Transdisciplinary Intelligence for Sustainable Arctic Mining

Alexandra Middleton, Lars H. Smedsrud, Rikke Østergaard, Penny Gage, Åsa K. Rennermalm, Anna Karlsdóttir, and Rachael Lorna Johnstone

Increased attention to critical mineral mining in the Arctic has exposed a fundamental governance gap: existing regulatory frameworks often prioritize compressed timelines that fail to integrate diverse knowledge systems or respect multigenerational community interests. This paper demonstrates that bridging this gap requires transdisciplinary intelligence,a systematic, collaborative approach that mobilizes intellectual capital across academic, corporate and Indigenous boundaries. Drawing on a collaborative autoethnography conducted by an international research group within the Fulbright Arctic Initiative, we analyze the process of co-producing a policy brief intended to serve as a boundary object, a socio-technical artifact designed to mediate between different actors. We examine the tensions inherent in this process, highlighting how differences in temporal horizons, disciplinary priorities, and institutional needs shape the development of sustainability guidelines. The concept of time is analytically central in our study, for example, compressed permitting timelines, such as those introduced by the Critical Raw Materials Act (CRMA), foreclose knowledge-gathering processes, and multi-generational Indigenous relationships with land can be potentially sidelined. We demonstrate that the governance of mineral extraction in the Arctic is a question of whose knowledge counts, on what timeline, at whose cost, and whose benefit. Our findings suggest that effective governance of Arctic mineral extraction requires a shift toward frameworks that recognize Indigenous self-determination, local embeddedness, and long-term community well-being as legitimate inputs. We conclude that while transdisciplinary collaboration is challenging, it is essential for fostering equitable decision-making processes necessary for creating a boundary object in form of policy brief for sustainable mining.

Alexandra Middleton is Adjunct Professor at Oulu Business School, University of Oulu, Finland.

Lars H. Smedsrud is Professor at the Geophysical Institute, University of Bergen & Bjerknes Centre for Climate Research, Norway.

Rikke Østergaard is PhD Fellow in Arctic Social Science at Ilisimatusarfik, University of Greenland.

Penny Gage is Chief Policy & Partnerships Officer at Launch Alaska in Anchorage, Alaska.

Åsa K. Rennermalm is Professor, Department of Geography at Rutgers, The State University of New Jersey, USA.

Anna Karlsdóttir is Docent in Human Geography and Tourism studies, University of Iceland.

Rachael Lorna Johnstone is Research Director and Professor of Law at the University of Akureyri, Iceland.

Introduction

The global transition to low-carbon energy has ignited unprecedented attention to the demand for critical minerals, positioning the Arctic as the next frontier in critical mineral mining (Dale & Gross, 2023; Middleton, 2026). However, critical minerals are used by multiple industries unrelated to energy harnessing, including communications, weapons technology, and even fireworks and all mining projects necessarily entail their own environmental impacts (CRMA 2024; Storr 2025). While the Arctic holds many critical mineral resources, the resulting mining projects may threaten vulnerable Arctic ecosystems, human well-being, the livelihoods and rights of Indigenous communities (Sörlin, 2022).

The current geopolitical climate prioritizes speed and Western scientific metrics in mineral extraction. For instance, the EU Critical Raw Materials Act (CRMA) sets accelerated licensing permits that can potentially marginalize Indigenous knowledge and create a governance gap. This challenge is further widened by conflicting timescales: commodity markets move rapidly based on short-term price volatility, whereas building cultural resilience and sustaining local communities require a steady, long-term commitment (Arsenault et al., 2019). Navigating these asymmetries and complex socio-ecological challenges requires transdisciplinary intelligence (Klein, 2021), a collaborative approach that mobilizes intellectual capital across academic, corporate, and cultural boundaries to co-produce equitable and real-world solutions.

These problems are now well documented. However, this study aims to document and exemplify how transdisciplinary intelligence can be used constructively to seek pragmatic steps to mitigate the negative impacts of Arctic Mining. We argue that soft law instruments, specifically voluntary guidelines targeting the pre-permitting stages of mining operations, have the potential to act as critical early interventions that foster equitable decision making. We developed a policy brief "Time to Mine? Mining With and For Arctic Communities" (Johnstone et al. 2026; Gage et al. 2026) as a boundary object (Star & Griesemer, 1989) to bridge actors across the corporate, state, Indigenous, and local spheres. By acting as an artifact characterized by "interpretive flexibility," these guidelines can adapt to the localized needs of Indigenous populations while remaining functional to fulfill the structural and operational requirements of the mining industry. We recognize that the concept of sustainable mining is contested because it exhausts a finite resource. In this study, we use the term sustainable mining to characterize mining operations that are socially and environmentally responsible over multi-generational timeframes.

To explore systematically this process, we applied a collaborative autoethnography methodology (Chang et al. 2016; Hernandez et al. 2017) in our multinational Fulbright Arctic Initiative group. By bringing together researchers and practitioners from Finland, Iceland, Greenland, Norway, USA and Sweden, this methodology allowed us to collectively document and analyze our internal tensions and shared meaning-making while co-producing the transdisciplinary policy brief as a boundary object. The members of the working group shared expertise in business studies, business development, physical oceanography, natural and human geography, social sciences, and law.

Theoretical Framework

Understanding Transdisciplinary Intelligence

Transdisciplinarity can be described as an integrated mode of knowledge production that transcends traditional academic boundaries to generate actionable, real-world solutions. Instead of

linking different scholarly fields, it operates simultaneously between, across, and beyond all disciplines to establish a unified, boundary-less intellectual domain (Nicolescu 2006). Within this shared space, academic researchers, policymakers, and non-academic actors, including Indigenous and local knowledge holders, have the opportunity to co-create frameworks and solve problems collectively (Nyssa et al., 2024).

A transdisciplinary approach is required to solve the complexity of modern socio-ecological challenges (Klein, 2001), such as climate governance and multifaceted environmental crises (Murphy, 2011). Operating strictly within specialized, isolated academic silos often results in a fragmented understanding of reality (Nicolescu, 2012) and perpetuates injustice by ignoring community perspectives. Transdisciplinarity addresses this by directly sharing power and integrating diverse research methods. This approach bridges the gap between research and action, ensuring that interventions are equitable, relevant, and capable of driving transformative sustainability (Khoo et al., 2019; Haregeweyn et al., 2025).

Furthermore, transdisciplinarity is intertwined with the expansion of individual and collective intelligence. By mobilizing intellectual capital boundaries, it fosters dynamic collective intelligence capable of surpassing the structural limitations of single-discipline thinking (Klein, 2001). The role of boundary-spanning "integrators" and "pracademics" are essential for effective delivery and societal impact beyond scientific advances (French et.al. 2024). Ultimately, by demanding a profound conceptual shift away from rigid cognitive frameworks toward paradigms of interconnectedness and pluralism, transdisciplinarity expands the overall intellectual capacity, empowering society to innovate and intelligently manage the complexities of our shared world (McGregor 2014).

The Boundary Object

The notion of a boundary object, introduced by Star and Griesemer (1989), captures sociotechnical artifacts that operate simultaneously across multiple social worlds while accommodating each world's informational requirements. A defining feature of such objects is their interpretive flexibility. They are sufficiently adaptable to respond to context-specific needs and constraints while remaining stable enough to retain a coherent identity across different settings (Akkerman & Bakker, 2011). The literature distinguishes four principal types, namely: repositories, ideal types, coincident boundaries, and standardized forms, applied across diverse disciplinary domains (Star & Griesemer 1989; Star, 2010; Bender, 2017). Early empirical illustrations from the natural sciences include zoological specimens, field notes, and species classifications that enabled coordination between amateur collectors and professional researchers. Subsequent applications have extended this framework to GIS standards and CAD systems in engineering (Harvey & Chrisman, 1998), medical records and clinical simulations in healthcare (Saidi et al., 2023), and routine artifacts, such as forms, maps, and costing systems (Oswick & Robertson, 2009). Across these domains, boundary objects function as infrastructural mechanisms for organizing distributed knowledge.

Functionally, boundary objects act as essential mediating mechanisms that bridge cultural, organizational, and disciplinary divides, facilitating knowledge transfer, translation, and mutual learning without requiring participating groups to reach an absolute theoretical consensus (Star 2010). By providing a standardized shared reference point, these artifacts allow highly heterogeneous actors to interact productively and coordinate collaborative work while safely maintaining their own distinct viewpoints and practices (Doolin & McLeod, 2012).

The creation of a policy brief for sustainable mining directed at corporations and investors as part of the Fulbright Arctic Initiative program is a practical application of such a boundary object. Sustainable mining guidelines operate as boundary objects by acting as a shared mediating language between corporate industry actors, policymakers, and local and Indigenous Arctic communities.

Context of Critical Minerals Mining

The growing demand for critical minerals has placed mining at the center of global efforts to advance the green energy transition. Governments and international organizations increasingly view minerals such as lithium, rare earth elements, graphite, and nickel as essential for achieving climate goals, strengthening energy security, and reducing dependence on global supply chains (IRENA, 2023). As a result, new policy frameworks, including the European Union's Critical Raw Materials Act (CRMA) adopted in 2024 (European Commission, 2023), seek to accelerate permitting processes by setting a limit of 27 months to accelerate schedules and increase domestic mineral production through streamlined regulatory procedures.

Throughout discussions within the Fulbright Arctic Initiative, time emerged as a central analytical variable for understanding the tensions surrounding critical mineral development. Participants highlighted a stark contrast between the compressed timelines promoted by governments and industry,the longer time horizons required for meaningful engagement with local and Indigenous communities (Merrild Hansen & Johnstone 2019) and the even longer timelines of climate change and geological timescales of the formation of mineral deposits.

Policy initiatives often frame critical minerals extraction as an urgent necessity, emphasizing the need to secure mineral supplies in response to climate change and geopolitical uncertainty. Quicker permitting processes are therefore presented as tools for reducing delays and attracting investment. Calls for a quick fix to this most urgent environmental crisis overshadow interrogations about the structural inequalities that have brought us to this stage and sideline moral values (Whyte, 2021). The long-term view is lost as the focus is on addressing the immediate problem with minimal disruption to the relations and power structures of the status quo. Justice must wait. However, for many Indigenous Peoples, the status quo is the crisis.

This tension is significant in Indigenous territories, where knowledge systems are often grounded in long term relationships with land, water, and ecosystems. Indigenous knowledge is developed and transmitted across generations and cannot be easily incorporated into decision-making processes that prioritize speed and efficiency. Consultation processes must allow sufficient time for communities to review information, engage in internal discussions, and consider potential impacts from both contemporary and intergenerational perspectives (Merrild Hansen & Johnstone 2019). Respecting Indigenous rights requires not only access to information and opportunities for participation but also recognition of the time necessary to support informed decision making and self-determination (ICESCR, 1966; ICCPR, 1966; UNDRIP, 2007).

From this perspective, time should not only be understood as an administrative or economic factor. It also represents a critical condition for legitimacy, trust, and fair decision making. Therefore, the challenge facing critical mineral development is not simply how to accelerate extraction but how to combine the urgency of the energy transition with the different paces required for meaningful consultation, Indigenous self-determination, and socially sustainable development.

Fulbright Arctic Initiative Team

This research was conducted as part of the Fulbright Arctic Initiative IV and the seven authors were appointed to the working group, "Climate Change and Arctic Resources", later renamed "Arctic Resources." Our academic disciplines include natural and social sciences, law, business studies, physical oceanography, and physical and human geography, and one of us has extensive professional experience in the business world. Some of us had significant experience of interdisciplinary work while for others, it was rather new.

We met for the first time in person during a week in Sápmi, in the northern part of Norway, in September 2024, and then spent one additional week together in Nuuk and Sisimiut, Greenland, in June 2025. We all met once more in Iceland before and during the Arctic Circle Assembly in October 2025 to work on the project. We otherwise met regularly online to develop the project and used an online file-sharing system to coordinate the research activities and writing. We each brought different research and work experiences to the project. Some were more accustomed to desk-based research, while others had fieldwork experience. Some were familiar with ethical standards when working with communities, and especially with Indigenous Peoples. We began by sharing ethical protocols and considering how to build them into the project. There was a commitment and recognition of the importance of engaging with communities and doing listening sessions to ensure the relevance of the research and reduce the risk of duplication. Our final policy brief was published in April 2026 (Gage et al. 2026) and presented at the Arctic Encounter meeting in Anchorage, USA, in April 2026. Over the span of 18 months, we spent approximately 300 hours together (in-person and online meetings combined).

The Fulbright Arctic Initiative program

The Fulbright Arctic Initiative Program brought together researchers from across the Arctic region for collaborative research, policy engagement, and knowledge exchange over an 18-month period. During the program, participants engaged in regular group meetings, webinars, collaborative writing activities, policy development, and in person gatherings in several Arctic locations.

The working group met twice a month for 18 months. Meetings lasted approximately 1-1.5 hours, corresponding to an estimated 45 hours of meeting time. In addition to the scheduled meetings, participants collaborated on a range of shared outputs and activities, including the following:

- Development of a white paper
- Listening sessions with stakeholders
- Preparation of a policy brief
- Panel discussions and public engagement activities in Anchorage, Alaska
- Collaborative academic writing and publication activities.

The estimated time spent on collaborative work outside the scheduled meetings was 100 hours, with a total estimated workload of 145 hours. In addition, the program included monthly webinars conducted throughout the 18-month period. A total of 18 webinars were held, each lasting one hour, resulting in an additional 18 hours of engagement. Participants attended in person meetings and workshops in several locations e.g. Norway 60 hours, Greenland 40 hours and Alaska 40 hours, in total 140 hours (see Figure 1).

In addition to the shared program activities described above, the participants undertook individual research, fieldwork, stakeholder engagement, and project-related activities in various locations. Non-U.S. participants carried out these activities across the United States, while U.S. participants worked in other Arctic countries. These activities were tailored to each participant's research project and were therefore not included in the group-based hour estimate. Additionally, another 40-50 hours were spent browsing the literature, referencing, editing, and collaborative writing (not included in the total hour calculations).

The total estimated group participation per person in hours is therefore as follows:

Group meetings and collaborative work	145 hours
Monthly meetings FAI	18 hours
In person meetings	140 hours
In total	303 hours

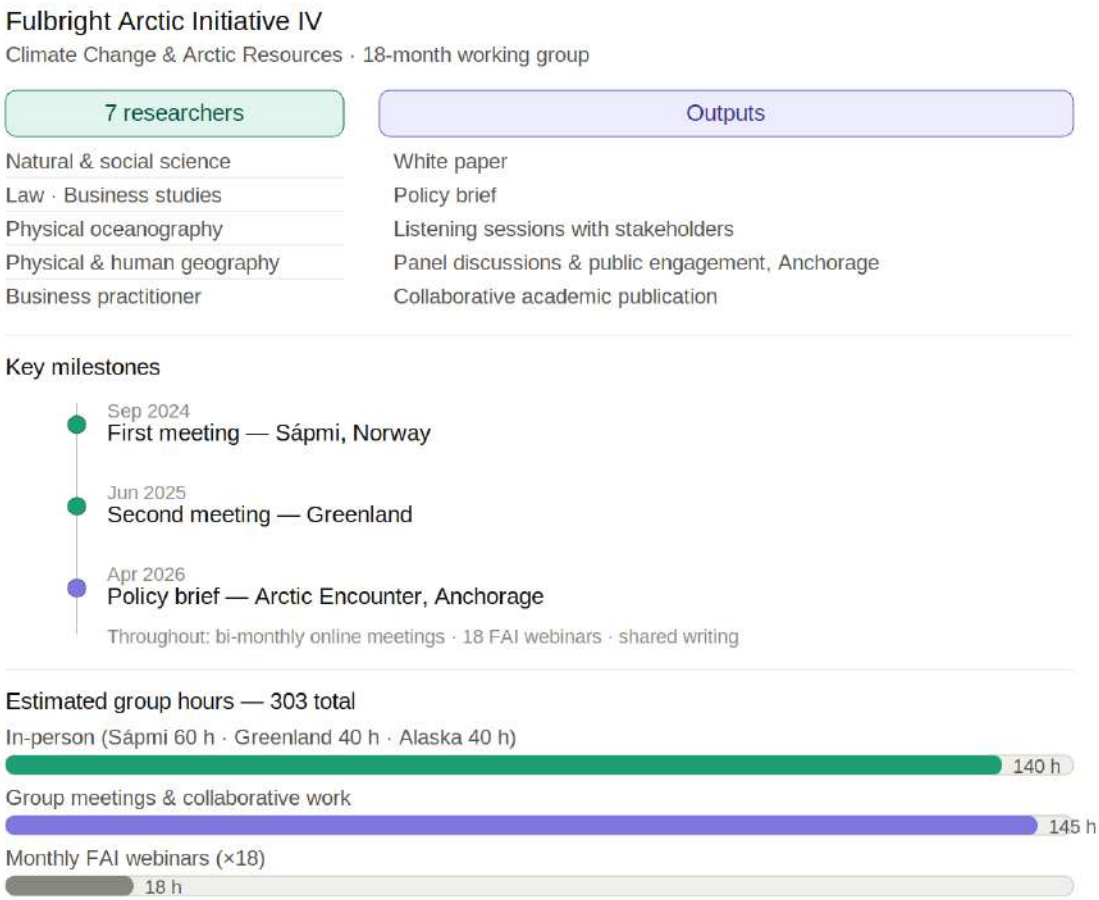

Figure 1. Overview of collaborative process

Listening sessions

Six listening sessions were held throughout the Fulbright Arctic Initiative 18-month project period to hear from community, Indigenous, and business leaders in the Arctic and beyond. Listening sessions were held as follows:

- March 2025: Anchorage, Alaska, Municipal League Infrastructure Symposium
- June 2025: Nuuk, Greenland, Greenland Human Rights Council
- August 2025: Anchorage, Alaska/Washington, DC, Lucid Motors (on-line)
- September 2025: Anchorage, Alaska, NANA Corporation and Resource Development Council (online)
- October 2025: (Two sessions held), Reykjavik, Iceland, Arctic Circle Assembly, various Indigenous representatives from the circumpolar Arctic.

The sessions were individually designed and conducted considering the experience and position of the "community" as well as our objectives and expectations at the time. Early on, they were an opportunity to identify important issues; later, they became more of an opportunity to check in, revise, and add nuance to our preliminary findings. Business and industry leaders from the mining and electric vehicle sectors provided input on how regulations and policies affect mining financing, exploration, and use and recycling in final products.

In some listening sessions, a guest gave a short presentation, which was followed by questions and answers. In others, a semi-structured interview format was used. Given the time constraints and ethical concerns, we decided to limit the community listening sessions to professionals and/or group spokespersons in most cases. During the first session which was held at Alaska Infrastructure Development Symposium, gathering municipal representatives and organized by The Alaskan Municipal League (2025), a questionnaire was also distributed amongst conference participants. The emphasis was on gathering responses from various communities around Alaska affected by mining and indigenous representatives. It was important to us that the community listening sessions did not constitute an additional burden on overstressed communities, often already experiencing "research fatigue" and that they should not be extractive. In Arctic and Indigenous contexts, research fatigue describes the exhaustion and frustration that can arise when communities are repeatedly approached by researchers, often addressing similar topics, without sustained relationships, reciprocal benefits, or tangible outcomes for the community. We reflected on the findings of each community listening session and considered how it could help steer the research project.

Methodology

Collaborative Autoethnography (CAE)

Autoethnography is a qualitative research methodology that intimately connects the personal to the cultural by utilizing the researcher's own lived experiences, memories, and reflections as primary data to investigate broader social and political phenomena (Wall 2006). This method requires deep, systematic reflexivity, embracing the researcher's subjectivity and emotionality as vital sources of insight. This method is highly relevant to transdisciplinary research because it actively dismantles the boundaries between traditional academic silos and lived human realities, effectively mirroring the goal of transdisciplinarity to integrate diverse knowledge systems. While traditional autoethnography often focuses on a single researcher's perspective, collaborative (or collective) autoethnography involves a team of two or more researchers who jointly share, analyze, and interpret their personal experiences of a common phenomenon. This joint approach expands the methodology by using iterative discussions, collective reading, and co-writing to incorporate

multiple, reflexive accounts (Chang et al., 2016; Hernandez et al., 2017). By co-constructing meaning across diverse voices, collaboration enriches the interpretive depth of the data and provides a more comprehensive understanding of the shared sociocultural context (Cordoncillo Acosta & Borrell-Porta, 2026).

In our study, we conducted a collective autoethnography, drawing on our team's diverse shared experiences and joint reflections to systematically document and co-produce a boundary object in the form of a policy brief. Additionally, the production of boundary objects required data collection and policy analysis, resulting in a white paper, listening sessions, and group-member reflections.

Data Collection and Policy Analysis

Data collection focused on the joint development of an unpublished white paper (a working paper for our internal process) that synthesised academic and grey literature on extractive industries in the Arctic, with particular attention to critical minerals. The document brings together perspectives from multiple disciplines, including law, political geography, postcolonial studies, critical Indigenous studies, gender analysis, natural sciences, and business and economics.

To position this work within a broader governance context, the white paper includes a global review of the policy frameworks. This covered international regulatory approaches, supply chain strategies, and geopolitical dimensions shaping critical mineral extraction. Together, these elements allowed the analysis to connect expert knowledge to broader institutional and policy developments. This co-written and co-constructed artifact served as a shared intellectual repository for constructing the policy brief.

Reflections

To capture the reflexive dynamics of the collaboration, contributors completed structured written reflections organized around four thematic axes of co-production: (1) foundational alignment, examining early goal-setting, unspoken assumptions, and disciplinary power dynamics; (2) interpretive friction, analyzing specific clashes in analytical assumptions and the mechanics of working through them; (3) disciplinary integration, evaluating the translation and visibility of individual paradigms within the final co-authored texts; and (4) synthesis, identifying emergent insights unreachable via single disciplines and the necessary conditions for transdisciplinary knowledge production.

Creating Policy Brief as a Transdisciplinary Boundary Object

The collaborative autoethnographic reflections provide deep insights into the operational realities of transdisciplinary research and the creation of boundary objects across four key areas.

Facilitating Collaboration

Establishing a transdisciplinary space requires immense initial coordination, and the reflections highlight that "friendship and trust" built during early in-person meetings were invaluable for sustaining the project through later virtual challenges. However, establishing shared goals proved difficult; early ambitions often "got lost," and the practical logistics of organizing the work around demanding careers and coordinating across time zones frequently disrupted workflows. Although natural science expertise was less visible in the policy brief, its integration from the beginning of the process alongside disciplines such as economics, political geography, sociology, and law ultimately sparked "innovative ideas about the nature of the topic itself." Despite the chosen

research topic not perfectly aligning with their disciplinary knowledge frameworks, the natural scientists were explicitly recognized by the team as being "very open to learning and contributing" to the collaborative process.

Managing Disagreement and Differences

Transdisciplinary knowledge production relies heavily on overcoming both discipline-bound and practical conflicts. Participants frequently had to pause and explain terminology or theoretical approaches that were considered "obvious" within their own academic silos. Significant tension emerged over how deeply complex issues, such as critical minerals, should be explored, largely driven by the differing priorities of business-policy circles and academic researchers. To prevent dominant perspectives from overshadowing "quiet personalities," the group had to enforce procedural justice through methods such as taking turns to speak. Despite moments of intense fatigue, where some "couldn't see the finish line," the formal requirement to produce a white paper and a policy brief acted as a stabilizing force, compelling the diverse team to negotiate and find common ground to realise these objectives on time.

Integrating Different Voices and Disciplines

The process of drafting the policy brief and white paper illustrated the inherent tensions in designing a boundary object. While most participants felt their voice was heard and were proud of the holistic outcome, it required significant compromises from the team. The need for group consensus meant that highly original ideas were often sidelined in favor of a broader agreement. The participants also felt that some of the innovative and unique ideas were lost in this group. While we were a diverse group, the sense of urgency overshadowed the more original ideas.

Furthermore, it was difficult to capture fully the reality of Arctic operations in a policy brief's short format, not least because the Arctic itself, its Peoples, its geographies, and its economies are so diverse. At the same time, in a transdisciplinary setting, the synthesis of disparate fields, ranging from geography to physical oceanography, generates an outcome that is significantly more relevant and practically useful than any isolated, discipline-specific work could be.

However, this integration inherently requires compromise. Experts frequently had to abandon their preferred methodological approaches in favor of a shared framework, and specific disciplinary priorities received less prominence than an individual researcher might desire. The reflections indicate that even when a researcher's specific technical expertise plays only a "modest role" in the final output, they can adapt by drawing upon their broader, generalized experiential knowledge, such as regional familiarity, to contribute meaningfully to the collaboration, Ultimately, while participants generally feel their voices are heard and take pride in the collective achievement, transdisciplinary integration requires a willingness to relinquish individual intellectual control.

What Collaboration Made Possible

Addressing a challenging and geopolitically charged problem such as sustainable mining demonstrates that transdisciplinary research is more effective than isolated disciplinary work. However, attempts to integrate non-academic voices through listening sessions proved challenging. For instance, the team encountered a so-called "catch-22": they could not effectively plan community listening sessions without a defined research topic, but they struggled to define a relevant topic without first listening to the communities. Ultimately, the reflections conclude that there is "no perfect playbook" for this type of work in the field. The most critical condition for co-

producing transdisciplinary knowledge is "simply time... time together in person" and online to build the essential "relational foundation" needed to weather disagreements and innovate together.

Discussion: Assessment of Policy Brief as a Transdisciplinary Boundary Object

The policy brief produced was titled "Time to Mine? Mining With and For Arctic Communities" and this Fulbright Arctic Policy Brief (Gage et al. 2026) serves as an example of both a transdisciplinary outcome and a boundary object. By applying the theoretical frameworks of transdisciplinarity (Khoo et al., 2019; Haregeweyn et al., 2025) and boundary objects to this text, we can assess what the policy brief recommends and how it functionally bridges diverse social worlds to address the "wicked problem" (i.e. a problem with no simple definition or solution) of Arctic resource extraction (Klein 2001; Murphy 2011).

Here are the five short recommendations for mining with and for Arctic communities outlined in the policy brief:

1. Engage early with local communities to ensure their rights are upheld
2. Develop entry and exit plans collaboratively with the community
3. Integrate expertise regarding the local impacts of environmental change
4. Align business models with the time horizons of the community
5. Apply sustainability reporting standards that are relevant to the Arctic context.

The transdisciplinarity is supported by Recommendation 3 (Integrate expertise regarding the local impacts of environmental change), which calls for the integration of technical and scientific expertise with local knowledge. This is important because environmental risks in the Arctic, including permafrost thaw, cannot be fully understood through technical assessments alone. Scientific modelling and engineering knowledge are necessary, but they must be complemented by place-based observations, lived experiences, and Indigenous knowledge. Recommendation 3 illustrates that sustainable mining in the Arctic depends on the inclusion of multiple knowledge systems rather than relying on a single discipline.

Recommendations 1 and 2 further demonstrate that transdisciplinarity involves changing the conditions under which knowledge is used in decision-making (sustainability) (Khoo et al., 2019; Haregeweyn et al., 2025). By emphasizing early community engagement, Free, Prior, and Informed Consent (FPIC), and the co-development of entry and exit plans with communities, these recommendations foreground procedural justice and power-sharing. Recommendations 1 and 2 position Indigenous and local communities as active participants in governance processes rather than as groups consulted after key decisions are made. In this sense, the recommendations connect knowledge integration with authority, legitimacy and accountability. The listening sessions' take-away message proved to be an important input into the recommendations–the red thread being the need for fair consultations, respecting self-determination, and securing environmental and social justice.

The collaborative autoethnographic reflections also show that producing such a synthesis requires researchers to work across disciplinary and institutional boundaries. The process involved moving beyond established academic silos and negotiating differences between business- and policy-

oriented perspectives, academic research traditions, and community-centered issues. These tensions were part of a transdisciplinary process. The final recommendations emerged through dialogue, reflexivity, and efforts to bring diverse perspectives into a shared analytical space. This demonstrates why Arctic mining governance cannot be addressed from a single disciplinary standpoint but requires sustained engagement across the scientific, policy, economic, legal, and Indigenous knowledge domains.

Theoretically conceptualized as mediating artifacts, boundary objects inhabit multiple intersecting social worlds. They possess what Star (2010) refers to as "interpretive flexibility," an inherent plasticity that enables them to adapt to the specific local needs of divergent groups while maintaining a common and universally recognizable identity across sites. Crucially, such objects allow heterogeneous actors to cooperate across divides without requiring them to abandon their unique worldviews or achieve absolute consensus. In this context, the policy brief is explicitly designed to function as this type of socio-technical infrastructure.

For instance, the policy brief operates as an interface between diverse domains such as corporate mining operators, state policymakers, and Arctic Indigenous communities. This mediation is exemplified by Recommendation 4 ("Align business models with community time horizons"), which bridges the accelerated, profit-driven timeframes of global commodity markets with the multi-generational, slow-paced resilience needs of local communities. Furthermore, the brief utilizes the classic boundary-object mechanism of a standardized form. Recommendation 5, which advocates for "Arctic-relevant sustainability reporting standards," acts as a stabilizing protocol; it satisfies the operational and risk-management imperatives of institutional investors while simultaneously ensuring that Indigenous rights and environmental constraints are formally codified and respected.

The socio-technical utility of the brief is closely tied to the costs arising from its interpretive flexibility. In practice, this means that the document must balance precision and broader applicability. If the project specifications are too rigid, they may limit use across different user groups. Conversely, if the policy brief is formulated too vaguely, different users may interpret it according to their own expectations and needs, which can result in costly structural misalignments when the intended use is put into practice. As the project's collective autoethnography revealed, the structural mandate to produce a "mutual delivery" generated profound internal tension: the imperative to consensus and wordcount limitations forced the team to compress textured, highly nuanced local stories into the broad, clean narratives demanded of a standard policy brief. It was challenging, especially for academics more used to detailed explanations of methodology or extensive parentheses and caveats, to parse the text. For example, in the final policy brief, the thread of time, which had been central to the research process, is not explicit in all the recommendations. While the editing necessitated a degree of theoretical depth, it succeeded in its primary objective: generating a stabilizing framework capable of holding competing actors in a boundary object. The policy brief and succinct recommendations are expected to be more accessible and actionable by investors and mining companies who may lack the time to engage in higher-level theoretical investigations. However, recognising the loss of nuance as well as last-minute editorial changes in the published version, the group agreed to publish an expanded, unredacted version of the Policy Brief (Johnstone et al. 2026), with short introduction, which can be found elsewhere in this volume of *Arctic Yearbook*.

Conclusion

The efforts described here resulted in a policy brief or a boundary object that specifies guidelines for sustainable Arctic mining using transdisciplinary intelligence. As a group of diverse scholars from five different Arctic countries, we have analyzed our own process of solving a "wicked problem." First, in our final policy brief, we contrast compressed permitting timelines with those of traditional knowledge-gathering processes and ongoing climate change on decadal timescales. Second, we emphasize that establishing a real transdisciplinary space requires initial coordination and patient dedication to build "friendship and trust" during early in-person meetings to overcome virtual meetings challenges. Establishing shared goals is difficult and practical logistics often disrupt workflows, but our example here shows that integrating disciplines can work well. Despite the chosen research topic not perfectly aligning with individual research frameworks, both social and natural scientists were explicitly recognized in the collaborative process.

The team brought substantial experience working with and within Arctic Indigenous and northern communities, which shaped how we designed the listening sessions, selected sources, and interpreted findings. A significant limitation, however, was that Indigenous Peoples, and Arctic communities were not more formally involved in the drafting of the final policy brief recommendations. Meaningful co-creation requires relationships grounded in trust, reciprocity, and long-term engagement. In Arctic contexts, where communities have often been the subjects rather than partners of research, such relationships cannot be established within a short project cycle or without funding for their research time, travel, and meeting costs. Consequently, the timeframe and funding structure of the program limited our ability to pursue the level of collaboration necessary for genuine co-creation.

We demonstrate that the governance of mineral extraction in the Arctic is fundamentally a question of whose knowledge counts, on what timeline, and at whose cost. Effective governance requires better epistemological frameworks that recognize Indigenous self-determination, local embeddedness, and long-term community well-being as legitimate inputs in sustainability frameworks.

Acknowledgements

During the preparation of this article, Alexandra Middleton, Lars H. Smedsrud, Rikke Østergaard, Penny Gage, Åsa K. Rennermalm, Anna Karlsdóttir, and Rachael Lorna Johnstone were supported by the Fulbright Arctic Initiative, sponsored by the U.S. Department of State and and partner governments. The contents of this publication are solely the responsibility of the authors and do not necessarily represent the official views of the Fulbright Program, the U.S. Department of State, Fulbright Finland, U.S.-Norway Fulbright Foundation for Educational Exchange, Fulbright Denmark or Fulbright Commission Iceland. This article has not been reviewed or endorsed by any of the Fulbright Commissions or their respective governments. Figure 1 was created by Åsa K. Rennermalm with assistance from Claude.ai.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of educational research*, *81*(2), 132-169.

Arsenault, R., Bourassa, C., Diver, S., McGregor, D., & Witham, A. (2019). Including indigenous knowledge systems in environmental assessments: restructuring the process. *Global Environmental Politics*, *19*(3), 120-132.

Bender, C. (2017). The Culture Area as Boundary Object. *Zeitschrift für Ethnologie*, (H. 2), 265-288.

Chang, H., Ngunjiri, F., & Hernandez, K. A. C. (2016). *Collaborative autoethnography*. Routledge.

Cordoncillo Acosta, C., & Borrell-Porta, M. (2026). Fostering innovation through collaboration: a comparison of collaborative approaches to policy design. *Policy & Politics*, *54*(1), 47-69.

Dale, R. F., & Gross, L. (2023). The arctic: Last frontier for energy and mineral exploitation?. In *Handbook on international development and the environment* (pp. 154-169). Edward Elgar Publishing.

Doolin, B., & McLeod, L. (2012). Sociomateriality and boundary objects in information systems development. *European Journal of Information Systems*, *21*(5), 570-586.

ECCRMA. (2023) European Commission European Critical Raw Materials Act. https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/european-critical-raw-materials-act_en.

French, M.A., Barker, S.F., Henry, R., Turagabeci, R., Ansariadi, A., Diego Ramirez-Lovering, A.T., Awaluddin, F., Latief, I.,Vakarewa, I., Taruc, R.R., Wong, T., Davis, B., Brown, R., & Leder, K. (2024) Responsible north–south research and innovation: A framework for transdisciplinary research leadership and management, *Research Policy*, 53(7), 2024, https://doi.org/10.1016/j.respol.2024.105048.

Gage, P., Johnstone, R. L., Karlsdóttir, A., Middleton, A., Rennermalm, Å., Smedsrud, L. H., & Østergaard, R. (2026). *Time to mine? Mining with and for Arctic communities*. Arctic Resource Group Policy Brief, Fulbright Arctic Initiative 2024–26. https://fulbrightscholars.org/sites/default/files/2026-04/Fulbright-Arctic-Policy-Brief-2026.pdf.

Haregeweyn, N., Tsunekawa, A., Fenta, A. A., Borrelli, P., Panagos, P., Aynekulu, E., ... & West, S. (2025). A Transdisciplinary Framework to Bridge Science–Policy–Development Gaps in Global Land Management Initiatives. *Global Challenges*, *9*(8), 2400261.

Harvey, F., & Chrisman, N. (1998). Boundary objects and the social construction of GIS technology. *Environment and planning A*, *30*(9), 1683-1694.

Hernandez, K. A. C., Chang, H., & Ngunjiri, F. W. (2017). Collaborative autoethnography as multivocal, relational, and democratic research: Opportunities, challenges, and aspirations. *A/b: Auto/Biography Studies*, *32*(2), 251-254.

ICCPR. (1966). International Covenant on Civil and Political Rights 999 UNTS 171.

ICESCR. (1966). International Covenant on Economic, Social and Cultural Rights, 993 UNTS 3.

IRENA. (2023). Geopolitics of the energy transition: Critical materials, International Renewable Energy Agency, Abu Dhabi.

Johnstone, R. L., Gage, P., Karlsdottir, A., Middleton, A., Rennermalm, Å., Smedsrud, L. H., & Østergaard, R. (2026). *Policy brief of the Arctic Resources Working Group with introduction*. Arctic Yearbook 2026.

Khoo, S. M., Haapakoski, J., Hellstén, M., & Malone, J. (2019). Moving from interdisciplinary research to transdisciplinary educational ethics: Bridging epistemological differences in researching higher education internationalization (s). *European Educational Research Journal*, *18*(2), 181-199.

Klein, J. T. (Ed.). (2001). *Transdisciplinarity: Joint problem solving among science, technology, and society: An effective way for managing complexity*. Springer Science & Business Media.

Leigh Star, S. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, technology, & human values*, *35*(5), 601-617.

McGregor, S. L. (2014). Transdisciplinarity and conceptual change. *World Futures*, *70*(3-4), 200-232.

Merrild Hansen, A. & Johnstone, R. L. (2019) In the Shadow of the Mountain: Assessing early impacts on community development from two mining prospects in South Greenland,The Extractive Industries and Society, Volume 6, Issue 2, https://doi.org/10.1016/j.exis.2019.01.012.

Middleton, A. (2026). Geopolitics of Rare Earth Elements (REE) in the Arctic: Study of evolving strategic, scholar, and media discourse. *Polar Record*, *62*. https://doi.org/10.1017/s0032247425100193.

Murphy, B. L. (2011). From interdisciplinary to inter-epistemological approaches: Confronting the challenges of integrated climate change research. *The Canadian Geographer/Le Géographe Canadien*, *55*(4), 490-509.

Nicolescu, B. (2006). Transdisciplinarity: past, present and future. *Moving Worldviews: Reshaping sciences, policies and practices for endogenous sustainable development, ETC/COMPAS, Leusden*, *1*, 142-166.

Nicolescu, B. (2012). The need for transdisciplinarity in higher education in a globalized world. *Transdisciplinary Journal of Engineering & Science*, *3*.

Nyssa, Z., Winkler-Schor, S., Lobo, D., Eyster, H. N., & Wright, A. J. (2024). A framework for promoting disciplinary diversity and inclusion through epistemic justice. Conservation Biology, 38(6), e14409.

Oswick, C., & Robertson, M. (2009). Boundary objects reconsidered: From bridges and anchors to barricades and mazes. *Journal of Change Management*, *9*(2), 179-193.

Saidi, T., Mork, E., Aminoff, S., Lobban, F., & Romm, K. L. (2023). Crossing boundaries in the delivery of healthcare–a qualitative study of an eHealth intervention in relation to boundary object theory. *Digital Health*, *9*, 20552076231196970.

Sörlin, S. (Ed.). (2022). *Resource extraction and arctic communities*. Cambridge University Press.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology,translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Social studies of science, 19(3), 387-420.Storr, C. (2025 forthcoming). The Third Wave of critical minerals, Leiden Journal of International Law, https://www.academia.edu/144606291/The_Third_Wave_of_Critical_Minerals.

UNDRIP. (2007). UN General Assembly Res 61/295. Declaration on the Rights of Indigenous Peoples.

Wall, S. (2006). An autoethnography on learning about autoethnography. International journal of qualitative methods, 5(2), 146-160.

Whyte, K. (2021) 'Against Crisis Epistemology,' in Routledge Handbook of Critical Indigenous Studies, B Hokowhitu and others (eds), Routledge.