for and during the course of a dismantling project. In the hope of redeveloping the Bollrich site, the elimination of the risk of dam bursting, renaturation of the area after dismantling, and creation of jobs in the region were formulated by a particularly large number of interviewees.

In terms of fear, many interviewees focused on the impact of mining on citizens and nature. In the specialist literature, the environmental impact of mining projects is cited as an important factor in the emergence of resistance to mining projects (Conde and Le Billon 2017). These concerns should be understood as areas of potential conflict. In preparation for and during a remining project, care should be taken to ensure that fears are addressed calmly and comprehensibly as part of the public relations work that accompanies the project. This is particularly important when communicating uncertainty or crises (Federal Ministry of the Interior 2014; Petersen et al. 2013). If reliable information that provides answers to open questions in connection with fear is available, it should be made available to the public in the course of a dismantling project. Therefore, care should be taken to present the advantages and disadvantages of remining projects as realistically as possible (Mononen and Sairinen 2021). It should also be communicated if individual aspects are not yet known and answers may only emerge in the course of the project. A strategy to address these unanswered questions should be made available to the public.

It should also be noted that some Oker residents have little detailed knowledge or idea about the exact process of dismantling the tailings ponds in connection with the extraction of raw materials. Some expectations, such as those regarding certain subsequent uses of the area, have already been discussed, whereas others, such as the exact process of extraction, are still abstract. Irritations regarding the spatial changes associated with quarrying are expected, particularly when removing local vegetation and visibly changing the height of dams. The use of clearly audible and visible technologies is also likely to be discussed, raising questions among residents (Bleicher et al. 2022; Suopajärvi et al. 2019). Therefore, it is advisable to provide information and consultation opportunities to residents throughout the dismantling process.

In addition, the expected timeframe of such a remining project was often estimated by some interviewees to be shorter than the forecast of the actors on the project side (especially scientists); however, at least as often, the interviewees' time expectations were unclear. In both cases, it can make sense to openly communicate the probable duration of the dismantling project (e.g., approximately five years until the start and then approximately 10 years for the actual dismantling in connection with raw material extraction) and to explain why this time frame makes sense to cause less irritation during the dismantling process.

Overall, it became clear that expectations regarding the extraction of tailings ponds at Bollrich were very diverse and sometimes even contradictory. Diverse opinions among the local population regarding the actual extraction of tailings ponds are expected.

4. District specifics of Oker

This section discusses the specific features of the district of Oker that can influence the perception of the extraction of raw materials from the tailings ponds at Bollrich in Goslar. The focus here is on the Goslar district of Oker, where Bollrich is located. Oker was first incorporated into Goslar in 1972 (Sturde 2022). It has been the center of the smelting industry in the past centuries. Even today, it is a district with its own culture, which differs from the Goslar culture in parts relevant to raw material extraction projects. In the first step, the characteristics of the district were presented based on the perceptions of Oker residents. In the next step, external perceptions are presented, and their respective implications for raw material extraction projects are reflected. Finally, the effects of the political situation in Oker on the perception of tailings pond recycling were discussed.

a) Own and external perceptions

When Oker residents describe their districts, they speak of places in many cultures. However, the residents are united according to their status as workers:

> *"...it's a classic smelting location, which means a workers' location. It smells like work here and it tastes like work. [...]"* (Interview 14, 2022)

Shaped by its history as a traditional industrial location, particularly in the areas of smelting, heavy, and chemical industries, certain worker ethos and pride still prevail today, according to the interviewees. Environmental pollution is associated with its history as an industrial location. In Oker exist a variety of soil, air, and odor pollution. It is understood in some sections of the population as part of their own history and as belonging to them, as the continuation of the quote above makes clear:

> *"[...] and our legacy is an expression of the work that we sometimes didn't manage better back then because we didn't know any better.*" (Interview 14, 2022)

Although people from the district are aware that Oker has been a target of the media, at least since national press publications in the 1980s (Der Spiegel 1980; Duhm et al. 1990), Oker has a negative reputation as an area with poor environmental quality[4], and there is a positive self-perception as part of the local identity. The perceived devaluation of Oker as a district by outsiders, for example, through the scandalization of local environmental problems, often reacts to the rejection of further evaluations of the district. This is expressed in the following account by the same interviewee regarding reactions to negative press coverage:

[4] The negative perception of others also became clear in our interviews: the interviewees from Goslar who do not live in Oker often rated the environmental pollution in Oker more negatively than the interviewees from Oker. For example, Oker was described as a "polluted" place where it is extremely dangerous to live due to exhaust fumes, soil pollution, and flooding. This contrasts with the self-perception and the district pride of some Oker residents that was evident in many parts of the analyzed material.

> *"This image-damaged place reacts very allergically when it comes to environmental scandals and refuses to agree to any further development [of local projects/industries] if you [e.g. the press] make a particular issue of something [and] scandalize it."* (Interview 14, 2022)

Projects that are associated with heavy environmental impacts or cannot credibly demonstrate that no heavy environmental impacts will be generated that could lead to new devaluations and stigmatization of the location, are rejected locally and provoke resistance.

In addition to the criticism of specific local environmental impacts, local criticism is directed toward the creation/maintenance of a negative local image by external actors. This observation should be considered in the design of projects, particularly in external communications. For example, rather than emphasizing the habituation of the local population to contaminated landscapes and their specific impacts, concerns about the environmental impacts should be taken seriously.

b) Political situation

The results show that the political situation in Oker impacts the perception of tailings pond recycling. According to the interviewees, Oker, a historically-growing, working-class stronghold, ensured that the election results of the SPD in the district of Goslar were often higher than the national average (Goslar 2022; The Federal Election Commissioner 2022). From this, the interviewees concluded that job creation associated with a dismantling project in Oker would be particularly well-received locally. Regarding interviewees' perceptions, environmental issues were included in most local election programs. According to one interviewee, cross-party cooperation is typical of Oker:

> *"So, in local politics, party affiliation often plays a role until the last six weeks before the election, otherwise it doesn't matter."* (Interview 14, 2022)

The issue of tailings ponds in Bollrich is also being addressed by various parties in terms of stability and environmental impact, and there appears to be cross-party support for dismantling plans with remediation concerns. Dismantling projects can build upon the sensitization of local political actors.

Owing to the specific situation in the Oker district, it is always recommended that public participation formats in remining projects explicitly address Oker residents rather than Gosla residents. Oker's identity as a district should be respected and recognized. This includes, for example, recognizing the experience of living under environmental stress and being particularly sensitive to environmental issues in the implementation of planned projects and, if necessary, going beyond official requirements for emissions. This sensitivity should be reflected in planned public relations measures; possible environmental impacts should be communicated transparently but should not be scandalized, particularly with regard to their impact on the local image. Attention should be paid to clear, factual descriptions of the risks that are easy for the local population to understand (Federal Ministry of the Interior 2014; Petersen et al. 2013; Taddicken et al. 2020). Taddicken et al. (2020) example, meeting the expectations of comprehensibility, professionalism, and credibility can increase the positive evaluation of dialog-oriented science formats. This can be achieved through the use of short sentences, content structuring, and little scientific jargon as well as through links to the recipients' everyday world (Taddicken et al. 2020). In addition, feedback and queries, as well as the risks perceived by the public, should be addressed calmly and transparently (Federal Ministry of the Interior 2014; Petersen et al. 2013). If new jobs are created in the course of relining projects that can be filled by people from the district, it can be expected that the self-image of the district as a working-class district will be well established, and that the projects will be met with approval.

5. Citizen participation culture in Oker

The specific local culture of participation can influence how citizens engage in new projects for the extraction of raw materials from tailings ponds. For example, in places with strong and established civil society initiatives and a history of frequent civil society mobilization, the organization of further initiatives can take place more quickly as local actors are better networked (Amezcua and Sotomayor 2022; Diani 2009). Specific expectations regarding citizen participation in local projects in Oker are discussed below.

Many interviewees estimated that the public in Oker took a critical look at (technical) projects using scientific arguments. A lively local culture of participation can be inferred from the various interview accounts. Several examples of quickly-initiated and often successful petitions were mentioned in connection with the perceived impact of odor or noise on residential areas or the expected impact on children. For example, in the 1980s, protests and citizen initiatives prevented the construction of a hazardous waste incineration plant in the Oker–Harlingerode region. The site of an asbestos processing plant was also relocated after a citizens' initiative was formed. Another example worth mentioning is the citizens initiative against truck transport in Ravensburger Straße, where residents criticized the noise pollution caused by delivery traffic. Interviewees clarified that letters to the editor and citizen initiatives were expected if projects were expected to have a negative environmental impact. Petitions are another typical form of citizen participation in Oker.

However, there were also interviewees who emphasized the inertia of Oker residents to participate. For example, the "tiredness" of residents to report odor nuisances at all was mentioned, as they were habituated to them in Oker, compared to other districts. A regional business promoter summarizes the culture of participation in general as:

> "*Only when people are directly affected, does anything happen. Otherwise it's actually a sleepy, small town; it's not a big city, so.*" (Interview 6, 2021).

For local technical projects, it can be deduced from these prerequisites that local opposition to citizen initiatives is likely to occur if the environmental impact is perceived as severe. This opposition should be actively addressed from the project side, reasons for the opposition should be asked, and possible alternatives should be sought together with those affected (e.g., other routes for heavy goods vehicles or changed time windows for activities that cause acoustic pollution).

6. Expectations of participation in local projects

Another factor that influences the perception of raw material extraction from the tailings ponds at Goslarer Bollrich and can have an impact on possible dismantling and remediation processes is the specific expectations of Oker residents with regard to public participation. Citizen participation opportunities in dismantling projects perceived as too limited can increase rejection or resistance to such projects (Conde and Le Billon 2017; Moffat and Zhang 2014). General expectations and demands regarding involvement in local projects in Oker may also impact expectations regarding involvement in projects at Bollrich. In the analysis of the empirical material, two relevant expectations crystallized: First, the interviewees always communicated the expectation of being proactively informed about the progress of the project. Second, the expectation of direct involvement in planning was expressed.

a) Being proactively informed

Being openly and proactively informed about projects that impact one's own living environment is an extremely important issue for Oker. Proactive and open communication about relevant topics, such as the potential or actual environmental impacts of projects, or problems that arise during projects, is a widely shared expectation of Oker residents. Statements about this can be found in almost all the interviews. This is because of the variety of experiences since the 1960s, with delayed communication and disclosure of information about negative environmental impacts by companies or administrations. For example, in the 1960s, local residents and environmentalists drew attention to unusual odor nuisances emanating from slag heaps in a zinc smelter. The responsible authorities–the public administration and companies - were slow to react and only responded to the insistence of the environmentalists. Negative experiences were also made with some local companies. A comment from an interviewee from Oker:

> *"Yes, these experiences have been repeated time and again, and it's fair to say that this has also been reported in the media, that large companies [...] haven't always played their cards close to their chests and the risks have been downplayed. [...] Depending on the managing director, there was a great deal of secrecy or no open words, and that arouses mistrust. And this mistrust is of course then transferred to other projects, especially in the environmental sector, logically."* (Interview 10, 2022)

The fact that such events led to a loss of trust, which continues to have an impact today, is clarified in this quote. Therefore, these and other experiences have led to the expectation of comprehensive and transparent information. Thus, it is particularly expected of local projects that project managers communicate proactively. From the interviewees' perspective, project managers should communicate as early as possible, before impacts on the population occurs. If unexpected problems associated with unplanned burdens arise that cannot be ruled out in technical projects, especially with new procedures, they should be reported immediately (e.g. Felt and Wynne 2007; van de Poel et al. 2017).

It is also important that information about projects is presented in a way that is understandable and accessible to laypeople, and that questions are answered competently (Prospectors & Developers Association of Canada (PDAC) 2015). As a positive example, one interviewee cited the presentation of the Duhm study (Duhm et al. 1990) in which the results were perceived as particularly comprehensible. It was positively noted that, despite the sensitive topic of children's exposure to heavy metals, the experts spoke at eye level with the residents and were open to questions. On the other hand, a negative example was given of a public information event on a local landfill where the speaker was unable to explain what "soil contaminated with resin" was that was to be applied during remediation. This has led to significant criticism, as described in the following quote:

> "*The alarm signals went off again: Hello, you don't want to improve here, you say: it's enough for Oker if you keep taking the dirt, yes? [...] The way that was communicated was so bad*" (Interview 7, 2021)

The quote also makes it clear that strategies of "verbal concealment" - "typically contaminated by resin" as a synonym for material that poses an environmental and possibly health hazard - run the risk of being quickly recognized as such due to the local attention paid to environmental issues. When communicating potential burdens, it is advisable, as shown in the factor "District specifics of Oker”, to take care to recognize local collective experiences and local identity and not to devalue them through words and actions.

Note that the expectation of being informed does not always lead to the expectation of direct codetermination in projects. However, this expectation also exists.

b) Involvement in project planning

The desire to be involved in the planning of local projects was expressed in some interviews but less clearly than the desire to be informed. In particular, local environmental civil society initiatives have specific knowledge of the local environment, which can be a valuable addition to the knowledge available in a project, such as in contaminated site remediation projects. The importance of regional knowledge and the consequences of its non-observance on the acceptance of mining projects have already been demonstrated (Bebbington and Bury 2009; Himley 2014). Local populations can also provide helpful insights into usage expectations and needs when determining options for the subsequent use of revitalized areas. It is important to note that some local environmentalists in Oker had negative experiences with a participation process in the past. Local environmentalists were involved in the question of which tree species would make sense in an area to be renaturalized. During the implementation of the measures, trees other than those recommended by environmentalists were ultimately planted, and the decision was not communicated to the environmentalists in a comprehensible manner. Involving local expertise must be taken seriously and should be performed through dialog. The limitations of the implementation should be clearly communicated from the outset.

The expectation of involvement in the planning of local projects was also always expressed in connection with the demand for prompt visibility of project results. The input of the population and the visible implementation of this input in the project should be as close as possible. Stakeholders from civil society, politics, and the administration have clarified this point. In the case of the dismantling of the tailings ponds at Bollrich, for example, this means only involving local residents in the planning for the subsequent use of the area when this is imminent, e.g. 1-2 years before the end of dismantling. However, information that residents should be involved in this plan can already be provided beforehand. With regard to citizen participation formats, it was reported from experience that on-site participation opportunities in Oker are much better accepted than those in digital formats.

7. Local players

How commodity projects are perceived depends on the actors involved (Prno and Slocombe 2014). Therefore, we present the local constellation of actors that will be relevant to a potential raw material extraction project below. It should be noted that not all actors who will be involved in the future remining project were known at the time of our research, for example, the company that will extract raw materials is not yet defined.

The following stakeholders are particularly relevant for the potential extraction of raw materials from the tailings ponds at Goslar Bollrich: companies extracting raw materials, possibly from the local business landscape; landowners; local and regional environmental authorities; mining authorities; local politics (especially parties and interest groups); science (especially the Clausthal University of Technology); environmental protection organizations; civil society; and the press.

Local stakeholders have an opinion regarding *regional companies* that may produce raw materials in the future, particularly in respect of their environmentally-relevant activities. These have been repeatedly referred to in discussions during the public event we organized. Raw-material-producing companies play a central role in the production and maintenance of social licenses. The company that owns the tailings pond also will play a role in the production of SLO. This company is seen by many local stakeholders as the successor to Preussag AG (dissolved in 2002), which was formerly influential in the region in terms of raw material extraction, and may go hand in hand with certain associations with the mining and smelting past of the region.

On the part of the *authorities,* for example, the Lower Nature Conservation Authority; the State Office for Mining, Energy, and Geology; the Soil Protection Authority, or the Trade Supervisory Office are important players whose activities are only partially perceived by the local population. Administrative actors play a central role in monitoring compliance with legal regulations and requirements and can play a key role in shaping trust in state institutions through their actions.

Local political actors claim to represent the interests of local populations. In Oker, these actors include local groups of parties represented in the Bundestag (national parliament) and some regional parties. In addition, the "Oker Working Group" has been in existence for over 20 years. This working group holds regular meetings (several times a year) with citizens to discuss issues relevant to the district, such as housing, school, and environmental problems. Topics related to tailings ponds were also addressed.

Local political players are actively involved in issues related to tailings ponds. For example, the Green Party (Bündnis 90/Die Grünen) and the Social Democratic Party (SPD) convened a round table in 2021 on the topic "Remediation cases – the Bollrich tailings pond, landfills Paradiesgrund and Formsandgrube" under the moderation of the district. In addition to political stakeholders and the Clausthal University of Technology, district administrators and relevant authorities, such as the Lower Saxony Ministry of the Environment, State Mining Authority, Trade Supervisory Office, and Lower Water Authority also contribute to the work of this committee. The round table meets on an ad hoc basis. Furthermore, the working group can be an important player in involving the local population in raw material extraction projects.

Scientific stakeholders play an important role in the Oker case, as the envisaged project is a new type of project that is not only accompanied by research, but also initiated by it. Many interviewees associated research at Bollrich directly with the Clausthal University of Technology; for example, with the Institute for Processing, Recycling, and Circular Economy Systems.

Finally, various *environmental protection* actors were active in Oker. One reason for this is that the environmental impact of mining and smelting in the region is particularly high and there have been various successful local environmental protection initiatives in the past. It should be emphasized that there are special actors in Oker who are perceived by many residents as absolutely central to environmental protection in Oker and the surrounding area such as a prominent representative of the BUND regional association, Westharz.

Another actor that influences the social perception of raw material extraction from the tailings ponds at Bollrich in Goslar is the *local press*, particularly the Goslarsche Zeitung (local newspaper). This continues to serve as an important information medium for the local population and is often used to present the positions and knowledge of project actors and local civil society actors, such as environmentalists. The analyzed material also shows that the reporting of the Goslarsche Zeitung is perceived by some actors as too gimmicky and negative. Nevertheless, cooperation with Goslarsche Zeitung still makes sense because of its central position in informing the local population about project events. The press is also identified as an actor in some academic studies on SLOs; in these cases, it takes on the role of representing the interests of the local community, which can influence the achievement of an SLO (Prno & Slocombe 2014). It becomes particularly relevant as an actor when companies lose their legitimacy (Mononen & Sairinen 2021). Boutilier (2021) concluded that the role of media (traditional and social media) in SLO contexts requires further research.

8. Trust

Research on SLO indicates that trust is an important factor that influences whether an SLO for extractive projects occurs (Moffat and Zhang 2014; Zhang et al. 2018; Conde and Le Billon 2017). Trust in economic, administrative, and political actors has a particularly strong influence on the attitudes of the local population towards mining projects (Jijelava and Vanclay 2017; Zhang et al. 2018). Therefore, we interpret the results of our analyses below regarding the aspects that influence the formation of trust between local communities and project managers.

Measham et al. (2021) identified procedural fairness, distributive justice, perceived impacts and benefits, and trust in the organization and governance of projects as crucial aspects for establishing trust in extractive projects in former mining regions. Procedural fairness refers to whether the voices of community members are heard and whether their perspectives are considered in decision-making processes. Trust exists when members of a community have the impression that both are occurring.

Trust in organization and governance refers to the belief of local community members that regulations, legal frameworks, and arrangements enable and safeguard responsible resource extraction. Finally, distributive justice reflects the idea that the impacts and benefits are fairly distributed among members of the local community and within the region. Measham et al. (2021) show that, in the case they studied, trust was created by project managers being visible on the ground and involved in the local community, that is, not being perceived as external or alien. The early provision of information about the technology to be used also built trust in the project goals and objectives of the research program. It was also important to build trust that the central research questions were answered first and that the project objectives were readjusted in line with these findings. Neither the local politicians nor the project managers were committed to specific project outcomes. This finding is of particular importance in connection with considerations of experimental project designs, as such that designs are based on both a fundamental openness to results and the transparent communication of knowledge gaps and are considered (socially) robust designs (Gross and Hoffmann-Riem 2005).

The relevance of trust in institutions' problem-solving capacities is discussed in the context of risk perception research (Renn and Benighaus 2013).

Based on the results presented for the Oker context, the following considerations can be derived regarding the trust of the local population and local actors involved in raw material extraction projects at the tailings ponds in Bollrich. To present these considerations, we were guided by the aspects proposed by Measham et al. (2021).

Procedural fairness
Owing to the different histories and experiences in dealing with environmental impacts and the involvement of local stakeholders, it cannot be assumed that there is unrestricted trust that the positions, concerns, and ideas of local stakeholders will be taken on board in the decision-making processes. Nevertheless, the analyses clearly show that the expectation of being included in one's concerns in the context of a project that uses innovative technologies is very high. If stakeholders in mining projects want to gain the trust of Oker residents, it is essential to ensure procedural fairness, that is, to ensure that the local population has a tangible say in the process.

Fair distribution of impacts and benefits
The material analyzed revealed clear fears and hopes regarding the consequences of mining tailings ponds. If trust of the local community is to be gained and maintained, care should be taken not only to minimize the negative impacts and reinforce the already perceived benefits, but also to distribute the negative impacts and benefits fairly. Distributive justice was addressed in the analyzed material, primarily with regard to acute environmental impacts. Because it is probably only possible to distribute environmental impacts fairly to a limited extent in the context of mining projects, it is advisable to influence a fair distribution of the benefits of mining wherever possible. One example would be the local creation of jobs for people from Oker, who would ultimately be the most affected by the environmental impact. Similarly, the subsequent use of the area welcomed by the local public (for example, as a local recreational or leisure area) would probably have a positive effect on the perceived fairness of distribution and would therefore strengthen local confidence.

Local involvement of the project managers

Some scientists involved in the current research project from the Institute for Processing, Recycling, and Circular Economy Systems at Clausthal University of Technology are well integrated locally. They were referred to several times in the interviews, as they are regularly present in Goslar and Oker, have a media presence, and have been networked with various local stakeholders from business, politics, and environmental associations for many years. The analysis revealed that the actors were trustworthy. Trust in these scientists was also generally transferred by some interviewees to science and research on tailings ponds at Bollrich.

If a mining project is conducted under the responsibility of local companies, it can be assumed that their local ties will also have a positive effect on trust in the local community. However, there is an area of tension here, as some companies have lost trust in their past actions. This aspect should be considered when selecting mining project partners.

The landowner (Bergbau Goslar GmbH) appeared to have little to no local involvement. They are ultimately responsible for decisions associated with the site. It has already become clear from the analyses that there is currently a certain mistrust of the company as decisions, and in particular, precautions in connection with hazards are not perceived by the local community. Involving the company and making it more visible locally is important for strengthening trust in projects around the Bollrich.

Confidence in the organization and management of projects, including openness to project adjustments

In the past, there have been negative experiences with local industrial companies. For example, interviewees reported incidents in which companies circumvented legal requirements for environmental protection, leading to local pollution or odor nuisance. To this day, these experiences have given rise to mistrust in the organizational capacity of industrial and economic actors. Local administrations are also addressed here, as they must ensure that laws and regulations cannot simply be circumvented. As became clear from the interviews, their ability to act was perceived as limited, for example, when it came to reacting promptly to local environmental hazards. Therefore, trust in the authority's ability to act is limited.

Similar to the case analyzed by Measham et al. (2021), there are still some open questions among the population in connection with the project envisaged in Oker, the scientific answers to which are still pending. Interviewees pointed out such questions and expressed their expectation that they must first be answered before decisions are made regarding dismantling. The early communication of new research results is necessary to strengthen trust in scientific stakeholders as project participants. Depending on the new findings, project goals may need to be transparently adjusted for the local public.

Against this backdrop, it is of great importance for future mining projects to clarify that the capacities for responsible organization and management of raw material extraction are on the industrial and official sides. Project management includes procedural and distributive justice. Open communication about possible (but not yet precisely known) environmental impacts, which may also necessitate a change in project objectives or a readjustment of procedures, is part of responsible project management. Authorities should regularly make their work in monitor legal requirements (e.g., inspections) that are transparent to the public.

Early provision of (technical) information

The analyses clarify that it is important for local stakeholders to be informed about planned projects at an early stage. Therefore, it is crucial to fulfill this expectation in order to build trust in Oker.

9. Summary of the recommendations for action

Recommendations resulting from the individual factors of the local perception of possible raw material extraction projects from the tailings ponds at Bollrich in Oker are summarized below. The recommendations are specifically aimed at extracting projects from this location.

The following general conclusions can be drawn from the section "Expectations of participation in local projects": In Oker, it is particularly expected of local projects that project managers communicate proactively instead of citizens having to actively request information. Attention should always be paid to presentations that should be accessible and understandable to laypersons. Ideally, project managers should communicate as early as possible, before (negative) impacts occur. This preference is also reflected in the timing of the recommendations for the action proposed in the table. Locally-accessible public participation formats are generally better accepted in Oker than digital formats (as of 2022). For most of the proposed instruments and means, i.e., public participation formats in re-mining projects, it makes sense to explicitly address Oker residents rather than Gosla residents in general (justification of this recommendation in the section "Oker district specifics").

The recommendations for action proposed below are based on different discussions of public participation. The communication of non-knowledge and unforeseen events in the field of public relations has been addressed in the context of non-knowledge research, for example, by Gross and Bleicher (2013) and Parviainen et al.(2021). Publications by Petersen et al. (2013), Ruhrmann (2003), and Renn and Beninghaus (2013) deal with risk and uncertainty communication for (large-scale) technical projects in general. The "Guidelines for Risk Communication" of the Federal Office of Civil Protection and Disaster Assistance (2022) was also included. Because many of the following suggestions relate to communication between science and the public, research and format recommendations in this field are further sources of inspiration (Schäfer 2017; Taddicken et al. 2020; Wissenschaft im Dialog et al. 2023). Furthermore, suggestions for instruments and means of science communication and public involvement in scientific projects focusing on raw materials were drawn from the "methodological toolbox for transdisciplinary raw material research" (Ayeh et al. 2023). Strategies for public participation in the context of extractive projects are described in the PDAC guide "First Engagement. Field guide for explorers which has also been used to formulate recommendations for action (PDAC 2015)[5].

The list is drawn according to the point in time at which the measure makes sense; the measures that occur earlier in the project process are named first.

[5] These sources, but in particular the methodological toolkit for transdisciplinary raw materials research (Ayeh et al. 2023) or the PDAC guide "First Engagement: A field guide for explorers." (Prospectors & Developers Association of Canada (PDAC) 2015), but also the guidelines for risk communication (Federal Office of Civil Protection and Disaster Assistance 2022) are recommended for further public relations work.

What?	When?	Possible instruments and resources	Please note	Justification in the section
Strengthen perceptions of the tailings ponds that are conducive to the project	As of now and in the planning phase of the dismantling project	• Use of the frames contaminated site, recyclable material source and private site for press releases, public events, outreach walks, site inspections, presentation of project results, etc.		• 3. perception of the mountain ponds
Address positive & negative associations with the recycling industry in project communication	As of now and in the planning phase of the dismantling project	• Link to positive associations, press releases, public events, presentation of project results • Communicate negative associations in project communication clearly & openly and respond to concerns	• Positive associations: as an important employer, promotion of sustainability and national resource sovereignty • negative associations: high energy consumption or possible environmental impact	• 2. local perception of the recycling industry
Cooperation recommendations (status 2022): • Oker working group • Goslarsche Zeitung • Stakeholders of the round table "Bollrich sedimentation basin, Paradiesgrund and Formsandgrube landfills" remediation cases • Landowner • local environmental protection associations	As of now and in the planning phase of the dismantling project	• Actively invite people to public project events • Organize joint events • Inform proactively about project activities • Involve in project design/win over as project partner • Exclusive events (e.g. workshops between authorities and applicants)	• Greater public involvement of the landowner is advisable • Locally-based companies are particularly useful as project partners	• 8. local actors, • 9.Confidence

What?	When?	Possible instruments and resources	Please note	Justification in the section
• locally-based companies • Authorities				
Provide the local population with up-to-date information on the project process and objectives (such as expected material gains, approach to remediation)	from project decision	• Citizens' meetings • Press • Social media • Information materials (e.g., flyers) in publicly-accessible places; by posting; make available to well-connected stakeholders such as associations • Information at the round table • Provide contact options for information and queries from the public, e.g., special email address • Training of project staff in public relations communication	• Create a participation plan • Provide comprehensive, up-to-date information that is understandable and transparent for the local population • make it clear that there is capacity for responsible organization and management of raw material extraction on the industrial and official side	• 7. expectations of participation in local projects, • 9. trust
Information about handling of residual materials from mining; provide during remining	Planning phase of the dismantling project, Continuous project support	• Citizens' meeting, e.g., with the participation of the Oker working group • Press • Social media • Information materials (e.g., flyers) in publicly-accessible places; by posting, make available to well-connected stakeholders such as associations • Information at the round table • Provide contact options for information and queries from the	• Provide information openly and proactively and give reasons if necessary (e.g. regarding time frame) to reduce irritation	• 3. perception of the tailings ponds, • 4. expectations in relation to the tailings ponds, • 7. participation expectations for local projects

What?	When?	Possible instruments and resources	Please note	Justification in the section
		public, e.g. special email address, contact person		
Provide information on the stability of the dam and continued protective function of a rebuilt Bollrich dam	Planning phase of the dismantling project, continuous project support	• Take measures to prevent dam failure (and other hazards) • Continuously provide information on the current state of the tailings ponds at Bollrich and possible hazards and scientific risk assessment, process it, and make it available and explain it to the public, e.g., as part of: ○ Publications and ideas ○ Press releases ○ Social media ○ Citizen events ○ Lectures ○ Information material (e.g. flyers): in publicly accessible places; by posting; make available to well-connected stakeholders such as associations ○ Contact option for queries ○ Training of project staff in public relations communication	• Provide information openly and proactively • Present risks to the local population in an understandable, direct, factual, and not overdramatized way • Address the safety needs and fears of local residents about dam failure • Address (as yet) unknown dangers and communicate ignorance • Explain why the dismantling plans make sense (e.g., in comparison to not dismantling or quickly filling in the ponds) for the local population • in cooperation with the competent authorities, make the frequency and results of inspections transparent to the public	• 3. perception of the tailings ponds, • 4. expectations in relation to the tailings ponds, • 5. district specifics Okers, • 7. expectations of participation in local projects, • 9. trust
Addressing the impact on the environment and people during dismantling	Planning phase of the dismantling project, continuous project support	• Take measures to reduce environmental pollution • In the context of publications and presentations • Press releases • Social media • Citizen events	• Allow critical comments • Respond to queries calmly and transparently • Take local experiences and concerns about (environmental) pollution seriously	• 1. regional reference to the mining and smelting past, • 3. perception of the tailings ponds, • 5. district specifics Okers,

What?	When?	Possible instruments and resources	Please note	Justification in the section
		• Lectures • Information materials (e.g. flyers): in publicly-accessible places; by posting; make available to well-connected stakeholders, such as associations • Contact option for queries • Training of project staff in risk communication	• be particularly sensitive with regard to environmental issues and, if necessary, go beyond official requirements for emissions • Present possible burdens in a transparent, understandable, direct, factual, and not overdramatized way for the local population • also address (as yet) unknown dangers and communicate ignorance • Explaining why dismantling makes sense • Clearly show invisible burdens on the tailings ponds before dismantling (+ flora and fauna) • Immediate information about unexpected problems associated with unplanned loads	• 7. expectations of participation in local projects, • 9. trust
Communicate and justify the duration of the dismantling project	Planning phase of the dismantling project, Continuous project support	• In the context of publications and presentations • Press releases • Social media • Citizen events • Lectures • Information materials (e.g., flyers): in publicly-accessible places; by posting; make available to well-connected stakeholders such as associations • Contact option for queries	• Provide and justify information openly and proactively to reduce irritation	• 4. expectations in relation to the tailings ponds

What?	When?	Possible instruments and resources	Please note	Justification in the section
Where realistically positive reference is made to hopes of mining the tailings ponds	Planning phase of the dismantling project, continuous project support	• influence the broad distribution of the benefits of mining (e.g., creation of jobs for people from Oker, subsequent use of the area as a local recreation or leisure area) • In the context of publications and presentations • Press releases • Citizen events • Lectures • Information materials (e.g., flyers): in publicly-accessible places; by post; make available to well-connected stakeholders such as associations • Contact option for queries	• Hopes e.g. for redevelopment of the Bollrich site, elimination or reduction of the risk of dam failure, renaturation of the area after dismantling, creation of jobs in the region (for all hopes see table under "Expectations in relation to the tailings ponds") • When presenting the advantages and disadvantages of downsizing, make sure to present them as realistically as possible • Communication of as yet unknown aspects that only emerge in the course of the project (lack of knowledge) and public provision of the project-internal strategy to counter this lack of knowledge	• 4. expectations in relation to the tailings ponds, • 7. expectations of participation in local projects, • 9. trust
Addressing fears relating to the mining of tailings ponds	Planning phase of the dismantling project, Continuous project support	• In the context of publications and presentations • Press releases • Citizen events • Lectures • Information materials (e.g. flyers): in publicly accessible places; by post; make available to well-connected stakeholders such as associations • Contact option for queries	• Fears of, e.g., negative impacts on citizens and nature as a result of mining (for all fears, see table under "Expectations in relation to the tailings ponds") • Address fears calmly and clearly • When presenting the advantages and disadvantages of downsizing, make sure to present them as realistically as possible • Communication of as yet unknown aspects that only emerge in the	• 4. expectations in relation to the tailings ponds, • 5. district specifics of Oker • 7. participation expectations for local projects

What?	When?	Possible instruments and resources	Please note	Justification in the section
		• Training of project staff in risk communication	course of the project (lack of knowledge) and public provision of the project-internal strategy to counter this lack of knowledge	
Actively address references to mining and smelting in the region and relate them to the planned project	Planning phase of the dismantling project, continuously accompanying the project	• Train researchers in science communication and inform them about typical smelting processes in the region in the past • Communication and answering questions in the context of public relations work	• Researchers should be able to respond to detailed scientific and technical questions (e.g., on differences & innovations between re-mining and processing methods commonly used in the 1980s and those used today, especially with regard to environmental impact)	• 1. regional reference to the mining and smelting past
Involve local stakeholders who are considered particularly central and competent in the project	Planning phase of the dismantling project, Continuous project support	• Regular evaluation of who these actors are (by actors with a high level of local expertise) • Actively invite stakeholders to public project events • Organize joint events • Obtain the opinions of these stakeholders on specific topics		• 1. regional reference to the mining and smelting past, • 8. Local actors
Actively dealing with opposition to the project	If a contradiction is perceived	• Ask for reasons for objection • Where possible, look for alternatives together with those affected (e.g., other routes for heavy goods vehicles or changed time slots for acoustically stressful activities, etc.) → Enable a tangible say in processes	• Revise participation plan if necessary (e.g., if more involvement is desired)	• 6. citizen participation culture in Oker, • 9. trust
Actively incorporating local knowledge, suggestions, and ideas from citizens into	Accompanying the project and in particular when realization of	• Organized participation process with information events, workshops for contributing and developing ideas (e.g. scenario workshop), workshops	• Inclusion of local expertise must be taken seriously and take place in dialog → enable a tangible say in processes	• 3. perception of the tailings ponds,

What?	When?	Possible instruments and resources	Please note	Justification in the section
decision-making processes (e.g., on the subsequent use of the area)	selected proposals is foreseeable (e.g., for use 1–2 years before the end of dismantling), information on inclusion in planning already during the project term	for discussing results involving, for example, the Oker working group and other multipliers	• The limits of what can be implemented should be clearly communicated from the outset • Area not available as a local recreation area during extraction → inclusion in planning for subsequent use could reduce frustration	• 7. expectations of participation in local projects, • 9. trust

Table 3: Recommendations for action

3.4.2 Perception in the building materials industry

The factors identified in the empirical research that can inhibit the use of materials from tailings ponds in the building materials industry are presented below. In addition to obstacles that have already been described in the literature on other recycled building materials, additional obstacles were identified in the course of the analysis, which were primarily due to the local context of the tailings pond material. These obstacles could also be of significance in other projects involving the use of raw materials from tailings ponds.

We first present all the inhibiting factors in the weighting that result from our empirical material (six expert interviews and an online workshop with 20 participants), each with a focus on tailings pond materials from the perspective of practitioners and scientists. Not all of the factors presented are necessarily barriers; in the case of factors that are only barriers under certain conditions, these conditions are made clear. When evaluating the potential barriers as central (*graphic: darker blue*) and less central (*graphic: lighter blue*), the frequency with which they were mentioned was considered, as was the importance attributed to them by the interview participants and how easy it was considered to overcome them. The 14 identified potential obstacles are shown in Figure 1.

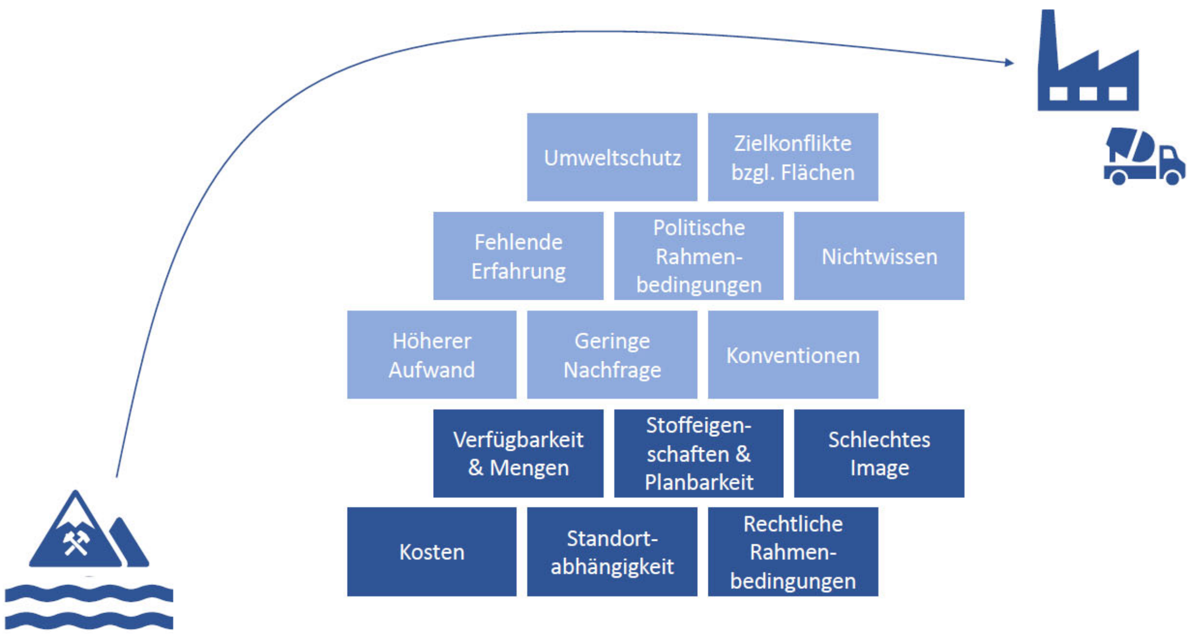

Figure 2 Barriers to the use of materials from tailings ponds in the building materials industry

These obstacles are presented individually below, along with recommendations for counteracting them. It should be noted that scientific project results show that there are various problems with the usability of materials in the building materials industry. Based on our considerations and recommendations, we assume that the possibility of using tailings pond materials in the building materials industry will be proven in the future. Only then will the proposed measures make sense.

In summary, the barriers to the use of secondary raw materials in the building materials industry are assessed regardless the material flow in which they could be used. The results of an internal ReMin cluster workshop with 44 participants focusing on various RC materials in the building materials sector were used for this purpose.

Key potential obstacles

a) Costs & profitability

Cost and presumed cost-effectiveness play a decisive role in the integration of tailings pond materials into the building materials industry. This factor has been extensively confirmed in the literature, as shown in studies by Chileshe et al. (2018), Ding et al. (2021), Gorgolewski (2008), Shooshtarian et al. (2020), Densley Tingley et al. (2017), Dunant et al. (2017), and Badraddin et al. (2021).

Our empirical study revealed that expected costs and presumed cost-effectiveness were the most frequently cited barriers to the use of tailings pond materials. High costs make tailings pond materials less attractive. Cost-effectiveness is a relative factor, as the exact costs are often unknown, especially in comparison to the costs of primary materials, which are easier to calculate based on experience.

Different costs are associated with the use of tailings pond materials. These include research, new machinery and technology, and permitting, processing, and transportation costs. For other building materials such as gypsum, a processing plant is usually set up directly near the natural deposit so that the end product can be produced without additional transportation, which is rarely the case for secondary raw materials. For materials from secondary deposits, the available quantities of secondary raw materials are so small that the construction of a processing plant is not economically viable. This results in longer journeys, and therefore, higher costs. These logistics costs account for a significant proportion of the material extraction costs. The justifiable costs depend on the expected sales price of the end product with recycled content. This, in turn, is strongly influenced by the images of the RC building materials. Finally, economic efficiency is also influenced by the quantity of material available in a deposit, as its quality differs between deposits, making necessary adjustments to the processing line in each case. The costs incurred, processing effort, and expected demand are key parameters in the economic efficiency analysis. Currently, experts consider these to be less favorable than natural raw materials. An illustrative quote from a workshop underlines the challenge that although many in the building materials industry support the idea of recycling, only a few want to bear the currently still high or uncertain costs: "What I took away from today is that everyone wants recycling, but nobody wants to do it/pay for it." (Workshop 2023).

However, it is also emphasized that political or legal incentives could make tailings pond materials substantially more attractive than primary raw materials.

b) Location dependency

The location dependence of materials from tailings ponds is a factor that is rarely considered in the literature on other secondary raw materials. Location dependency implies that the location of a mining legacy plays a decisive role in determining whether the use of a material is economically feasible. Particularly relevant here is whether the material can be processed in immediate surroundings. The low local availability of recycling factories is also evident in the recycling of concrete, which according to Badraddin et al. 2021 is an obstacle to its use of recycled concrete in the building materials industry. Shooshtarian et al. 2020 showed that, even in the recycling of general construction waste, only limited recycling technologies are available, hindering their further use.

The location of tailings ponds can both inhibit and promote the use of stored materials. However, its use is inhibited when long transportation routes are required. This is mainly due to the fact that, compared to materials such as concrete or steel, tailings pond materials can only be transported at great expense. This is due to the material properties, particularly the high water content, fine grain size, and often high pollutant content. The location of tailings ponds is advantageous if processing plants and sites are regionally available, and if comparable primary raw materials need to be sourced, transported and delivered over long distances. If the infrastructure for recycling already exists locally that can be (re)used for recycling of tailings material, this can be beneficial for the use of secondary raw materials. A quote from a workshop participant illustrates the dependence on regional availability and structure.

> *"It is essential to know what infrastructure still exists in the region: For example, is there a treatment plant? How far is it to the nearest hut? The less there is, the more I have to build first. To what extent can I fall back on (semi-)mobile solutions (e.g. containers for processing)?"* (WS 2023).

Overall, it can be said that the location dependency of the material is associated with major obstacles but can also be beneficial if the material can be processed locally.

c) Legal framework

Scientific literature describes inappropriate legal frameworks in many national contexts as obstacles to the use of recycled raw materials in the construction materials industry. For example, case studies in the USA, Australia, China, Malaysia, United Kingdom, and Switzerland have found that existing laws and standards represent a significant barrier to the use of recycled steel, concrete, and building materials (Badraddin et al. 2021; Dunant et al. 2017; Shooshtarian et al. 2020; Park and Tucker 2017). In the German context, the use of recycled concrete is primarily hindered by a lack of government support and uncertain and inconsistent government regulations from the perspective of companies that want to use it (Katerusha 2021).

These observations are consistent with our findings. The current laws, norms, and standards for the use of recycled raw materials in Germany were mentioned as some of the most important obstacles by all experts interviewed and in all group discussions in the workshop. Much-discussed topics include ownership of old mining waste, approval of new building materials, and general criticism of the lack of government support.

Ownership structure

One point raised by some people is the ownership structure of the contaminated sites. It is relevant in which federal state the respective tailings pond is located, whether it is privately or publicly owned, and what legal consequences this entails (e.g., administration under mining law, exemption from contaminated sites in the eastern federal states). This is particularly important when negotiating whether the focus should be on the extraction of recyclable materials or hazard prevention when dismantling a tailings pond, as private owners and public institutions may have different priorities. Private owners may be more interested in the economic use and recovery of recyclable materials, whereas public institutions may pay more attention to public safety and environmental compatibility. Depending on the state and ownership status, different laws and regulations may influence how deconstruction is carried out.

Approvals of new building materials

Difficulties in obtaining approval for new, recycled building materials have been frequently discussed. It was criticized that there are exceptionally high bureaucratic hurdles to overcome to obtain permits and approvals under the building law for the use of new, recycled raw materials. Approval procedures are often lengthy and expensive, and there is a lack of a clear and standardized orientation framework for limit values for pollutants, for example. One point that has been highlighted as particularly important is the lack of legal equality in the environmental requirements for primary and secondary raw materials; pollutant limits for primary raw materials are sometimes lower than those for recycled materials. Waste and product legislation in Germany, which has been criticized for being too complex and inconsistent, is also closely linked to this. Among other things, it is unclear under what circumstances the waste status of a material ends and it can be defined as a product, which is an important question in the context of tailings reuse. There are also differences in the regulations of the various federal states. German law is also partly unaligned with the EU taxonomy. Furthermore, in some cases, competent authorities may have limited experience with such problems. The question of who is liable in the event of inadequate-quality recycled materials has not yet been conclusively clarified.

General lack of government support
Apart from specific applicable laws or standards, the general lack of political will to change a complicated situation was also criticized, which persisted despite the commitment of many politicians to a circular economy. According to the interviewees, one example is the public procurement law, which currently does not give preference to construction projects that use recycled materials. There is also a lack of consistent implementation of the existing recycling-friendly regulations. The reason for this is partly seen in the fact that too little is communicated about changes made to regulations. With regard to some issues concerning the use of recycled building materials, there is a lack of regulations, while in the perception of the interviewees, there are too many requirements and regulations that contradict each other. For example, on the one hand, high recycling percentages are required in construction, while on the other hand, maximum percentages are specified in building material standards).

The lack of clarity, binding nature, and cross-national standardization regarding the use of secondary raw materials has been regretted. The workshop participants and interviewees wished that this should be addressed by the state. As most of the regulations requiring change relate not only to raw materials from mining residues, but to secondary raw materials in general, we refer to the final communiqué of the cluster workshop of the BMBF funding measure ReMin "Resource-efficient circular economy, construction, and mineral material cycles" for specific recommendations for action (Gentzmann et al. 2023b).

d) Availability & quantities of the material
However, the availability of tailings pond materials is a key obstacle to their use in the building materials industry. The problem of availability as an obstacle has already been well documented in the literature for other materials in different spatial contexts, for example, in studies by Shooshtarian et al. (2020), Densley Tingley et al. (2017), Dunant et al. (2017), and Katerusha (2021) for the construction and demolition of waste and Badraddin et al. (2021)recycled concrete in Malaysia.

The quantity of raw materials stored in tailings ponds and dumps is crucial for their use. According to a statement from the online workshop, this is precisely where the challenge lies: "The quantities in the tailings ponds are not a large enough amount of raw materials that we can convert into building materials in one year" (Workshop 2023). One interviewee stated that five years was the minimum period for which a raw material source with similar raw material properties should last, and 10 years was considered ideal. Nevertheless, this person also pointed out that it is not only the quantity of the secondary raw material that is decisive, but also its quality and material properties - even very small proportions in an end product–that can be worthwhile provided they are of the right quality. Overall, several of the experts interviewed confirmed that secondary raw materials in the building materials industry can only ever be additives and can never cover the entire demand for raw materials or completely replace primary raw materials.

Against the background of these observations and statements, it seems advisable to consider the possibility of parallel mining of several tailings ponds with similar deposited materials to deal with insufficient quantities of material. Careful planning and, if necessary, the control of material availability during the mining process would also appear to make sense.

e) Material properties & plannability of the manufacturing processes
Another potential obstacle raised by several experts is the material properties of the substances that can be extracted from tailings ponds. According to experts' perceptions, this is associated with the poorer predictability of processing procedures. The background here is the assessment and fear already identified in various studies that the quality and performance of recycled building materials are too low, and the contamination is too high (Chileshe et al. 2018; Shooshtarian et al. 2020; Dunant et al. 2017; Badraddin et al. 2021). For example, in the case of recycled steel, the fact that there are few quality control options inhibits the use of the product regardless of its quality (Densley Tingley et al. 2017). This shows that it is not only the measurable material properties that hinder its use, but that

the expectation of inadequate material properties and their poor predictability are already obstacles. The situation appears to be very similar for materials from tailing ponds.

The experts surveyed considered various properties of materials from tailings ponds to hinder their use in the construction industry, for example, as additives in cement clinkers or bricks. Most doubts were expressed about the *physical nature of the raw materials* from the tailings ponds, their *chemical properties and,* less frequently, their *optical properties.* Whether one of the material properties is an obstacle depends heavily on the intended product, as these have different application areas, input material requirements, and standards. Furthermore, *concerns regarding the quality assurance process were* a much-discussed topic. These four aspects are explained in detail below.

Physical properties
Physical properties refer to characteristics such as the composition of the material mixtures from tailings ponds and aspects such as the grain sizes of the individual substances or the moisture content of the material.

The high heterogeneity of material mixtures is one of the greatest challenges. The composition of tailings often varies within a pond. The reasons for this are, for example, changes in the treatment processes from which the deposited material originates, the geological structures and properties of the geological deposit, the contamination of the open tailings ponds, for example through the deposition of organic material over decades, and changes in the materials due to the long storage period (e.g., through erosion, see *chemical properties*).

Because materials for the manufacture of end products should be homogeneous, complex processes are required to separate heterogeneous mixtures of substances. Particularly important is the separation of contaminants and impurities such as heavy metals, which may only be present in the end product to a certain extent. Even when investigating which substances are present in a specific tailings pond is time-consuming and costly, rarely is precise documentation available on the deposited substances, and even if information is available on the original composition of the material, it cannot be ruled out that contamination has occurred. An example reported by a workshop participant regarding the location of dumps is:

> "*In the east of the country, a kind of "wild west" atmosphere has often prevailed with regard to the privatization and storage of waste rock piles. You can't rely on the fact that there are only homogeneous materials in dumps. I wouldn't be surprised if there are still dumps with asbestos deposits etc. to be found. These nasty surprises don't occur everywhere, but occasionally.*" (WS 2023).

The different compositions of the layers in the stockpile and tailings pond also mean that different processing systems are required and that the continuous provision of similar materials is more difficult. Changing the initial conditions for tailings poses a challenge for processing systems, as frequent fine-tuning of the machines for end products that must always achieve the same quality (in compliance with quality standards) is very time-consuming. According to experts, there is still a need for a detailed investigation into the maximum quantities of mining material that can be added to maintain the desired quality of the end product.

In addition, the fineness of the material from the tailings ponds, high grain size variability, high moisture content, and high bulk density can make the processing of these materials markedly more complex.

Chemical properties
Under the heading of chemical properties, experts primarily addressed potentially harmful and interfering substances in the materials. This can lead to unwanted reactions and changes in the material during the storage or treatment process, as well as the release of unwanted substances from the end products.

If pollutants escape during the treatment process, certain exhaust gas limits cannot be met, and air pollution can occur. The occupational safety of workers handling substances is also an important aspect.

The release of pollutants from end products, which contain processed materials from tailings ponds, can also lead to environmental or health damage. According to interviewees, there were major concerns regarding such processes, particularly in public administration.

Optical properties
A subordinate, but not negligible, role is attributed to the properties of the materials that influence the desired appearance of the end product. For example, color changes in end products can lead to their perception as unaesthetic or inferior.

Concerns regarding quality assurance
In addition to fears of lower-quality end products due to pollutants, concerns about the possibility of quality control also play a role. In view of the difficulties in obtaining homogeneous material flows from tailings pond materials, there is a greater need for quality control than with primary raw materials, as the material compositions vary to a lesser extent. Environmental, chemical, and physical quality requirements are imposed by both industries and authorities.

These multiple concerns regarding the properties of raw materials from tailing ponds can be addressed by a thorough scientific analysis of their feasibility and potential risks. This requires a detailed investigation of the composition of each potential deposit and an analysis of the material with regard to its properties and impurities. Depending on the product, whether degrees of freedom are possible in the quality requirements should also be examined. Discussion forums would be appropriate specialist conferences, but also specifically created working groups of material manufacturers and users with the involvement of political players. In addition, it is advisable to prepare for the knowledge gained in an understandable manner for laypersons.

f) Poor image
Negative perceptions of recycled materials and their limited acceptance of recycled materials in the building materials industry are often described as barriers to the use of secondary raw materials (Badraddin et al. 2021; Dunant et al. 2017; Densley Tingley et al. 2017; Shooshtarian et al. 2020; Park and Tucker 2017). Research suggests that this problem occurs across all material streams in the building materials industry.

In our analysis, we identified various stakeholder groups to whom a poor image of recycled materials was attributed.

- *Authorities*
- *Players in the building materials industry*
- *General population*

The experts we spoke to assumed that the negative perception of materials from tailings ponds had an impact on their use in the building materials industry. The poor image of tailings pond materials in the building materials industry directly influences their use. It is assumed that the presumed poor image among the authorities and the general public has the effect of less demand, and therefore fewer sales opportunities for the material. The poor image and the associated lack of openness on the part of the authorities were seen as key obstacles, whereas the poor image of recycling materials from tailings ponds among stakeholders in the building materials industry and the general public was seen as existing but easier to overcome.

Authorities

The poor image and lack of openness towards secondary materials among the authorities are particular obstacles when formulating public tenders for and approving construction projects in which secondary materials can be used as building materials. Secondary raw materials are seen as "waste" and there is a great fear of contamination. This applies particularly to materials used in mining applications. One expert described the authorities' views on secondary raw materials as:

> *"When the public sector invites tenders, it is not uncommon for secondary material to be omitted. [...] because you're afraid you'll miss the mark and in five years' time, you'll have junk with some kind of contamination that may have been in the material after all."* (Members of the Building Materials Industry Association, 2022)

As this quote illustrates, it is assumed that the combination of the fear of contamination and a pronounced risk-avoidance attitude by some authorities is an obstacle to the use of secondary raw materials from tailings ponds. In the material analyzed, it was often criticized that the existing structures of authorities promote risk-averse decision-making behavior, making changes towards the use of secondary raw materials very unlikely, even if these are only associated with minimal risks compared with their generally positive ecological impact (e.g., avoiding the use of primary raw materials). Existing conventions and habits, as well as unclear responsibilities, also have an influence. Another point raised by some interviewees was the perceived lack of knowledge about secondary materials by some authorities. The reason for this is that employees who make decisions often only have training as administrative staff and are therefore unable to assess the technical and scientific aspects well.

However, we must note that it was not possible for us to speak to representatives of the authorities on this topic as part of the project; therefore, only an external view of the authorities is presented here.

Players in the building materials industry

The interviewees explained that materials from tailings ponds are also very often perceived as "waste" by stakeholders in the building materials industry (e.g., concrete and brick manufacturers). This is closely related to the expected inadequate material properties. This goes hand in hand with the conviction that waste is not something that can be turned into a product. In official tenders, recycled materials are rarely requested or rejected (*see above*). It is not easy to turn recycled materials into products for end customers from the general population because it is assumed that recycled raw materials do not have a good image.

General population

According to some of the experts interviewed, it is more difficult to sell products made from recycled materials advertised as such. This subsequently affects companies' profitability. A quote from a workshop illustrates this problem: "Who wants material that was once hazardous waste? It could be difficult to convey this to the house builder." (WS 2023).

However, our analyses also indicate that the image of recycled materials is seen as less negative by the general population than by the authorities. Some experts even rated the image of recycled materials among the general European population as neutral to positive. Many of the experts surveyed also suggested that one reason for the poor or, at best, nonexistent image among the general public is that marketing was not sufficiently effective. Better marketing, it was assumed, would promote the social acceptance of former "hazardous waste materials".

In view of the negative image in the general population, it can be stated that social re-evaluation and revaluation processes are necessary with regard to the material. As research in this area clarifies, such processes can be initiated by political objectives and supported by the establishment of appropriate infrastructures and processes, as well as by a corresponding public discourse (Reno 2009; Bleicher 2018; Levidow and Raman 2019; Schramm and Thi Thanh Mai 2019). In addition to political initiatives, one starting point for concrete measures could be reducing information asymmetry to strengthen the confidence of companies that use secondary materials. A company's image can be improved through targeted marketing and positioning in sustainability and resource conservation.

With regard to the negative image in the *building materials industry,* it can be said that targeted further training courses for players in the building materials industry could be beneficial if the materials extracted from the tailings ponds prove to be suitable for use in the building materials industry. A stronger exchange of knowledge between researchers, the government, the building materials industry, and environmental organizations could also promote the use of secondary raw materials.

To counteract the negative image of secondary raw materials among *authorities,* initiatives focusing on information and training are beneficial. At the administrative management level, further training events on the possibilities and limitations of secondary materials in the construction sector could be as useful as training events for public authority employees who make decisions on specific projects and issue permits. In addition, it would be beneficial to organize and intensify the exchange of experiences between administrations. Forums for this could be specialist conferences, but also the federal and state working groups (e.g. water and soil), which should shed light on the topic and the associated challenges from their respective perspectives. A revision of the procurement guidelines to prioritize environmentally friendly and sustainable building materials, including secondary materials, would also be useful. The fact that the circular economy is given greater weight in the current federal raw materials strategy (2020) with regard to the provision of raw materials could be taken as a concrete opportunity here. Last but not least, carrying out pilot projects to demonstrate the use of secondary materials and accompanying them with communication measures tailored to the relevant stakeholder groups is a good way of reducing uncertainty and building confidence in the use of secondary raw materials.

Other potential obstacles

g) Higher expenses

In the literature on barriers to the use of recycled materials, various types of increased costs have been reported for different material flows. For example, in the case of recycled steel, the increased storage costs are an obstacle (Densley Tingley et al. 2017; Gorgolewski 2008). For recycled building materials in general, increased logistics costs, increased time expenditure, and a generally defined "increased complexity" are described as obstacles compared to primary raw materials (Gorgolewski 2008; Chileshe et al. 2018). Badraddin et al. (2021) showed that secondary concrete requires a different type of project planning than primary concrete, because the processing step must also be considered.
Regarding mining residues, the experts also mentioned a potentially longer time and financial outlay, with the mining materials to be recycled as a problem or obstacle. The expected effort is set in relation to the expenses for known materials (primary raw materials). Higher expenses are expected for:

- Transportation and logistics
- Approvals (especially for new building materials)
- Analysis (in particular with regard to available quantities considered to be low)
- Preparation
- Conversion of processes for manufacturing products from recycled material (e.g., technology or workflows)

Some interviewees described the various higher expenses as an important reason why the use of materials from tailings ponds still requires conscious and committed decisions. According to experts, the poor predictability of the exact additional time or cost expenditure also means that many industries prefer to use primary raw materials.

However, greater effort is not necessarily an obstacle if it does not have a significant impact on the economic efficiency of building materials. In the words of one workshop participant: "*If something is of higher quality, I can go to more effort.*" (WS 2023).
Simplification of approval procedures or other regulatory or tax measures could increase the economic attractiveness of building materials made from recycled materials, making their use more likely.

h) Low demand
The low demand for recycled materials is another obstacle to the use of tailings pond materials in the construction industry. As scientific literature shows, the phenomenon of a lack of or too little demand is an issue in the UK, for example, in the context of the use of recycled steel, as well as for recycled building materials in Australia (Densley Tingley et al. 2017; Park and Tucker 2017). According to Katerusha (2021), this problem exists for recycled concrete in Switzerland and Germany.

In the construction industry, recycled building materials tend to be used in response to explicit customer requests (e.g., from tendering authorities, companies, or private customers) rather than being proactively offered by manufacturers. Although some private customers ask for these materials for environmental reasons, this demand does not exist on a broad scale to the extent that their production is economically worthwhile for companies. There is also very little demand from public authorities or processing companies for such materials. This is particularly true when the primary raw materials are considered reliable and readily-available. Consequently, little investment has been made in the use of recycled building materials. One workshop participant commented, "The demand may not be there and there is a supply [of primary raw materials]. You have to do the groundwork." (Workshop 2023). Other reasons cited for the low demand include the conservative attitude of some building material customers who do not want to take any risks or conduct experiments, poor image of substitute building materials, lack of knowledge about their benefits, and the general possibility of using such products. Nevertheless, some of the surveyed experts considered the demand to be definitely present or potentially present as soon as gaps in knowledge regarding the existence and advantages of such materials were eliminated.

As with the poor image of secondary raw materials, marketing and information campaigns for the wider public, such as those launched by trade associations and interest groups, can be useful. Successful marketing can serve as a guide. For example, if green cement is advertised, the production of which generates less CO_2, higher prices can be charged. Training courses or workshops on the added value of materials from tailings ponds for certain potential customer groups can also help increase the demand.

i) Conventions
The use of primary raw materials is well established compared to the use of secondary raw materials and is therefore based on existing structures and relationships, as well as accepted implicit rules (conventions). For example, the customary use of primary steel prevents the use of recycled steel (Dunant et al. (2017). The use of recycled steel involves the cooperation of substantially more specialists and companies than that of primary steel (Dunant et al. 2017). The use of secondary steel is also associated with the loss of well-established working relationships, and a lack of trust and communication between new players (Dunant et al. 2017). In addition, inertia plays a role in changes in the construction industry, indicating that the industry is often reluctant to accept and implement new materials and approaches (Densley Tingley et al. 2017).

According to many of the experts interviewed, using primary raw materials as building materials is also the industry standard for material flows relevant to tailings pond residue (cement, brick, and clinker production). This means that changes in the use of secondary raw materials require a high level of self-motivation to overcome existing conventions. The various conventions that can inhibit the use of raw materials from tailing ponds can be divided into three areas: *Infrastructure, habits,* and *relationships*.

Infrastructure refers to both existing machinery and technology and the application knowledge associated with their use and experience. *Habits are defined* as routine daily practices in the building materials sector, such as purchasing and distributing materials. It also refers to "perceived" standards of the raw materials or technology used - i.e. raw materials and technology that are used as standard without actively thinking about whether they could be changed. Closely linked to this are the established *relationships* that go hand-in-hand with the standard approach. Existing trust plays a role here as did established communication channels (Dunant et al. 2017). However, the lock-in effects promoted by contractual ties in purchasing relationships are also relevant, as a quote from the workshop illustrates:

> *"The willingness to change is there. But there are supply contracts. If primary raw materials are around the corner and you know the suppliers, then the risk [of using them] is lower than breaking new ground. [...]" (Workshop 2023)*

Some interviewees emphasized the importance of trust between business partners arising from long-term cooperation. Such a relationship must first be established with the suppliers of secondary raw materials. However, a person from the workshop added, *" [...] But if something catches on elsewhere, then you become more willing to take risks everywhere." (Workshop 2023).* This shows the potential for well-established relationships to be offered in the building materials sector. For example, if an established business partner decides to offer more secondary raw materials from tailings ponds, this can attract other partners. Some interviewees also noted a general willingness to break with existing conventions, particularly in small and medium-sized companies, especially if it makes economic sense.

In addition, moments of change, such as the phase-out of lignite, can be actively used for the placement of recycled materials, as they break certain supply chains in the building materials industry. This is also supported by interest groups.

j) Lack of experience

As materials from mining residues have not yet been used in the building materials industry apart from research projects, the respective stakeholders (building material manufacturers, construction planners, architects, customers, representatives of authorities, etc.) have not yet gained experience with these materials. According to some interviewees, this lack of experience and the associated lack of know-how led to uncertainties in dealing with recycled building materials, making their use more difficult.

For other material flows such as steel recycling, the lack of experience among players in the construction industry in handling recycled steel also inhibits its use (Densley Tingley et al. 2017; Dunant et al. 2017).

In addition, the limited experience with technologies for processing recycled materials has played a role. Some of the experts interviewed reported that although most of the necessary processing technologies already exist (e.g., in the area of sorting technology), no experience has yet been gained in using them for materials other than those known. However, in some cases, technologies necessary for further processing and use of the materials do not yet exist.

Finally, the lack of networking between companies makes it difficult to share experiences in dealing with recycled materials, which could make it easier to reduce uncertainty.

Regarding missing technologies, R&D are sensible measures. From the time of the first large-scale projects on the use of materials from mining residues in the construction materials industry, industry internal events for the exchange of experience could be beneficial. Industry interest groups can also play an important role, similar to regular specialist events.

k) Political framework conditions
In interviews and workshops, a lack of political will, and consequently, incentives for the use of recycled materials in the construction industry, were frequently cited as obstacles. Case studies on concrete, steel, and construction waste recycling in Malaysia, the UK, Germany, and Switzerland have cited low political incentives and the current political climate as barriers to the use of recycled materials in the construction industry (Badraddin et al. 2021; Densley Tingley et al. 2017; Katerusha 2021; Knoeri et al. 2011).

The lack of or unclear political incentives is also a problem in the context of materials from tailings ponds, as reflected in the legal framework for recycling tailings. Although sustainability has been promoted in Germany for many years (see the National Sustainability Strategy) and is mentioned as a central goal in the political actions of many governing parties, what is considered sustainable is not always clearly defined (The Federal Government 2021; Fleig and Tosun 2017). For the construction and infrastructure sectors in particular, respondents criticized the fact that, for example, there was no priority given to secondary raw materials in public procurement laws across federal states. This makes it difficult to use such materials in construction projects and leads to uncertainties when using recycled materials such as materials from tailings ponds.

One solution could be a stronger exchange of knowledge between science, industry, society, and politics, which would ideally lead to a greater understanding of society and politics regarding the relevance of secondary materials in the building materials industry.

l) Not knowing
A lack of knowledge about secondary materials and existing structures are cited as obstacles regarding recycled steel and the reuse of construction waste (Densley Tingley et al. 2017; Shooshtarian et al. 2020).
Research on tailings pond materials as a source of raw materials has a high novelty value, but there are still large gaps in knowledge that are perceived as obstacles to the use of these materials. The material contained indications of a lack of knowledge in relation to various topics:

- Possible use of tailings pond materials as a resource
- Costs (including price trends)
- Availability and quantities
- Fabric properties and material quality
- Future demand
- (Future) legal regulations (e.g., minimum proportion of secondary raw materials in public tenders and guidelines for pollutants)
- Deposits of mining residues (including content)

The lack of knowledge regarding the existence and properties of secondary raw materials has also been criticized by authorities, inspection bodies, users (e.g., engineering firms), and lending banks. For example, interviewees justified the low demand for secondary raw materials, poor image, lack of openness, and low level of knowledge. The interviewees stated that the transfer of knowledge from research to practitioners was inadequate, as a reason for the diverse lack of knowledge associated with tailings pond materials. In addition, the limited focus on recycling materials in scientific and technical training and study contexts was cited as a reason for the lack of knowledge regarding their possible applications.

It was also noted that comparatively little research is being conducted in Germany on the use of tailings materials, for example, with regard to the material properties of tailings pond materials. In the workshop, one participant commented:

> "*I would draw a distinction between Germany and the major mining countries such as Canada, Chile or Australia. There are a lot of activities there to meet the tailings challenges. This is not the*

case in Germany, because Germany practically closed down its mining industry in 1990. As far as the volume of waste is concerned, it is also rather minimalistic here. From a global perspective, the issue is bigger than in Germany."

In addition to the loss of knowledge associated with the abandonment of primary mining, the low level of research efforts in Germany is associated with relatively small quantities of material. Another problem mentioned, which leads to a lack of knowledge in the field of secondary raw materials, is the difficulty of obtaining permits for some research projects that deal with certain highly-contaminated materials, such as asbestos.

Further research should be conducted to close the knowledge gaps mentioned by stakeholders in the building materials industry. However, the continuous transfer of research results to practitioners or representatives of authority is particularly important. Another starting point is to open people's eyes to nontraditional materials, such as lectures or project days, on the usability of secondary raw materials in scientific and technical training courses and degree programs. Finally, the publication of overviews on mining residue deposits, including their content and volume, is a possible step.

m) Environmental protection

The environmental benefits of building materials with recycled content are often considered advantageous (Ding et al. 2021; Darof et al. 2021; Shooshtarian et al. 2020). However, some interviewees also had environmental concerns regarding the use of building materials made from tailings ponds. For example, air and environmental pollution are possible owing to the industrial treatment process of the mining material, which is sometimes heavily contaminated if not counteracted to an appropriate extent.

The processing of materials that have already been used can also contribute to a poorer CO_2 balance than the use of primary materials. Factors such as the location from which the material is extracted and the exact composition of the material have a major influence on CO_2 emissions during transportation and material processing. For example, the high moisture content of tailings pond materials means that they require energy-intensive drying or transportation. In this case, the environmental objectives related to the circular economy and emissions reduction must be weighed against each other. The use of materials from tailings ponds does not always have to be accompanied by higher CO_2 emissions; for example, if they are used as corrective materials in cement production, they can replace corrective materials with a higher CO_2 balance.

Another environmental argument in favor of using secondary raw materials from tailings ponds is that it may be possible to destroy nature less than when mining primary raw materials. Sensible utilization of contaminated sites is also an important environmental factor and a win–win situation in which raw material extraction and remediation of contaminated sites are combined.

It is recommended that all relevant environmental impacts of the intended reuse of a specific mining repository be determined and weighed.

n) Conflicting objectives regarding the use of limited space

Dealing with the areas of tailings ponds or other mining waste dumps involves specific conflicting objectives that have thus far received less attention in the literature, as tailings pond materials have a different land use than building materials such as steel or concrete.

These conflicting objectives can arise, for example, when determining whether renaturalized waste rock piles or tailing pond areas should be preserved as nature conservation areas, possibly local recreation areas, or whether they should be dismantled to minimize risks or recover valuable materials. In the specific case of deconstruction, the focus should be on whether the extraction of recyclable materials or the remediation of the area is the main focus. Even if both objectives can be combined, the prioritization of one of the two objectives can lead to differences in the schedule or environmental requirements.

Conflicting land-use objectives can also arise when mining dumps are used, as a quote from the workshop underlines:

> "*There is also the question of competition for land use: for example, if there are dumps with solar plants in the region, do you tear them down again? Do you intervene where and what was once redeveloped with public money?*" (WS 2023).

This illustrates the challenge of how limited space in a region can be used in the best possible way and how these conflicts of use can be resolved.

Other places where competition for scarce space plays a role are the processing areas in processing plants. The areas required to process various secondary or primary materials compete with each other.

Most important potential barriers to use, including other material flows

In April 2023, a cluster workshop was held as part of the Federal Ministry of Education and Research (BMBF) funding measure, ReMin: "Resource-efficient circular economy - construction and mineral material cycles" on the topic of "Impurities, contamination and limit values - the bottlenecks to the usability of RC materials in the building materials sector". Unlike the workshop we held, this did not deal exclusively with material flows that could be considered for tailings pond materials but did provide a comprehensive overview of the barriers to the use of a wide range of mineral secondary raw materials (Gentzmann et al. 2023a).

The barriers to use discussed in the workshop were also reflected in our interviews and workshops with experts and practitioners. There were slight differences in the relevance attributed to the individual barriers. If the data from the ReMin cluster workshop are considered, the key barriers are as follows:

- Legal regulations and standards
- Material properties & plannability
- Costs
- Availability & quantities
- Not knowing

Lack of knowledge was seen as a much more central obstacle than in our analyses, but the poor image of secondary raw materials was seen as easy to overcome. The (presumed) lack of openness on the part of the authorities towards recycled raw materials, which became clear in our analyses, was also addressed relatively little in the ReMin cluster workshop.

Summary of recommendations for reducing barriers to the use of materials from tailings ponds in the building materials industry

The following recommendations, broken down by stakeholder group, offer starting points for facilitating the use of materials from tailings ponds in the building materials industry. As mentioned previously, these measures should only be considered once further research projects have confirmed the usability of the materials. If this condition is satisfied, the proposed recommendations can help various stakeholders overcome the challenges outlined and promote the use of secondary raw materials from mining residues in the construction materials industry. Reference should also be made here once again to the proposed solutions published as part of the BMBF cluster workshop on "Impurities, contamination, and limit values: The bottlenecks in the usability of RC materials in the building materials sector" (Gentzmann et al. 2023a)which overlap with our considerations due to their thematic proximity.

Measures aimed at stakeholders in science, research, and teaching:

- *Scientific studies* - conducting thorough scientific studies on the feasibility and hazard potential of raw materials from tailings ponds, including comprehensive analyses of the deposit composition
- *Exchange* - knowledge exchange within the scientific community, e.g., at specialist conferences
- *Transfer* - continuous transfer of research results to practitioners and representatives of authorities, for example within the framework of specifically created working groups of material manufacturers and users with the involvement of political actors
- *Addressing the topic of secondary raw materials in education* - e.g., lectures or project days on the usability of secondary raw materials in scientific and technical education and degree programs

Measures aimed at political actors:

- *Create usage incentives* - implement cost incentives such as tax breaks and preferential consideration in tenders to increase the attractiveness of tailings pond materials compared with primary raw materials; revise procurement guidelines
- *Investment in technology development* - Promotion of research and technology development
- *Harmonization of legal framework conditions* - Supporting the harmonization of legal regulations
- *Forums for the exchange of knowledge* - Promoting an increased exchange of knowledge between science, industry, society, and politics to create a greater understanding of the relevance and possibilities of using secondary materials.

Measures directed at administrative actors:

- *Simplification of approval procedures* - Examination of simplifications in approval procedures without restricting transparency and appeal options
- *Transparency* - Where available and possible – Publication of overviews of mining residue deposits, including their content and volume.
- *Further training for public authority employees* - Development and provision of further training events for public authority employees on recycled building materials
- *Creation and use of forums for exchange between administrative bodies* - Organization and intensification of forums for cooperation between administrations to exchange experiences.

Measures aimed at players in the building materials industry:

- *Check local conditions for mining* - e.g. check possibilities of parallel mining of several tailings ponds to increase volumes.
- *Dissemination of information and knowledge* - Offering and taking advantage of information and training measures to create and broaden understanding of the possibilities and limitations of secondary materials.
- *Carry out pilot projects* - that demonstrate the use of secondary materials in practice to minimize uncertainties.
- *Exchange of knowledge* - Promotion of internal industry events and specialist conferences to facilitate the exchange of experiences

- *Leveraging moments of change* - Actively using moments of change, such as the phasing out of lignite mining, to position recycled materials.
- *Marketing and information campaigns* - Implementation of marketing and information campaigns for the general public to increase awareness and social acceptance of secondary raw materials (e.g., through positioning in the area of sustainability and resource conservation), launched by trade associations and interest groups.

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