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TERRITOIRES, ENVIRONNEMENTS, RISQUES & RESILIENCE*

'TERRITORIES, ENVIRONMENTS, RISKS & RESILIENCE'

En route pour la COP CLIMAT UNIVERSITÉ CÔTE D'AZUR

COP31, ANTALYA - RESOURCES



Natural wood, Vallon des Erps, Mercantour, France – Christophe Den Auwer

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Editorial

This "COP Climate Special Issue" of the online journal of the Academy "Territories, Environments, Risks, and Resilience" addresses the broad and complex theme of "resources," a concept whose boundaries are difficult to delineate, or at the very least, whose scope varies depending on the perspective taken. Natural, mineral, and energy resources—these terms all describe capacities that states, communities, businesses, or even individuals seek to obtain. These resources are not only assets that human societies can harness; they are also essential for sustaining life on Earth and preserving ecosystems and biodiversity. Conversely, the balance and capacity for renewal of these ecosystems determine the availability and sustainable use of the planet's resources, as implicitly reflected in the nine planetary boundaries defined in 2009 by J. Rockström and W. Steffen.[1] Updated periodically, their model assesses over time how our planet is faring with respect to these boundaries and their interconnections. A further topic that can be addressed only partially is the development of these resources, a vast field combining economics, geopolitics, law, sociology, geophysics, and geochemistry, among others. The articles in this issue therefore do not seek to provide a comprehensive overview of the state of our resources; they only offer a few illustrations.

Although international law, as a legal order shared by states, extensively uses the concept of resources, it provides no clear, general definition. A good example concerning the central concept of "natural resources"[2] is the well-established principle known as "permanent sovereignty over natural resources," according to which every state has the right to control, develop, and manage its natural resources. United Nations General Assembly Resolution 1803 (XVII), which enshrined this principle in 1962, offers no definition of the term but links it to the concept of "wealth" ("their wealth and natural resources"). A classification system for "natural resources" has nevertheless been established in international law, which notably serves to define the jurisdiction, rights, and obligations of states. A major distinction is drawn between "biological resources" and "non-biological resources," which include mineral resources.[3] The United Nations Convention on the Law of the Sea (Montego Bay, 1982) is surprising in this respect. It contains no definition of the central concepts of "resources," "natural resources," "biological resources," or "mineral resources;"[4] even though it uses these terms repeatedly, given that one of the convention's aims is to regulate their development and conservation. However, other complementary treaties define certain concepts to clarify their purpose and delineate the scope of their provisions, as with "marine genetic resources," in the new agreement on the high seas.[5] As early as 1992, the Convention on Biological Diversity (Rio, 1992), which applies to the land territory of states and to the parts of the oceans under their jurisdiction as coastal states, defined the concepts of "biological resources" and "genetic resources."[6]
Similarly, although certain international legal instruments deal specifically with "energy resources," none provides an internationally accepted definition of this concept. The Energy Charter Treaty (Lisbon, 1994), for example, sets out a list of "energy materials and products"[7] to which the treaty applies, rather than offering a general definition.
Beyond the question of definitions, resource-related issues have long been a key driver of international relations. They have led to rivalry or cooperation and to the search for common rules to curb sovereign claims or unilateral attempts at monopolization, while constantly evolving with scientific and technological progress and raising new questions (as in the case of extraterrestrial natural resources, for example). It is, of course, impossible to address these issues fully here, or even provide a general overview of their various dimensions (geostrategic, economic, diplomatic, environmental, scientific, etc.).

The reasons behind the Academy's decision to focus this "COP Climate Special Issue" on resources are clear. The topic is critical given the links between the climate crisis and natural resources: the share of

greenhouse gas emissions attributable to fossil fuels; the need to secure critical resources (and their associated environmental impact) to drive the energy transition; the need to protect natural resources (oceans, forests, etc.) that serve as carbon sinks; the erosion of biodiversity exacerbated by climate change; the overexploitation of resources; the destruction of natural habitats; the proliferation of invasive alien species; and pollution. Added to this is the impact of resource extraction on the interactions between the geosphere, hydrosphere, atmosphere, and biosphere, whose interdependencies and feedback loops underscore the complexity of the Earth system and the need for a comprehensive approach to its preservation.

Although imperfect and all too often disappointing, the Climate COP remains the main forum for negotiations, and Université Côte d'Azur has chosen to take part by contributing its intellectual, and particularly scientific, resources. In this context, the transdisciplinary approach that the Academy promotes becomes a fundamental means of addressing a problem that is complex by nature.

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Université Côte d'Azur

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Ce numéro « spécial COP Climat » des Cahiers de l'Académie Territoires, Environnements, Risques et Résilience est dédié à la thématique vaste et complexe des « ressources », notion difficile à circonscrire ou, tout du moins, qui couvre des contenus dont les limites peuvent varier en fonction des angles d'approche. Ressources naturelles, minérales, énergétiques, autant de termes pour définir des capacités que des états, des communautés, des entreprises, ou même des individus peuvent solliciter. Ces ressources ne constituent pas seulement des capacités mobilisables pas les sociétés humaines, elles sont également indispensables au maintien de la vie sur Terre et à la préservation des écosystèmes et de la biodiversité. Ces écosystèmes dont les équilibres et les capacités de renouvellement conditionnent leur disponibilité et leur exploitation durable. Elles s'inscrivent enfin en filigrane des neuf limites planétaires définies en 2009 par J. Rockström et W. Steffen [1]. Actualisé périodiquement, ce modèle évalue la progression du fonctionnement de notre planète confrontée à ces limites et à leur interconnexion. Que dire donc sur l'exploitation des ressources, vaste domaine mêlant économie, géopolitique, droit, sociologie, géophysique et géochimie (et plus encore) qui ne soit nécessairement partiel ? Ce numéro ne cherchera donc pas à dresser un panorama général de l'état de nos ressources mais se propose d'en donner quelques illustrations, sans matière à exhaustivité.

Le droit (le droit international, en tant qu'ordre juridique commun aux États), s'il utilise abondamment la notion de ressources, n'en donne pas une définition univoque et générale. Un bon exemple est donné, au sujet de la notion centrale de « ressources naturelles » [2], par le principe bien établi du droit international dit de « souveraineté permanente sur les ressources naturelles », selon lequel chaque État a le droit de contrôler, exploiter et gérer ses ressources naturelles. La résolution 1803 (XVII) de l'Assemblée générale des Nations Unies qui le consacre en 1962 ne contient aucune définition de la notion, qui est même associée dans le texte à celle de « richesses » (« leurs richesses et leurs ressources naturelles »). En droit international, la notion de « ressources naturelles » donne cependant lieu à une classification, permettant de délimiter notamment les compétences, droits et obligations des États. Une distinction majeure est ainsi opérée entre les « ressources biologiques » et les « ressources non-biologiques », dont les ressources minérales [3]. Le droit de la mer présente en la matière un éclairage intéressant : la Convention des Nations Unies sur le droit de la mer (Montego Bay, 1982) ne donne en effet aucune définition des notions centrales de « ressources », « ressources naturelles », « ressources biologiques », « ressources minérales » [4], qu'elle emploie à de très nombreuses reprises puisqu'un des objectifs de la convention est d'organiser leur exploitation et leur préservation. D'autres traités

complémentaires définissent en revanche, en raison de leur but et pour délimiter leur champ d'application des leurs dispositions, certaines notions comme celle de « ressources génétiques marines », dans le nouvel accord sur la haute mer par exemple [5]. En 1992 déjà, la Convention sur la diversité biologique (Rio, 1992) (qui s'applique au territoire terrestre des États et à la partie des océans sous leur juridiction en tant qu'États côtiers) définissait les notions de « ressources biologiques » et de « ressources génétiques » [6].
Par ailleurs, si certains instruments juridiques internationaux portent sur les ressources énergétiques, cette notion ne donne pas lieu non plus à une définition internationale. Le traité sur la Charte de l'énergie (Lisbonne, 1994) donne par exemple une liste des « matières et produits énergétiques » [7] auxquels il s'applique plutôt que d'en donner une définition générale.
Par-delà ces questions définitionnelles, les enjeux relatifs aux ressources constituent de longue date un vecteur puissant d'animation des relations internationales. Entre rivalité et coopération, quête de règles communes contenant les souverainetés et velléités unilatérales d'accaparement, l'évolution de ces enjeux, à la faveur des progrès scientifiques et technologiques, emporte de nouvelles questions (comme c'est le cas ressources naturelles extra-terrestres par exemple). Il est évidemment impossible de saisir ici, même dans un survol, ces enjeux, dans leurs multiples déclinaisons (géostratégiques, économiques, diplomatiques, environnementales, scientifiques, etc.).

Les raisons guidant le choix de l'Académie à consacrer ce numéro « spécial COP climat » des Cahiers aux ressources sont donc évidentes, au regard des liens entre défi climatique et ressources naturelles, que l'on songe à la part des émissions de gaz à effets de serre attribuée aux ressources énergétiques fossiles, aux besoins d'approvisionnement en ressources critiques (et l'impact environnemental corrélatif) pour conduire la transition énergétique, aux ressources naturelles (océans, forêts…) constituant des puits de carbone à protéger, à l'érosion de la biodiversité accentuée par le changement climatique, la surexploitation des ressources et la destruction des habitats naturels, la pollution et la prolifération d'espèces exotiques envahissante. Sans oublier les impacts de l'exploitation des ressources sur les interactions entre géosphère, hydrosphère, atmosphère et biosphère, dont les interdépendances et les rétroactions soulignent la complexité du système Terre et la nécessité d'une approche globale de sa préservation.

Bien qu'imparfaite et si souvent décevante, la « COP Climat » constitue l'élément principal de négociations, dans le cadre duquel Université Côte d'Azur a choisi d'agir en y partageant des ressources intellectuelles, en particulier scientifiques. Dans ce contexte, la transdisciplinarité dont l'Académie se revendique devient alors un élément fondamental pour traiter d'un problème par nature complexe.

Novembre 2026,
Le Comité de pilotage de l'Académie « Territoires, environnements, Risques et Résilience »,
Université Côte d'Azur

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See also PLANETARY HEALTH CHECK 2026, Ed. Niklas Kitzmann, Boris Sakschewski, Levke Caesar, and Johan Rockström, DOI: 10.48485/pik.2026.25.

[2] Our approach focuses primarily on the concept of "natural resources," to the exclusion of other types of resources such as human, financial, informational, digital, and intangible resources (cultural assets, etc.). However, in the field of energy, resources include not only natural energy resources but also processed products derived from them.

[3] The phrase "mineral and other non-biological resources" is used in reference to the seabed and its subsoil in Article 77 of the United Nations Convention on the Law of the Sea (concerning a coastal state's jurisdiction over its continental shelf).

[4] The only exception is Part XI of the Convention, which deals with the "Area" of the deep seabed beyond the limits of national jurisdiction and defines the term "resources" solely for the purposes of that part (as follows: "all solid, liquid or gaseous mineral resources *in situ* in the Area at or beneath the seabed, including polymetallic nodules").

[5] The Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (New York, 2023), also known as the High Seas Treaty (or BBNJ Agreement: Biodiversity Beyond National Jurisdiction Agreement) defines marine genetic resources as: "any material of marine plant, animal, microbial or other origin containing functional units of heredity of actual or potential value" (Article 1).

[6] Respectively: "genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity"; "genetic material of actual or potential value."

[7] The EM Annex classifies the materials and products it lists into the following categories: "Nuclear Energy," "Coal, Natural Gas, Petroleum Products, Electrical Energy," and "Other Energy" (which includes fuel wood and wood charcoal).



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Highlight

Unlocking Climate Adaptation at COP31

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Adaptation: a priority for COP31

Developing countries will need over US$310 billion annually for adaptation to climate change by 2035, yet international public adaptation finance amounted to only US$26–28 billion annually in 2022–2023.[1]

Adaptation to climate change consists in anticipating and responding to climate risks to reduce harm and seize opportunities. Negotiations to coordinate adaptation have made significant progress since COP21 established the global goal on adaptation in 2015. COP28 defined seven thematic targets (including water, food and health) while, last year, COP30 adopted 59 indicators to track progress.[2]

Yet, investment lags, making financing a priority for COP31. Adaptation also cuts across many of the Turkish COP31 Presidency's ten priorities, including resilient energy systems, agriculture, cities and human health. Although the June 2026 talks on the Global Goal on Adaptation did not produce an agreed text, they helped define the agenda for COP31. Outstanding questions include how to organise the technical body tasked with refining the COP30 indicators and how the goal relates to the COP30 commitment to triple adaptation finance by 2035.

Recommendation 1: Treat adaptation as an investment

The commitment to triple adaptation finance is an opportunity to scale up investments with positive economic and social returns.

The risk is that adaptation be perceived as a cost and governments default to financial precaution rather than moving forward with the COP30 commitment. This could have the opposite effect than the one intended, limiting investments that are protective of economic growth and public expenditure. COP31 should encourage governments and financial institutions to assess adaptation projects by their full economic returns, including avoided losses and benefits for health, productivity and public finances. This may include co-benefits beyond the climate hazards targeted, supporting wider economic, environmental and social objectives.

Evidence points in that direction, since adaptation is not merely protective spending: it enhances infrastructure, productivity, public health and fiscal capacity. Building more resilient infrastructure in low- and middle-income countries returns about four dollars for every dollar spent in the median case, and pays for itself in 96 per cent of the thousands of futures the World Bank tested.[3] The Global Commission on Adaptation set US$1.8 trillion of investment between 2020 and 2030 against US$7.1 trillion in net benefits.[4]

Recommendation 2: Close the adaptation gap in health

While the benefits of health adaptation are well established, financing remains exceptionally low. COP31 should highlight this mismatch and encourage greater support for health-focused adaptation through national adaptation plans and development finance.

Research on the health costs of climate change shows that adaptation can substantially reduce climate-related morbidity and mortality. One global assessment estimates the mortality reduction at around 30 per cent.[5] Conversely, inadequate protection from temperature exposure increases healthcare spending, adding pressure to already overstretched public services.[6] Where health provision is thinner, the health burden of temperature is higher.[7] Where exposure to extreme temperatures is greater, temperature is also likely to account for a much larger share of the overall disease burden.

Yet, health is the smallest slice of adaptation finance. Between 2009 and 2019, health activities received US$1.4 billion, or 4.9 per cent, of all bilateral and multilateral adaptation finance. Projects with health as their main purpose received about one fifth of one per cent.[8] Health is a priority in the COP31 Action Agenda set by the Turkish Presidency, and investments to protect human health should be given specific prominence. With health as an outcome, investments should include both those within the health sector and those outside it that affect health, including housing, access to cooling and nutrition.

Recommendation 3: Define objectives for adaptation, not technologies

Focusing on objectives and expected outcomes broadens the range of effective investments and facilitates public-private cooperation, helping COP31 reach agreement on how adaptation finance can achieve shared goals, or delimit technical support for reaching targets.

Adaptation is often defined in terms of particular technologies, such as home insulation for protection from heat, or infrastructure for coastal management. This can narrow policy in two ways. First, technologies are treated as competing alternatives, even though available evidence may not support a reliable ranking by effectiveness or cost-effectiveness.[9] Second, public finance tends to favour large, easily identifiable infrastructure projects, while dispersed household-level adaptation receives less support.

In contrast, defining adaptation by the outcome to be achieved, such as maintaining safe indoor temperatures, reveals a wider system of complementary interventions. Public and private actors can then address different points within that system, expanding the reach and effectiveness of public support.[10,11] Organising public support around a common outcome, rather than a prescribed technology, could also connect household action with public institutions and widen participation in adaptation. A global review found that individuals and households are the most prominent actors implementing adaptation, yet among those least integrated into institutional responses, particularly in the Global South.[12]

A short example: Food security, health and adaptation

Food security is increasingly threatened by climate change. Adaptation in food security constitutes an investment in human health and human capital, which strongly connects to the need for health-based climate adaptation. When such adaptation is defined by technologies, attention tends to centre on agricultural production, particularly seeds and farming methods. When adaptation is instead defined by the outcome of food security, the relevant system becomes much broader.[13] It includes not only resilient agricultural production but also distribution networks, cold chains, last-mile access and affordability programmes. Public investment and coordination can play a direct role in these areas. In remote areas, where weaknesses in distribution and access may affect nutrition as much as production shocks, effective adaptation must encompass the entire food system. Recent work shows that cold storage and logistical infrastructure are central to modernizing agri-food systems, particularly by enabling the distribution of perishable and animal-sourced foods.[14,15]

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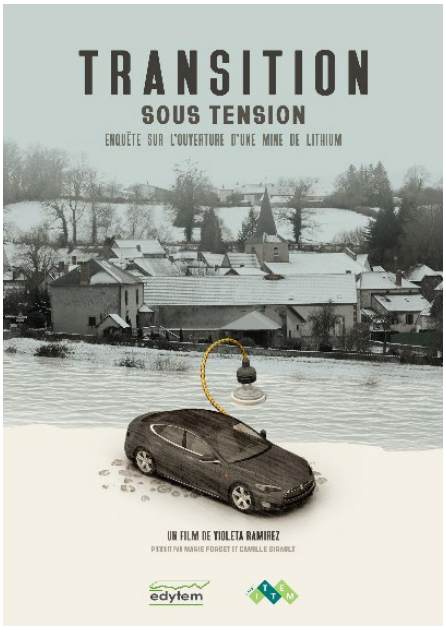
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Highlight

"Transition In Tension": The Energy Transition Viewed Through an Ethnological Lens

Violeta Ramirez

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The documentary film Transition sous tension (Transition in tension, 2024, 53 minutes) offers an immersive and nuanced exploration of the environmental and social issues associated with plans to open a lithium mine in the Allier department. Over the course of a year, Violeta Ramirez conducted an ethnographic study, filming testimonies from local residents and observing reactions to the announcement of the mining project. Th ethnographic documentary is the result of this fieldwork. It captures the local controversy surrounding the project and, more broadly, shows how various stakeholders in the region perceive energy, environmental, and social issues in a context of climate change. This experience was part of an innovative research project at the intersection of anthropology, geography, and documentary filmmaking.

Focus on Emerging Environmental Values and Transitions

The TRAM project (*TRAnsitions énergétiques en Montagne* - Energy Transitions in the Mountains) aimed to investigate how environmental values are constructed in the context of the development and commercialization of a new resource linked to the energy transition. Funded by LabEx ITTEM, the project was led by two geographers from the EDYTEM laboratory: Marie Forget and Camille Girault. They decided to use an immersive, film-based methodology to produce audiovisual materials with the aim of making the research findings accessible to a wide audience. To explore these issues in a specific field, they opened a postdoctoral position and awarded it to Violeta Ramirez, a visual anthropologist.
The field site selected for the study is located around the Bosse granite massif, on the border between the Allier and Puy-de-Dôme departments. On October 24, 2022, Imerys announced the startup of a new lithium mining project, named EMILI, in this very location, within the municipality of Échassières. The company plans to produce 34,000 metric tons of lithium hydroxide annually starting in 2030. Due to lithium's strategic importance, particularly for the manufacture of electric vehicle batteries, the French government designated this venture a Project of Major National Interest.



Kaolin Quarry in Echassières: Imerys is already operating a kaolin quarry on the same site.

Just a few months after the mining project was announced, Violeta Ramirez began her ethnographic fieldwork, observing the environment and everyday interactions and gathering the perspectives of residents and other stakeholders. She was in charge of both the ethnographic study (observations, semi-structured interviews and interactions) and the audiovisual project (recording sound and images).
Her fieldwork was conducted in the context of intense public debate around the new mining project and public energy transition policies. The prospect of opening a mine for the sake of the energy transition drew heated reactions, both locally and nationally. For some, the project represented the promise of energy and industrial sovereignty—and even of rebalancing the scales of environmental justice between the Global North and the Global South—in a tense geopolitical context marked by increased competition for critical resources. For others, it amounted to a false solution to the climate crisis by generating new forms of pollution and consumption while exposing the lack of political will to promote energy frugality. The aim of the investigation was to gather these different opinions about the project, along with perceptions of the region, the environment, and climate change.

A Documentary Format for Wide Distribution

From observations and interviews filmed on site, Violeta Ramirez created the documentary *Transition sous tension: Enquête sur l'ouverture d'une mine de lithium* (Transition In Tension: An Investigation into the Opening of a Lithium Mine). It is built entirely from interviews, observed situations, local landscapes, and archival documents, without any voice-over or explanations. The absence of commentary gives greater resonance to the respondents' own voices, and the documentary format marks a departure from the usual written format of scientific productions.
The film premiered on the site of the investigation in March 2024. The aim of allowing the respondents to view the findings was to initiate conversations, invite participants to voice possible opposition, and reaffirm or challenge the relationship of trust established during fieldwork. Following this first screening, additional viewings were organized in the area impacted by the project and in a wide variety of settings throughout France and abroad. Between 2024 and 2025, the film was screened more than 50 times in various locations (universities, movie theaters, cultural centers) as part of film festivals or at the request of activist groups, researchers, and others. The screenings were followed by question-and-answer sessions with the film's research team, often alongside other speakers (researchers, journalists, members of environmental organizations, or local activists).
As a tool for scientific outreach, the film has proven particularly effective in engaging diverse audiences. Because of its accessibility and emotional appeal, viewers identify more strongly with the people featured in the film and feel more concerned about the issues raised. The documentary thus contributes directly to the public debate on new mining projects and the energy transition in France.



The documentary is available on the streaming platform CinéMutins (https://www.cinemutins.com). The DVD and VOD versions of the film are also available for purchase by university and public libraries from ADAV (www.adav-assoc.com). Find more information on the documentary's website: https://labexittem.fr/science-et-societe/transition-sous-tension-dans-le-massif-central-enquete-et-documentaire/



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Highlight

Toward an Interdisciplinary Approach to Environmental Risk: The Case of Uranium mines

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To achieve the green transition needed today, a careful examination of the health and environmental consequences of our territories' industrial past is required. This is precisely the framework for the research project Traces, Transfer, and Legacy, an interdisciplinary initiative investigating what happened to France's former uranium mines. As part of a research program at the intersection of sociology and radiochemistry, it aims to characterize the footprint of uranium by analyzing its traces, investigating its transfer processes, and characterizing its legacy. Due to the increased natural radioactivity resulting from post-mining uranium operations, it is important to gain a deeper understanding of the dynamics specific to a territory and its contaminants in order to ultimately achieve more integrated and proactive risk management.

The Fragmented and Controversial History of Uranium

In France, debates on nuclear power mainly focus on the future of the industry: whether to shut down power plants or upgrade reactors. However, they largely fail to address the legacy of the past, particularly that of former uranium mines, even though remnants of their production will require monitoring over several hundred years. While mining operations in France were limited to a period of about forty years in the postwar period, the potential effects of radon and water contamination will need to be monitored over the very long term as part of the post-operational phase. The management of former uranium mines has been on the government's agenda since the circular dated July 22, 2009, which provides for monitoring former mining sites by conducting inspections, improving safety, and sharing information. However, in the context of sustainable environmental management, questions have been raised about the level of vigilance required for managing these mines. How can the legacy of these mines be shared with future generations to ensure that oversight is maintained? This implies that mine monitoring protocols factor in long-term issues, notably the period of radioactive decay. The extended timeframe associated with radioactivity raises questions about how our society manages a legacy laden with risk over the long term. As Philippe Brunet (2004) points out, "timeframe and scale variations contribute to increased uncertainty: the few decades of mining operations become negligible compared to the radioactive half-life of the waste." To deal with these very long time periods, it is important to understand how history has shaped very different perceptions of the uranium industry.

From a Fluctuating History to Environmental Monitoring

Uranium mines illustrate the complexity of the transitions faced by regions shaped by France's strategic nuclear industry as they return to a "normal" state after mining operations ceased. The management of production remnants continues to spark controversy today because of the contrasting and fragmented history of these mines. In France, activities related to the exploration, production, and processing of uranium ore—the first step of the nuclear fuel cycle—as well as the storage of processing residues, were

spread over approximately 250 sites across 27 departments over a period of nearly fifty years, from 1948 to 2001 (Blanc, 2008). Mining operations extended over three major periods. The first period, from 1945 to 1970, corresponds to the nuclear industry's legendary era, when it was part of a grand national project (Paucard, 1994) until opposition to uranium extraction started to grow in the 1970s. The second period saw the development of a nuclear power program in 1973 combined with the discontinuation of graphite-gas reactor technology (Hecht, 2004). This led to changes in mining techniques and in the organization of uranium production. The growth of uranium production in France under the management of Cogema (Compagnie Générale des Matières Nucléaires), along with the development and introduction of uranium on the global market, contributed to an increase in production volumes during the 1970s. An anti-nuclear movement specifically focused on the uranium industry also gathered momentum during this period. Different advocacy organizations were created in line with the anti-nuclear movement, particularly in response to research activities or new mining sites. The third period, during the 1990s, corresponds to the end of production operations and the growth of environmental concerns. The drop in the price of uranium on the world market led Cogema to reduce its production starting in 1989 until the last mine was permanently closed in 2001, in Jouac, in the Haute-Vienne department. In the years that followed, concerns about the waste left behind and the industry's legacy pushed environmental issues to the forefront. The presence of mine tailings, for example, represents an inescapable risk for the surrounding areas. Thus, three narratives coexist and confirm the multifaceted nature of history: the "golden age" of uranium was followed by a controversial period and finally an uncertain one (Brunet, 2004).

In today's context, four key measures regulate the environmental management of mining sites. First, while the operator is in charge of environmental monitoring of mining sites, the DREALs (Regional Directorates for the Environment, Planning, and Housing), in coordination with the Nuclear Safety Authority (ASN), are responsible for its oversight. This includes entrances, fencing, tailings reuse, environmental monitoring procedures, and the overall condition of mining sites and containment systems. Second, the operator is required to conduct environmental assessments to provide information about the sites. These assessments, which notably include sediment deposits in waterways and bodies of water, are submitted every three years. Third, an inventory of tailings must be completed in relation to land use. Finally, the results of radiological monitoring and the environmental measurements taken are reported to the local information and oversight committees in each municipality. All these obligations are carried out in accordance with the Mining Code and the Environmental Code. One of the key issues in risk management is land use. Practices in this respect vary depending on each territory's history and available resources. Thus, decisions regarding land use depend on both national oversight systems and the interests of local stakeholders, which means that the type of management varies depending on the territory (Becerra et al., 2016). Given this context, risk management requires a twofold approach: on the one hand, an investigation of the objective traces left by history, and on the other, an analysis of human activity in contemporary land use.

An Interdisciplinary Approach: Traces, Transfer, and Legacy

The Traces, Transfer, and Legacy (TTL) project seeks to understand both the physical and social dimensions of environmental risk. Conducted at IMT Atlantique by the Department of Social Sciences and Management and the Radiochemistry Group of UMR Subatech, it aims to characterize the footprint of a uranium mine. The initiative arose from a shared resolve to understand the extent of risk by investigating the mine's physical and human footprint within a specific space. This choice was made because very different approaches have been taken to manage post-production uranium mines from one region to another in France, and a wide range of attitudes toward risk can be observed. These different interactions between uranium, its production, and its environmental impact have given rise to various controversies regarding the management of the mining legacy and its traces. This tension therefore requires a comprehensive assessment of the territory's contaminants and characteristics. Using a pilot site (La Commanderie) as a starting point, an interdisciplinary approach was adopted to investigate how physical risk was managed and how land use evolved over time.

A Pilot Site: La Commanderie (Vendée and Deux-Sèvres, Fr)

This mine was selected because it served as both a uranium extraction and processing site and was rehabilitated for multiple uses. Known as La Commanderie, it is the second-largest uranium deposit in the Vendée Division, with 3,978 metric tons of uranium produced between 1955 and 1991. The mine was part of the Mallièvre concession, which straddles two municipalities—Treize-Vents and Le Temple (which has been part of Mauléon since 1973)—two departments—Vendée and Deux-Sèvres—and two regions—Pays de la Loire and Nouvelle-Aquitaine. Discovered in May 1955 on farmland, La Commanderie is named after an estate founded in the early twelfth century and later occupied by the monastic-military Order of the Knights Templar.

The project originated from the need to understand the origin and impact of the traces left by uranium mining in the region. This need arose because the decommissioning and redevelopment of mining sites carried out during the 1990s had gradually erased the industrial traces of uranium extraction and established a strict boundary between monitored areas and the rest of the territory. Over time, this division was contested due to the presence of "remnants" (waste, residues) that revealed—depending on the region and local culture—various "border zones" (Thom, 1993) for which no long-term risk management plans had been implemented. Risks in these zones can only be understood by studying the dynamics of radioelement transfer and the interactions between the environment and its residents. The Traces section of the project thus focuses on identifying and characterizing the sources of pollution (emission and discharge points) and the traces left behind by industrial operations. The Transfer section seeks to study the transfer mechanisms behind the dispersion of pollutants (from the "water" compartment to the soil, for example), along with changes in land use (such as an industrial site converted into a residential area). The Legacy section aims to study the impact of pollutants on various targets, assess current land management practices under both continued and changed land use, and understand the mechanisms of public consultation. The results are then plotted on a map to establish links between the data, interconnect the knowledge gained, and disseminate it more easily.

Traces

The first stage of the investigation involved physically identifying the traces left by mining operations and drawing on history to understand the markings in certain areas. Research was first conducted within the archives to identify the different mining zones and distinguish ore processing areas, waste rock storage areas, and the location of buildings. As early as 1955, preliminary surveys were conducted to prepare for intensive mining operations in what would become an open-pit mine 500 meters long, 250 meters wide, and 110 meters deep spanning both departments and including 30 kilometers of underground tunnels. A 200-meter-wide waste dump rose on the western side as extraction progressed and cut-off grades were reached, while to the north, static leaching areas were installed as early as 1969. Residues of processing, consisting of water and sulfuric acid, piled up in the northern part of the site. Open-pit mining ended in 1977, while underground activities were halted in 1983. Despite evidence of pitchblende deposits to the north, the mine closed in 1991. It yielded a total of 3,978 metric tons of uranium and produced 5.6 million metric tons of tailings. Surprisingly, 250,000 metric tons of static leaching residue are still stored on site. Thus, by analyzing the archives, specific areas could be identified, notably areas used for processing residue. This historical knowledge is very valuable for radiochemistry studies because it serves for the identification of high-risk areas, as detailed in the next section. These trace elements then become part of a social and industrial history, which is the subject of the last section.

Transfer

In the second stage of the investigation, areas previously identified based on historical data were combined with physicochemical data. The most easily characterized traces are those that emit light (gamma rays) as a result of radioactive decay. This radiation was detected by a sensor equipped with an integrated GPS system, which was previously calibrated to convert the amount of radiation detected into

a level of risk. The traces found were mostly associated with diffuse contamination from natural sources and/or contamination resulting from mining operations. However, it is important to remember that these measurements were taken in environments with high levels of radioactivity, and that entirely natural phenomena can also lead to concentration processes and thus to "anomalies" when compared to the geochemical background whose "natural" component (rock transformation and natural inputs) must be distinguished from the "anthropogenic" component (the presence of elements resulting from human activities). The historical context is therefore essential for distinguishing between natural and industrial origins. The risk is assessed by identifying the source of contamination and the active transfer pathways, but also by understanding how the site has been used after operations ended, as changes in land use can affect the equilibria established when the site was repurposed.

Legacy

The third stage of the investigation aims to characterize the land uses specific to the territory by examining practices such as grazing and irrigation. At the La Commanderie site, after the open-pit mine was decommissioned in 1990, numerous requests for redevelopment were submitted to the former operator, including a quarry project that ultimately did not materialize. For about twenty years, three land uses coexisted. The water basin from the former mine was used for irrigation at the request of the local farmers' association. An equipment and packaging company purchased the former industrial buildings and added a new facility to expand its operations. Finally, on the former tailings dump, a company installed a solar panel power plant. These three uses—for energy, industry, and agriculture—coexist on the site, and successive elected officials have praised it as a model of successful redevelopment. During rehabilitation, three safety zones were established. The open-pit section of the mine was backfilled with materials from the remediation process and leaching residues. All these products were covered by a layer of limestone approximately 10 centimeters thick. The northern section was filled with mine tailings. It is crucial to keep a record of these practices, because a controversy arose on the site in the early 2000s over the use of the water basin. A group of 16 farmers were using the basin, while on other mining sites, these areas containing tailings are classified as subject to environmental protection regulations (ICPE). This issue was discussed within the interdepartmental commission chaired by the prefect—which was set up in 2009 to manage the site—notably the environmental impact and the legal provisions governing tailings storage. The local advocacy group called for environmental management aligned with national policy, seeking to ensure consistent implementation of all relevant legal provisions. The interdepartmental commission emphasized instead the need to refer to on-site assessments. Disagreements grew between the local advocacy group and government officials, who justified maintaining the status quo since the site's current uses and its redevelopment.

Another focus of the TTL (Traces, Transfer, and Legacy) project is the development of citizen science, with the aim of jointly addressing scientific, technological, and societal issues. The goal is to develop an interdisciplinary approach in collaboration with stakeholders from the industrial sector and civil society organizations to deal with environmental issues. To achieve this, the researchers involved in the project have been participating in one of the local monitoring committees in order to share their research findings with public officials. This project illustrates the commitment to study the full complexity of the concept of risk by focusing on a risk emerging from changes in land use. The concept of "emergent risk" has given rise to disputes within the various scientific communities. Faced with these new, sometimes unprecedented phenomena, experts have put forward hypotheses and expressed opinions that have created or strengthened epistemological divisions. These risks are due not only to the complexity of the factors driving these developments (new products, new technologies), but also to the prospect of unpredictable events, whose effects cannot be measured. While interdisciplinary approaches often focus on the theoretical combination of knowledge to address a shared issue, they often overlook practical concerns. However, the strategic nature of the issue of environmental risk compels all researchers to engage in a process of dialogue to make their findings understandable to their colleagues in other disciplines.

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Highlight

Scientific diplomacy and the climate emergency: Young researchers' perspectives on the COP

Nuclear Energy: From Student Perceptions to Energy Policies

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Energy policy choices are key to addressing climate change. These issues are—for good reason—the subject of ongoing debate in sevral continents, but they are complex, take on multiple forms, and are not always fully understood.

Before focusing more specifically on nuclear energy policies, some background information is needed. In its 2025 report on electricity, the IEA (International Energy Agency) notes that electricity accounts for about 20% of final energy consumption worldwide (28% in China, 22% in the U.S., and 21% in the EU).[1] Global demand for electricity is growing by 3 to 4% annually (with some variation) and could increase by 50% by 2040 or even double by 2050, according to several scenarios.[2] In 2025, approximately 38% of this electricity was generated from oil and coal (mostly coal), just over 20% from natural gas, just under 10% from nuclear power (9% exactly in 2024[3]), and about 34% from renewable energy sources.[4] Thus, coal remains the primary source of electricity today. However, renewable and nuclear power are expected to account for about half of global electricity generation by 2030. While the largest share of the increase in nuclear electricity production is expected to come from emerging economies by 2030 (China alone is projected to account for 40% of this increase), this overall growth is also driven by policies aimed at extending the lifespan of reactors or adding new energy capacity.[5]

While fossil fuels are responsible for most greenhouse gas emissions, nuclear power is nevertheless the object of intense debate: it produces little carbon dioxide but raises questions regarding risk management, radioactive waste management, long-term costs, and geopolitical implications. Global carbon dioxide emissions from electricity generation rose by 1% in 2024, following a 1.4% increase in 2023, against a backdrop of 4.3% growth in global electricity demand.[6] Carbon emissions from electricity generation are expected to decline even more rapidly by 2030, as the share of low-emission energy sources continues to grow. In spite of this, the 2023 IPCC report (AR6) states that the measures currently being implemented by countries will result in emissions (of all kinds) leading to global warming of 3.2°C by 2100 (ranging between 2.2°C to 3.5°C).[7] The drop in the carbon footprint of electricity generation, offset by the rise in global demand for electricity, will therefore not be sufficient to keep global warming below the 2°C target (set by the 2015 Paris Agreement).

This brief and necessarily incomplete overview highlights how difficult it is today to address global energy issues, without even going into the question of mineral resources that remain essential to a large extent to the development of future technologies. These issues are complex, and our understanding remains generally incomplete.

Nuclear power, more specifically, has historically been viewed in two ways. On the one hand, it represents postwar scientific progress, energy abundance, and now a possible solution for decarbonizing economies. On the other hand, it remains associated with the major disasters of Chernobyl and Fukushima, and with the threat of military uses of nuclear power (even though this is a separate issue from energy concerns). This ambiguity explains why it remains one of the most controversial issues in contemporary energy policy. The French Authority for Nuclear Safety and Radiation Protection (ASNR) regularly publishes a Nuclear Barometer that provides a useful statistical foundation for addressing the issue. Our study is obviously more limited in scope and focuses on a university student population. It investigated several questions: How do students today perceive the role of nuclear power in tomorrow's energy mix? Do national energy policies influence these perceptions? What reasons are advanced to support or oppose the development of nuclear power? Which risks do students point out most frequently?



Construction work at the nuclear power center of Taipingling, Guangdong, China, 2025

These questions draw on several concepts from the sociology of risk and of science. The first is the concept of "nuclearity," developed by historian Gabrielle Hecht.[8] "Nuclearity" describes how a place, an object, or a risk is socially defined as "nuclear." This perception not only depends on physical realities, but also on cultural, historical, and political factors. Since nuclear risk is usually invisible to the naked eye, its perception depends heavily on information systems, the media, experts, and whistleblowers who shed light on this risk and “make it visible” to the public.[9] Furthermore, this study adopted an approach taken from the sociology of science that rejects the systematic dichotomy between “experts” and “laypeople.” The initial objective was not to determine who is right or wrong, but to understand how individuals construct their perceptions of nuclear power based on their experiences, values, and sources of information.

Our study therefore undertook a quantitative survey in the form of a questionnaire proposed to students at several European universities of the Ulysseus network. The field of investigation initially included eight countries (Austria, Finland, France, Germany, Italy, Montenegro, Slovakia, and Spain). The questionnaire covered four main areas (students’ sociodemographic profile, perceptions of the nuclear industry, views on energy policies, and knowledge of nuclear risks and radioactivity). A total of 726 complete responses were received. However, due to difficulties in contacting students in other European universities, the sample remained predominantly representative of French students rather than European youth as a whole (91.6% were French nationals versus 8.4% of other nationalities).

One of the key findings of this study is the relatively high level of trust in nuclear power. The results show that 68% of the students (referred to below as "respondents") who answered the survey trust the civil nuclear industry; 78% consider nuclear power to be a carbon-free energy source; 72% perceive it as a safe energy source; and 63% as a green energy source. The respondents strongly associated nuclear power with the fight against climate change. For many of them, this energy is an important means of reducing carbon dioxide emissions. The sources of information considered most reliable are scientific reports, nuclear experts, and specialized documentaries. Conversely, social media, advocacy groups, and informal conversations were much less frequently reported as reliable sources. This hierarchy reflects a high degree of trust in scientific expertise. This relatively high level of confidence in the nuclear industry appears consistent with the results of the ASNR Barometer, which have shown for several years that the French public has a high level of trust in scientific institutions and considers that high nuclear safety requirements need to be maintained. In 2024, confidence in scientific institutions remained high, and more than eight out of ten French people agreed that a high level of nuclear safety is essential.[9]

Respondents in favor of further developing nuclear energy advanced three main reasons. First, they consider that nuclear power is a low-carbon energy source that can contribute to reducing global warming. This is the most frequently mentioned reason (69.7% of respondents). Many respondents also believe that nuclear power could strengthen France's energy independence (330 respondents, or 59.1%). This idea is widely disseminated in French national political communications, where sovereignty and energy independence are regularly associated with the need to maintain and develop the civil nuclear industry.[10] Some respondents (308, of whom 91.6% were French) view nuclear power as a technology of the future and express confidence in future innovations such as nuclear fusion or new forms of waste management. We associate this view with "technological solutionism," which is the belief that scientific progress will provide solutions to today's problems.[11]

Respondents opposed to nuclear power (117 respondents, or 16.1% of the total sample) primarily mentioned radioactive waste management as their main concern. This was the most frequently reported counterargument (advanced by 64.1% of respondents opposed to nuclear power development). Respondents highlighted the extremely long lifespan of radioactivity and the burden it places on future generations, while historical disasters and the increase in extreme weather events raise concerns about the safety of nuclear plants. None of the students agreed on a solution: 27% support temporary geological storage, a quarter want an alternative solution, while another quarter believe there is currently no truly satisfactory solution. Some responses—more difficult to quantify—focused on the health, environmental, and geopolitical consequences of uranium extraction in producing countries. In addition, potential threats to the future of the nuclear industry such as geopolitical tensions, droughts, aging power plants, and natural disasters, were also mentioned. For some respondents, the main problem is not how energy is produced, but the overall level of energy consumption. This position aligns with a philosophy of conservation or degrowth.

A majority of respondents (46.8%) believe that energy policies lack sufficient transparency, that institutional communication regarding nuclear power is inadequate or even nonexistent, and that, overall, citizens' views are not sufficiently taken into account in energy-related decisions. Even when respondents have a positive opinion of nuclear power, they express a strong demand for democratic participation and public dialogue.

In conclusion, the study shows that the students surveyed were generally in favor of nuclear energy, primarily because of its lower impact on the climate and its capacity to provide abundant, carbon-free electricity. However, this support was not unconditional. Issues related to radioactive waste, potential accidents, geopolitical concerns, and transparency in public decision-making remained central. The study's conclusion is that the debate over nuclear power is not limited to mere technical concerns. It is a profoundly social, political, and cultural issue, and citizens' perceptions will strongly determine the

acceptability of future energy choices. This conclusion aligns with the approaches developed by Gabrielle Hecht[8] on nuclearity, by Cyril Lemieux on making risks visible[12] and Grégoire Lits,[13] who demonstrate that nuclear issues cannot be understood solely from a technical or engineering perspective but require consideration of social and political views of the acceptability of energy choices and how they are communicated. The social sciences are thus equally essential to address nuclear issues.

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Highlight

Toward the Responsible Use of Rare Earth Elements
Conservation, Recycling, and Changing Production Methods

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[a] Based on and translate from the Collective Scientific Expertise Report (ESCo) on Rare Earth Elements: Toward the Responsible Use of Rare Earth Elements Throughout Their Life Cycle: What Are the Prospects in Terms of Resource Efficiency, Recycling, and Production Methods? (*Vers une utilisation responsable des terres rares tout au long de leur cycle de vie: quelles perspectives en termes de sobriété, recyclage et mode de production?*) CNRS. 2026. ⟨hal-05679183⟩

1. Strategic Metals at the Heart of Multiple Dependencies

Rare earth elements are a group of fifteen lanthanide elements plus yttrium and, depending on the definition used, scandium. Their name is misleading because they are not necessarily rare in the Earth's crust, but they are generally found in low concentrations and in association with one another. This dispersion makes their extraction—and especially their separation—complex. However, their magnetic, optical, and catalytic properties make them useful in a very wide range of applications: permanent magnets, catalysis, optical fibers, lasers, medical imaging, aerospace alloys, precision polishing, and a wide range of electronic devices.

The critical nature of rare earth elements is therefore neither uniform nor can it be reduced to their geological abundance. It depends on the concentration of deposits, the complexity of the separation processes, the required degree of purity, and market constraints. In 2025, lanthanum and cerium—used primarily in catalysis—were worth one hundred to one thousand times less than dysprosium or terbium, which are essential for certain high-performance magnets. Price volatility, amplified by industrial and geopolitical decisions, further increases uncertainty for all economic stakeholders.

Demand driven by strategic applications

Rare earth elements play a unique role in the energy and digital transitions. About one-third of global consumption goes toward producing permanent magnets, primarily NdFeB magnets, used in electric vehicle motors, offshore wind turbines, drones, hard drives, speakers, and many miniature actuators. However, the quantities used vary considerably: a few hundredths of a percent in an optical fiber, compared to nearly 30% of the mass of some magnets. A single offshore wind turbine motor can contain as many rare earth elements as approximately two million cell phones.

A highly concentrated value chain

With an estimated 478 Mt of primary resources and a production of 394 kt in 2024 (13% annual growth since 2015), Europe's vulnerability is not due to an absolute lack of resources but to the concentration of industrial capacity elsewhere. In 2024, China accounted for approximately 70% of global production and 90% of refining, while holding nearly 35% of identified reserves. The United States and Myanmar have expanded their mining operations, but a large share of the concentrates continues to be shipped to China for separation and processing. This control over the entire supply chain—from ore to intermediate materials and on to finished products—represents a major strategic advantage.

Europe has some mining prospects, particularly in Sweden and Norway, but only one European site could be harvested within the next five to ten years. France does not have any onshore deposits that could easily be developed in the short term. The European regulation on critical raw materials adopted in 2024 therefore aims to diversify supply sources, relocate certain production capacities, and expand recycling by 2030. This strategy, however, remains primarily supply-oriented, while long-term security of renewable energy sources also requires reducing demand, prioritizing uses, and considering the environmental and social costs of new energy production.

2. Reduce Demand: Substitution, Efficiency, and Conservation

To reduce dependence on rare earth elements, three complementary strategies need to be implemented: replacing critical rare earth elements with other elements or technologies, reducing the quantities required to achieve a given level of performance, and reassessing the applications themselves. None of these strategies are universal, and their suitability depends on the product's intended function, mass and volume constraints, lifespan, and the impact of shifting to other resources.

Substitutions are possible, but rarely without compromising performance

In NdFeB permanent magnets, the amount of dysprosium can be cut in half by optimizing its composition and microstructure without any significant loss in performance. Some of the neodymium can also be replaced with other, less critical rare earth elements, but at the cost of reduced magnetic performance. Completely eliminating rare earth elements would generally entail a considerable increase in magnet mass—often by a factor of four to five—to maintain comparable functionality. This trade-off may be acceptable in certain vehicles that can adapt to multiple engine architectures, but it becomes much more problematic in offshore wind turbines or devices subject to strict mass and size constraints.

Other strategies can be implemented within the motor itself, such as rearranging the magnets, combining magnets that contain rare earth elements with others that do not, or introducing motors without permanent magnets. However, when performance density is critical, the miniaturization of electronics limits possibilities for substitution. In what are called "dispersed" applications, just a few hundredths of a percent of rare earth elements are sufficient to impart a critical property to a material. In these cases, substitution is often technically impossible or environmentally unsound, since the material saved would be minimal compared to the loss of functionality.

Technological breakthroughs can shift the threshold of criticality

New technologies can significantly reduce the need for rare earth elements. The transition from phosphor lamps to white LEDs, for example, reduced the amount of rare earth elements required to achieve comparable light output by approximately two orders of magnitude. Similarly, nickel-metal hydride batteries containing rare earth elements have largely been replaced by lithium-ion batteries. However, this shift did not eliminate dependence on minerals; it simply shifted that dependence to lithium, cobalt, nickel, or manganese. All substitutions must therefore be assessed against multiple criteria and over the entire life cycle; otherwise, one vulnerability simply replaces another, as often happens—unnoticed—with false progress.

Introduce public policies that genuinely focus on conservation

Conservation is not limited to using fewer materials in an object. It raises questions about the level of performance that is truly necessary, how frequently parts need to be replaced, whether equipment should be shared and certain uses granted priority. The sharing economy, which emphasizes access to a service rather than individual ownership, can increase the utilization rate of equipment and slow the growth of equipment stock. Another option is eco-design, which can extend a product's lifespan and make it easier to repair, reuse, disassemble, and recover components rich in rare earth elements.

How these approaches apply to rare earth elements remains insufficiently documented, partly because their presence is not immediately visible to consumers or to many stakeholders in the industry. The 2024 European Ecodesign Regulation, with its traceability requirements and digital product passport, could improve transparency in value chains. However, the law does not yet systematically require manufacturers to declare the presence and quantity of rare earth elements in products. Without reliable data on composition, flows, and lifespans, it remains difficult to implement conservation measures, anticipate future deposits, and distribute efforts across sectors.

A comprehensive strategy must ultimately distinguish between uses where rare earth elements provide a collective benefit that is difficult to replace (health care, energy infrastructure, defense, or critical industrial technologies) and those where growth is primarily based on multiplying short-lived products. Technical expertise is not sufficient to determine these priorities. It requires a democratic debate on needs, priorities, and the distribution of environmental costs.

3. Recycling: Real Potential, Still Needing Industrial-Scale Organization

Less than 1% of rare earth elements are currently recycled worldwide, a rate that has remained stagnant since 2010. This figure contrasts with the technological advances achieved since then. Life-cycle assessments show that recovering rare earth elements from waste can leave a smaller carbon footprint than primary extraction. Pretreatment, hydrometallurgy, certain bioprocesses, and short-loop processing—such as the manufacture of a new magnet from a used one using the decrepitation method—achieve high recovery rates. Now that their scientific feasibility has been established, the main challenge is to transition to robust industrial production chains fed by regular and sufficiently concentrated streams.

Deposit concentration determines the benefits of recycling

Not all waste contributes to an equivalent urban mine. Recovering rare earth elements from a few large magnets from wind turbines or electric motors is more effective than collecting them from millions of small electronic devices. Dispersion has two main disadvantages: It increases logistical costs and dilutes the recoverable value per item. Cell phones are a case in point. About two million of them would need to be collected to reach the amount of rare earth elements found in a single offshore wind turbine.

Concentrated deposits are therefore strategic, but their availability is usually delayed. The magnets in a wind turbine or electric vehicle tend to remain in use for several decades before reaching end-of-life and entering recycling streams. Historical waste stockpiles alone cannot, therefore, meet the current rapid growth in demand. In the short and medium term, recycling will not replace traditional mining. However, it can offset certain imbalances, secure particularly critical rare earth elements, and gradually reduce the material intensity of supply chains.

Persistent economic and information-related barriers

High price volatility is a primary barrier to investment in recycling. A drop in raw material prices can temporarily render a recycling process uncompetitive, even if it is strategically and environmentally sound. Value also varies significantly depending on the recovered element: a stream rich in dysprosium

or terbium is not as profitable as one dominated by cerium or lanthanum. The stability of recycling chains therefore requires support mechanisms capable of cushioning price cycles (long-term contracts, supply guarantees, environmental criteria in procurement, targeted subsidies, or recycled content requirements).

Information is another barrier. Products containing rare earth elements are not subject to any specific legal framework. Directives on electronic waste, batteries, and vehicles have established collection and recovery targets, but these are often expressed in terms of total mass. An 85% recycling target for a vehicle automatically prioritizes the recovery of steel and other heavy materials, without guaranteeing the recovery of a few kilograms or grams of critical metals. The absence of labeling and composition data also makes it difficult to identify, sort, and route to the appropriate processes.

Develop a circular value chain

An effective policy must integrate several key elements, including a design that allows for disassembly, traceability of materials, selective collection, volume management, as well as scalable processes for disassembly, pretreatment, separation, purification, and reincorporation into new products. Coordination must also be ensured between manufacturers, equipment suppliers, environmental organizations, recyclers, local public structures, laboratories, and end users. A short magnet-to-magnet loop can preserve more value than a process that converts the waste into generic oxides, but it requires in-depth knowledge of alloys and strict control of contamination. While recycling is technically feasible, its implementation therefore depends primarily on collection, traceability, infrastructure, and an economically stable model.

Finally, to achieve a circular economy, reuse and repair should be the priority before recycling when these options truly extend a product's lifespan, but this approach should not serve as an excuse for increasing consumption. Even when highly efficient, recycling nevertheless involves losses, consumes energy, and cannot immediately supply the volumes required by a rapidly expanding market. It is one means to achieve resilience but does not justify every possible demand.

4. Diversify Resources and Transform Production Methods

In view of growing demand and the delayed availability of urban mining, other resources need to be explored. However, this diversification must not replicate the most harmful practices of conventional extraction. Rare earth elements are often associated with radioactive elements, and their separation requires multiple steps that consume water, energy, and reagents. The waste generated can thus cause long-term contamination of the soil and water around mining and metal-processing sites, with major health and social consequences. Relocating production to Europe would therefore only be legitimate if it is associated with high environmental and democratic standards.

Primary resources: limited but identifiable potential in Europe

Significant deposits have been identified in the igneous rocks of Northern Europe, notably in Kiruna, Sweden, and in Norway. Greenland also has several large, undeveloped deposits. The presence of resources in Brazil could, in the longer term, offer regional opportunities for French Guiana. This potential must be distinguished from proven reserves. Issues relating to grade, mineralogy, infrastructure, costs, permits, and social acceptability all determine whether a geological resource can be transformed into industrial production.

Marine resources are even more uncertain. France has the world's second-largest maritime zone. Polymetallic nodules and certain sediments found in its waters contain rare earth elements, but estimates of their quantities vary widely. Both technical feasibility and profitability thus remain hypothetical at this time. More importantly, damage to deep-sea ecosystems caused by extraction could be considerable

and potentially irreversible, knowing that these environments play a vital role in carbon storage. In view of current knowledge, seabed mining is therefore not a responsible short-term solution.

Mining and industrial waste: secondary resources to explore

Bauxite tailings, coal ash, and other mining or industrial wastes represent considerable volumes. Coal ash generated worldwide in 2020 contained approximately 320 kt of rare earth elements, and bauxite tailings contained nearly 150 kt. Even when the concentrations are low, these materials therefore have potential. They have already been extracted, stored, and have undergone energy-intensive processing such as crushing and grinding. In some bauxite residues, rare earth elements can be twice as concentrated as in the original ore before alumina extraction.

Recycling them can reduce waste while providing critical metals. However, obstacles remain such as a lack of data about historical volumes, variations in compositions, the presence of contaminants, and the actual availability of deposits. Harmonized characterization campaigns are needed to identify the most promising deposits, assess risks, and ensure that processing one type of waste does not simply produce another—more euphemistically called a by-product.

Toward integrated and more efficient processes

To reduce negative impacts, an integrated resources/processes/environment approach is needed. The process must be based on the specific mineralogy of the deposit and provide for internal recycling of water and reagents, limitation of effluents, and recovery of as many components as possible. As with recycling, solvometallurgical, ionometallurgical, and biometallurgical processes offer potential solutions for treating certain complex waste streams. Zero-waste strategies used to recover iron, titanium, and other elements from the residues can also improve overall economic efficiency and reduce the volumes requiring storage.

Sovereignty is inseparable from environmental justice

Corporate responsibility and the European duty of care are gradually increasing obligations throughout the value chain, including in third countries. However, public acceptability of a mining project cannot be achieved through belated communication or mere compensation. The issue at stake is whether production itself is needed: how will it be used, who will benefit from it, what risks does it entail, how will profits be distributed? It is essential to hold a sincere and open debate before anything is undertaken and to include all affected communities in decision-making and in monitoring the impacts.

Consequently, no single solution will be sufficient to reduce French and European vulnerability in securing the supply of rare earth elements. A robust strategy must combine the following four actions:

- Limit and prioritize demand.
- Reduce or replace rare earth elements where possible.
- Establish recycling industries capable of preserving the value of materials.
- Develop primary or secondary production in accordance with strict environmental standards.

Sovereignty is not measured solely by the number of metric tons available; it is also dependent on the collective ability to choose how to use them, master the processes involved, and democratically accept their consequences.



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Interview

Amina Schartup – Associate Professor of Marine Chemistry and Geochemistry at the Scripps Institution of Oceanography (University of San Diego)



Available on Canal-U, scan the QR Code below to watch it:

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