irtc24

raw materials in a changing world

February 21-23, 2024,
Torino, Italy

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Politecnico di Torino

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Content

About the Conference

After a very successful first IRTC conference in Lille (https://www.irtc-conference.org/) in 2023, the 2024 IRTC conference focuses on new approaches to criticality to face the challenges of a changing geopolitical configuration and the material needs to combat the climate crisis – looking at emerging policies, new ideas for criticality mitigation, and novel forms of collaboration between sectors and countries to foster supply security and sustainability.

Keynote Conversations

In a series of keynote conversations, international criticality experts will share their perspectives on critical raw materials for a sustainable future in moderated in-depth discussions.

Talks by Practitioners and Researchers

Practitioners and researchers in the field of critical raw materials are invited to contribute to the shape and content of the conference by sharing their work or case on critical raw materials in relation to thematic sessions as presented in the program below. The sessions will be chaired by multidisciplinary teams of experts to facilitate a discussion with the presenters. Next to these talks, participants will present their work by means of a poster in the exhibition hall.

Session Chairs will select the most novel contributions for publication in a special issue of the journal Mineral Economics (https://www.springer.com/journal/13563).

Workshops

The workshops are 2-hour events independently organized by various teams and have different formats such as panel debates, presentation series, and open discussions.

Participants

Participants are invited to join the two-and-a-half-day conference to meet colleagues, keynote speakers and conference Chairs, to engage in discussions in the sessions and to join the networking activities. On-site participation will be limited to around 200 people to encourage meaningful discussions and networking. Online participation in the sessions will be possible.

Practical information

Conference app

The full program and room schedule are available in the Conference App, which can be viewed and downloaded here: https://irtc24.sessionize.com/. The app is available for mobile phone, tablet, or desktop.

You can use the app to read abstracts, find speaker information, and highlight the presentations that you want to attend.

Website & LinkedIn

Visit the IRTC-website: https://irtc.info/conference/overview/

Follow IRTC on LinkedIn: https://ch.linkedin.com/company/irtc-international-round-table-on-materials-criticality

Best Poster Award

All participants can vote for the Best Poster Award.

You can vote until 23 February 12:00 CET via the following link or QR code:

https://app.sli.do/event/jxLNL2fC3eT3qvVSArHYj3

The awardee will be announced on 23 February 13:00 CET.

Conference dinner

The conference dinner takes place on 22 February at 18:30, at **Restaurant Esperia.**

Address: Esperia Restaurant, Corso Moncalieri 2

More information: https://esperiatorino.it/

Program

Tuesday, February 20

IRTC-Training course: A single-day introductory program covering the fundamentals of criticality and the evaluation of critical raw materials, providing essential background to profit the most from the conference.

Wednesday, February 21

9.00	*Registration and coffee at Politecnico di Torino*				
10.00	Workshop A: JRC Science for Policy Workshop *Organized by Fabrice Mathieux, Umberto Eynard, Thibaut Maury (Joint Research Center)*	Workshop B: Technical aspects of REE mining and processing *Organized by Alain Rollat (Carester)*	Workshop C: What is responsible mining? *Organized by Paul Ekins (UCL)*	Workshop D: Critical Youth in the Raw Materials Environment *Organized by Bianca Neumann, Ghadi Sabra (RMYMG), Francisco Veiga Simão (EIT RawMaterials Alumni), Dhruv Warrior (CEEW India)*	Site visit I: *PV recycling & industrial raw materials company* *Organized by Gian Andrea Blengini, Politecnico di Torino*
12.00	Lunch buffet at Politecnico di Torino				
13.00	Workshop E: Emerging sustainability standards *Organized by Harikrishnan Tulsidas (UNECE),*	Workshop F: Sustainable Finance and Raw Material Value Chains – Friends or Enemies?	Workshop G: Policies on strategic industries *Organized by Min-Ha Lee (KITECH), Andrew*	Workshop H: A new run on Africa and South America *Organized by Claudia Baranzelli*	Site visit II: *Politecnico di Torino Labs*

	Luisa Moreno (Tahuti Global)	*Organized by Antonella Amadei (independent consultant), Jana Plananksa (Norge Mining), Tom Dunlap (DIACSUS)*	*Grotto (Stanford University), Alan Hurd (Los Alamos National Laboratory), Ryan Ott (Ames National Laboratory), Evangelia Moschopoulou (NCSR Demokritos)*	*(OECD), Carlos Peiter (CETEM)*	*Organized by Gian Andrea Blengini, Politecnico di Torino*
15.00	*Coffee at the conference center*				
16.00	***"Mutually beneficial"? Creating value in cross-country cooperation*** *Open plenary discussion, co-organised by OECD* *Harmony Musiyarira (Namibia University of Science and Technology), Murtiani Hendriwardani (Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development), Paul Ekins (International Resource Panel), Stéphane Bourg (OFREMI), Nobuyuki Kikuchi (Mission of Japan to International Organisations in Vienna), Isabelle Magne (European Commission, DG INTPA), Andrea Di Masi (SQM), tbc;* *moderated by Claudia Baranzelli, OECD*				
17:45	Conference registration and welcome reception *Check-in, meet & greet*				
18:30	Apéro-dinner *Snacks, drinks & networking*				

Thursday, February 22

08.00	Conference registration & coffee	
09.00	**Introductory remarks** by the conference organizers	
09.15	**Welcome** by the Italian Ministry of Industry and Made in Italy and Rector of Politecnico di Torino	
09.30	**Opening speech** by EIT RawMaterials	
09.45	**Keynote speech:** **Transition Minerals and New Extractive Frontiers: An Indigenous Perspective** Edson Krenak (Indigenous Activist and Researcher, Cultural Survival/Vienna University)	
10.15	**Session presentations by the conference Chairs**	
10.30	*Coffee Break*	
11.00	**Session 1:** Emerging raw materials policies and their impacts *Chaired by Rod Eggert (Colorado School of Mines), Weiqiang Chen (Chinese Academy of Sciences), and Karen Hanghøj (BGS and UNECE Expert Group for Resource Management)*	**Session 2:** Forecasting CRM supply and demand *Chaired by Constanze Veeh (DG GROW, European Commission), Paul Lusty (Fastmarkets), and Tae-Yoon Kim (IEA)*
11.00	Global race to secure mineral supply chains: Collaboration, Competition, or Inequity? *Kriti Shah (India ZEV Research Centre, ITS, UC Davis USA), Shivani (India ZEV Research Centre, ITS, UC Davis India)*	Combined assessment of energy and material supply risks: a multi-objective energy system optimization *Gianvito Colucci (MAHTEP Group, Department of Energy "Galileo Ferraris", Politecnico di Torino), Valentin Bertsch (Chair of Energy Systems and Energy Economics, Ruhr-Universität Bochum, Germany), Valeria di Cosmo (Department of Economics and Statistics "Cognetti de Martiis", Università degli Studi di Torino), Laura Savoldi (MAHTEP Group, Department of Energy "Galileo Ferraris", Politecnico di Torino)*
11.15	Critical Minerals: Geopolitics, Security, and Balancing State-Market Dynamics *Vlado Vivoda (Rabdan Academy, UAE), Simon Lacey (World Economic Forum)*	Meeting an escalating Lithium-Ion Battery demand: Global Graphite Supply-Demand Scenarios *Francis Isidore Barre (IMPACT, NILU, Industrial Ecology Programme, Department of Energy and Process Engineering, NTNU), Romain Guillaume Billy (Industrial*

		Ecology Programme, Department of Energy and Process Engineering, NTNU), Fernando Lopez (Industrial Ecology Programme, Department of Energy and Process Engineering, NTNU), Daniel Beat Müller (Industrial Ecology Programme, Department of Energy and Process Engineering, NTNU)
11.30	National strategies to secure critical raw materials for high-tech industries of Korea *Min-Ha Lee (KITECH, CISAC, Stanford University)*	Unlocking the resources of end-of-life ICEVs: contributing platinum for green hydrogen production *Yanan Liang (CML, Leiden University), Rene Kleijn (CML, Leiden University), Ester van der Voet (CML, Leiden University)*
11.45	Current landscape and future prospects of the lithium in Bolivia *America Rocio Quinteros Condoretty (LUT University)*	Towards more reliable decision making via an enhanced composition model enabling recoverability asse *Kirsten Remmen (Empa), Manuele Capelli (Empa), Matthias Rösslein (Empa), Joana Francisco Morgado (Empa), Susanne Rotter (Technische Universität Berlin), Nathalie Korf (Technische Universität Berlin), Katharina Kippert (Technische Universität Berlin), Stewart Charles McDowall (Institute of Environmental Sciences (CML), Leiden University), Deepjyoti Das (Chalmers University of Technology), Maria Ljunggren (Chalmers University of Technology), Patrik Wäger (Empa)*
12:00	*Discussion, moderated by the session Chairs*	*Discussion, moderated by the session Chairs*
12.30	*Lunch and poster exhibition*	
14.00	Poster (incl. business ideas) speed-presentation	
14.30	**Keynote conversation i) Industry responses to supply chain risks** *Joseph Herzog (CM Aerospace, former GE), Hiroko Shinkai (Hitachi, Ltd.), Karol Bednarek (VDA); moderated by Luis Tercero, Fraunhofer ISI*	
15.15	*Coffee Break*	
15.45	**Session 3:** New forms of sustainable value creation *Chaired by Anders Sand (Boliden), Samuel Carrara (JRC), and Patrick Wäger (Empa)*	**Session 4:** Emerging sectors and materials *Chaired by Patrice Christmann (KRYSMINE), Min-Ha Lee (KITECH), and Magnus Ericsson (RMG Consulting)*

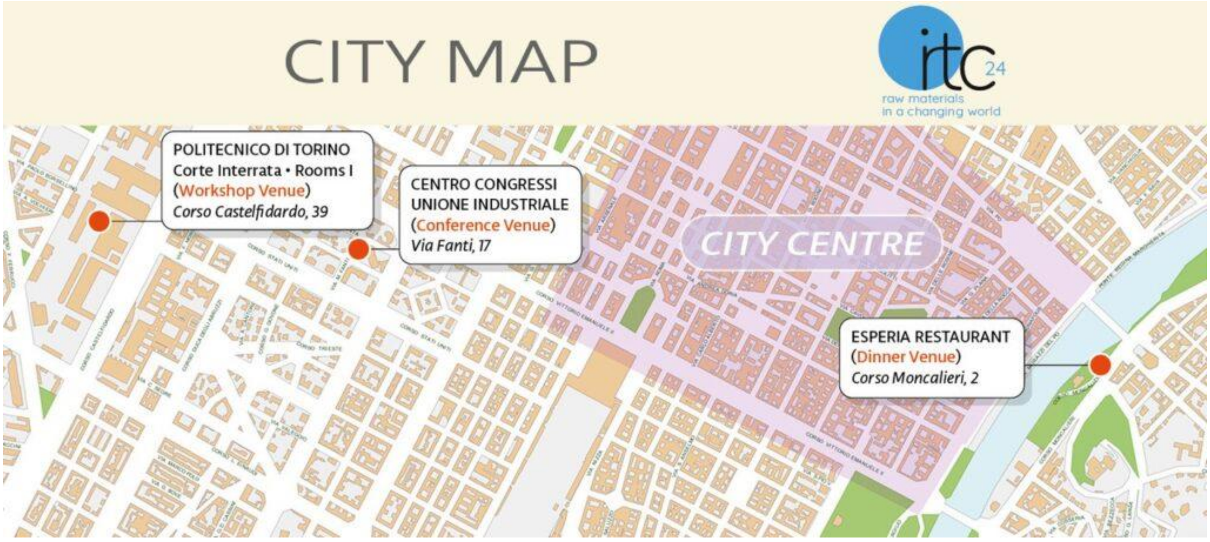
15.45	Circularity to reduce criticality from a primary supply perspective: micro to macro strategies *Eva Marquis (University of Exeter), Karen Hudson-Edwards (University of Exeter), Frances Wall (University of Exeter), Carol Pettit (University of Exeter)*	Circular Economy Research and Innovation (R&I) on Strategic Technologies *Brian Baldassarre (European Commission, Joint Research Centre), Alejandro Buesa (European Commission, Joint Research Centre), Paola Albizzati (European Commission, Joint Research Centre), Malgorzata Jakimów (European Commission, Joint Research Centre), Hans Saveyn (European Commission, Joint Research Centre), Samuel Carrara (European Commission, Joint Research Centre)*
16.00	Market strategies for scaling solar module recycling *Akanksha Tyagi (Council on Energy, Environment and Water, New Delhi, India), Neeraj Kuldeep (Council on Energy, Environment and Water, New Delhi, India), and Arzoo Kumari (Indian Institute of Technology Bombay)*	Next Generation batteries adoption: a survey-based study on users and experts' perspectives. *Alessandra Manzini A (Cleopa GmbH), Laura Martinez (Cleopa Gmbh), Pauliina Harrivaara (Cleopa Gmbh)*
16.15	The politics and sustainability of critical metals *Sampriti Mahanty (University College London), Frank Boons (University of Manchester, Maastricht University), Brian Baldassare (Joint Research Centre, European Commission), Riza Batista Navarro (University of Manchester)*	A descriptive study of innovativeness of Rare-Earth-Elements recycling sector based on patents *Marinella Favot (Area Science Park, Trieste), Riccardo Priore (Patlib - Area Science Park), Marco Compagnoni (University of Trento)*
16.30	Reducing primary critical raw materials through battery reuse & recycling in mining electrification *Maria Ljunggren (Division of Environmental Systems Analysis, Chalmers University of Technology), Harald Helander (Division of Environmental Systems Analysis, Chalmers University of Technology)*	Helium resource supply and demand shifts: Material flow analysis *Ankesh Siddhantakar (School of Environment, Enterprise and Development, University of Waterloo), Komal Habib (School of Environment, Enterprise and Development, University of Waterloo), Steven B. Young (School of Environment, Enterprise and Development, University of Waterloo)*
16.45	*Discussion, moderated by the session Chairs*	*Discussion, moderated by the session Chairs*
17.15	**Poster session**	
18:30	**Conference dinner**	

Friday, February 23

08.30	Coffee	
09.00	**Welcome and recap of day 1**	
09.15	**Update on the Critical Raw Materials Act** *Constanze Veeh, European Commission*	
09.30	**The evolution of the materials in the vehicles of the future: raw materials and new challenges** *Nello Li Pira, Stellantis*	
10.00	**Keynote conversation ii) Can we make do with less?** *Diego Marin (European Environmental Bureau), Tae-Yoon Kim (IEA), Astrid Wynne (Techbuyer Europe); Jean-Denis Curt (Renault);* *moderated by Dieuwertje Schrijvers, WeLOOP*	
10.45	**Coffee break**	
11.15	**Session 5:** New data and tools *Chaired by Peter Buchholz (DERA), Tatiana Vakhitova (Ansys), and Anthony Ku (Xiron Global)*	**Session 6:** New ideas on critical raw materials *Chaired by Yulia Lapko (Politecnico di Milano), Akanksha Tyagi (CEEW India), and Patrick d'Hugues (BRGM)*
11.15	Capabilities and limitations of AI Large Language Models (LLM) for materials criticality research *Anthony Ku (Xiron Global Ltd)*	How are critical raw materials different from a producer country's perspective? *Marianna Ottoni (SEED, Faculty of Environment, University of Waterloo), Komal Habib (SEED, Faculty of Environment, University of Waterloo), Steven B. Young (SEED, Faculty of Environment, University of Waterloo)*
11.30	Deconstructing nickel trade: a high-resolution material flow analysis of a critical supply chain *Marceau Cormery (Norwegian University of Science and Technology), Romain Guillaume Billy (Norwegian University of Science and Technology), Fernando Aguilar Lopez (Norwegian University of Science and Technology), Barbara Reck (Center for Industrial Ecology, Yale School of*	The Dark Sides of Sustainability: extractivism, global asymmetries and perspectives on transitions *Luíza Cerioli (University of Kassel)*

	the Environment), Daniel Beat Müller (Norwegian University of Science and Technology)	
11.45	The Economic Value Dissipation Potential method applied to a lithium-ion battery recycling process *Jair Santillán-Saldivar (BRGM), Emmanuelle Cor (Univ. Grenoble Alpes, CEA), Antoine Beylot (BRGM), Elise Monnier (Univ. Grenoble Alpes, CEA), Stéphanie Muller (BRGM)*	Technology-level supply disruption probabilities of RES and energy storage technologies *Steffen Schlosser (German Aerospace Center, Institute of Networked Energy Systems), Tobias Naegler (German Aerospace Center, Institute of Networked Energy Systems)*
12.00	Leveraging supplier material data to inform metal scarcity assessments in the automotive industry *Felipe Bitencourt de Oliveira (Chalmers University of Technology, Volvo Car Corporation), Anders Nordelöf (Chalmers University of Technology), Maria Bernander (Volvo Car Corporation), Björn Sandén (Chalmers University of Technology)*	From catch-up to forging ahead through (green) windows of opportunity: China and the REEs *Mihaela Gaglioti Roibu (Copenhagen Business School, Department of Organization), Stine Haakonsson (Sino-Danish Center)*
12.15	*Discussion, moderated by the session Chairs*	*Discussion, moderated by the session Chairs*
12:45	*Lunch & poster prize*	
14:00	Session recap by the session Chairs	
14.30	Skills required for the future: learnings from the conference	
14:45	Conference closing	
15.00	Farewell coffee	
15.30	Rooms available for individual meetings (on demand)	

Locations



Centro Congressi Unione Industriale

The conference sessions will be hosted at the Centro Congressi Unione Industriale located 10 minutes from the city's most important railway stations, Porta Susa and Porta Nuova.

Public Entrance: Via Vincenzo Vela, 17

Politecnico di Torino

Pre- conference workshops will be held at the Rooms I (Corte Interrata area) of the Politecnico Campus Cittadella.

Pedestrian access at corso Castelfidardo 34/A

February 20

IRTC Training, starting at 10 am: Sala Riunioni DIATI 3, Politecnico di Torino, Corso Castelfidardo, 39

February 21

	Politecnico di Torino					Centro Congressi Unione Industriale			
	Welcome area	Room 1	Room 3	Room 5	Room 7	Welcome area	Rooms Piramide and Torino	Room Giovanni Agnelli	Historic rooms
9.00	Registration and coffee								
10.00		Workshop A	Workshop B	Workshop C	Workshop D				
12.00	Lunch Buffet								
13.00		Workshop E	Workshop F	Workshop G	Workshop H				
15.00						Conference registration	Coffee break		
16.00								Plenary discussion	
17.45									
18.30									Apéro-dinner

February 22

	Centro Congressi Unione Industriale			
	Welcome area	Rooms Piramide and Torino	Room Giovanni Agnelli	Room Piemonte
8.00	Registration	Coffee		
9.00			Introductory remarks by the conference organizers	
9.15			Welcome	
9.30			Opening speech by Bernd Schäfer	
9.45			Keynote speech by Edson Krenak	
10.15			Session presentations by the conference Chairs	
10.30		Coffee break		
11.00			Session 1: Emerging raw materials policies and their impacts	Session 2: Forecasting CRM supply and demand
12.30		Lunch and poster exhibition		
14.00			Poster speed-presentation	
14.30			Keynote conversation i) Industry responses to supply chain risks	
15.15		Coffee break		
15.45			Session 3: New forms of sustainable value creation	Session 4: Emerging sectors and materials
17.15		Poster Session		

18.30: Bus service from Centro Congresso Unione Industriale to Conference Dinner Esperia Restaurant, Corso Moncalieri 2

February 23

	Centro Congressi Unione Industriale		
	Rooms Piramide & Torino	Room Giovanni Agnelli	Room Piemonte
8.30	Coffee break		
9.00		Welcome and recap of day 1	
9.15		CRMA update	
9.30		Industry intervention	
10.00		Keynote conversation ii) Can we make do with less?	
10.45	Coffee break		
11.15		Session 5: New data and tools	Session 6: New ideas on critical raw materials
12.45	Lunch & poster prize		
14.00		Session recap by the session Chairs	
14.30		Skills required for the future: learnings from the conference	
14.45		Conference closing	
15.00	Farewell coffee		

IRTC Training course

This course, organized by the IRTC Training team, and taught by Luis Tercero, Dieuwertje Schrijvers and Alessa Hool. This single-day introductory program covers the fundamentals of criticality and the evaluation of critical raw materials, providing essential background to profit the most from the conference. We take a deep dive into the EU assessment methodology and participants learn about its composition, factors, indicators, and common data sources. After the course, you will have an insight into the considerations behind criticality assessments, and be able to reproduce a standard procedure of a EU criticality assessment for a given material. We also analyze and discuss evolving CRM policies such as the EU Critical Raw Materials Act and their impact on critical raw materials and their management.

Workshops

The workshops are 2-hour events independently organized by various teams and have different formats such as panel debates, presentation series, and open discussions.

Wednesday February 21 – 10.00

Workshop A: Research needs to support policies on critical and strategic raw materials: a workshop organized by the Joint Research Centre

Organized by Fabrice Mathieux, Umberto Eynard, and Thibaut Maury (Joint Research Center)

Resources and Materials criticality had grown up in importance across the globe in recent years and various regions and countries have developed their own list of Critical Raw Materials. Recently, Critical Raw Materials have also been addressed by an increasing number of policies. In the EU for example, the European Commission launched a Critical Raw Materials Act proposal in March 2023, and this contains various provisions and targets in various domains, including strategic projects, enabling conditions, risk monitoring and mitigation, but also on circularity and environmental footprint. Similarly, circularity of key critical raw materials is being addressed by other pieces of legislation such as the battery regulation (e.g. lithium, cobalt) and the vehicle circularity proposal (e.g. permanent magnets). Many other ambitious initiatives on Critical Raw Materials exist in other regions of the world. In the upcoming years, these dynamic global policy developments based on innovative provisions will require substantial technical backing and science-for-policy support. This workshop aims at identifying and discussing with the community knowledge gaps and requirements for scientific advancements related to these policy developments, with a specific focus on circularity and sustainability. Contributions from policy makers, industry (including recyclers) and academia are welcome to address knowledge gaps, for example concerning data, metrics, tools, harmonization schemes. The workshop will be made up of 6 short pitch-style presentations (by Jørgen Hanson, Hydro; Gyslain Ngadi Sakatadi, Politecnico Di Torino; Rikarnto Bountis, EuRIC; Fiorenzo Fumanti, Istituto Superiore per la Protezione e la Ricerca Ambientale; Daniel Beat Müller, NTNU; Akanksha Tyagi, CEEW), followed by a structured discussion. Ideally, the discussion will lead to an initial draft of a research agenda on science-for-policy for the years to come, agreed by various global participants.

Full workshop A description

Wednesday February 21 – 10.00

Workshop B: Technical aspects of REE mining and processing

Organized by Alain Rollat (Carester)

This workshop gathers leading experts at every stage of the magnetic value chain, from REE mining, radioactivity management, separation, metal making, and magnet manufacturing. Each expert will have a presentation of 15 minutes about the current situation in the respective step, discussing challenges and proposing ways to improve the existing processes. Expert speakers include Frances Wall, University of Exeter; Dato H' K Sia, Malaco Mining; Albert Slot, Less Common Metals; and Oliver Gutfleisch, University of Darmstadt. The presentations will be followed by a 30-minute discussion with the audience. The workshop results will inform a factsheet about current challenges and possible solutions in the magnet value chain.

Full workshop B description

Wednesday February 21 – 10.00

Workshop C: What is responsible mining?

Organized by Paul Ekins (UCL)

Everyone these days is calling for 'responsible', and sometimes 'sustainable' mining. But what do these terms mean in real terms? How would mining change if they were to become a reality? And who is going to lead and implement that change? The industry, governments, civil society – all clearly have a role, but who is going to lead the change? This workshop four speakers to explore these critical questions: Helene Piaget, who led the Responsible Mining Index; Lee Mudenda, from the Copperbelt University in Zambia; Murtiana Hendriwardani from the Intergovernmental Forum on Mining, Metals and Sustainable Development, and Fabiana Di Lorenzo from the Responsible Minerals Initiative. The workshop will be moderated by Professor Paul Ekins of University College London.

Full workshop C description

Wednesday February 21 – 10.00

Workshop D: Critical Youth in the Raw Materials Environment

Organized by Bianca Neumann (RMYMG), Ghadi Sabra (RMYMG), Francisco Veiga Simão (EIT RawMaterials Alumni), and Dhruv Warrior (CEEW India)

In today's rapidly evolving world, innovation plays a pivotal role in shaping the future of various industries and societies. The conference session, "Critical Youth in the Raw Materials Environment" focuses on the indispensable contribution of youth in fostering innovation and addressing the challenges associated with supply and demand of critical raw materials. By involving young individuals from academia, industry, and governance, this session aims to explore the unique perspectives and fresh ideas that the youth bring to the table and, consequently, to their future. This session will provide a platform for dynamic discussions, knowledge sharing, and the exchange of ideas between academia, industry, civil society and governance, with a specific focus on engaging the youth through young leaders. The workshop will consist of a selection of four young representatives that bring their unique perspective from academia, industry, civil society and governance and give them the opportunity to

showcase their innovative and entrepreneurial journeys in front of an expert audience, including Ali Hassan (FreeMountain Consultancy/EIT RawMaterials Alumni), Eva Marquis (University of Exeter), and Léane Verhulst (BRGM).
Full workshop D description

Wednesday February 21 – 13.00

Workshop E: Emerging sustainability standards

Organized by Luisa Moreno (Tahuti Global) and Harikrishnan Tulsidas (UNECE)

The world is changing rapidly, as are the expectations and demands for sustainability in the raw materials sector. Emerging sustainability standards, such as UNRMS, GRI, SASB, ICMM principles, TSM, ISO, IRMA, ASI, Copper Mark, and others, are creating new challenges and opportunities for resource management. How can we adapt and thrive in this changing environment? How can we ensure our raw materials are sourced, processed and used responsibly and efficiently? How can we align and harmonize the different standards and initiatives in the sustainability field? This workshop will explore these questions by providing an overview of the emerging sustainability standards and their implications for the raw materials sector. It will also showcase best practices and examples of how these standards are implemented and applied in different contexts and regions. The workshop will also facilitate a dialogue among the participants, including representatives from governments, industry, academia, civil society and international organizations. The workshop will identify the key challenges and opportunities for achieving sustainability excellence in the raw materials sector and the potential synergies and collaborations among stakeholders.
Full workshop E description

Wednesday February 21 – 13.00

Workshop F: Sustainable Finance and Raw Material Value Chains – Friends or Enemies?

Organized by Antonella Amadei (independent consultant), Jana Plananksa (Norge Mining), and Tom Dunlap (DIACSUS)

To fulfil the goals of green and digital transition, the demand for critical raw materials (CRMs) is expected to massively grow upwards of 500% by 2050, according to the World Bank. Being constitutive elements of clean technologies from solar panels and electric motors to batteries and electronic devices, their supply will have to massively scale up, first from primary resources. However, there are real challenges to make this happen. New mining operations are very capital intensive with long lead times and with potentially adverse environmental and social impacts. A next generation of companies along the entire CRM value chain, from exploration and mining to processing and recycling, is emerging both in Europe and globally, aiming to make contributions to global goals and clean energy transition while adhering to the highest ESG standards in their operations. How should the investment community approach these new actors and developments? What would it take in terms of ESG assessment, data quality, regulations, and societal perceptions to turn these plans into reality and in turn help achieve the goals of green and digital transition? Join this focused workshop to learn experts' thoughts and views on these questions and others.
Full workshop F description

Wednesday February 21 – 13.00

Workshop G: Policies on strategic industries

Organized by Min-Ha Lee (KITECH), Andrew Grotto (Stanford University), Alan Hurd (Los Alamos National Laboratory), Ryan Ott (Ames National Laboratory), and Evangelia Moschopoulou (NCSR Demokritos)

This workshop is focused on the geopolitical approaches of industrial and regulatory policies for critical raw materials and supply chains to support the strategic industries. Through interactive panels and talks, we will explore goals and deliverables for strategic perspectives on digital technologies, such as A.I, and we will handle the geopolitics of sustainable technologies with applied industrial policy for critical raw materials and supply chains, including lesson from current worldwide regulations. Expert speakers include Thomas Lograsso, Ames Laboratory; Soctt McCall, Lawrence Livermore National Laboratory; and Allison Bennett-Irion, Argonne National Laboratory.
Full workshop G description

Wednesday February 21 – 13.00

Workshop H: A new run on Africa and South America: sharing raw materials value chains

Organized by Claudia Baranzelli (OECD) and Carlos Peiter (CETEM)

Critical raw materials are at the centre of the political agenda of the vast majority of countries worldwide and at the core of the on-going energy and digital transitions. On the one side, mineralsuser countries are increasing their efforts to promote secure and robust critical minerals supply chains, as they acknowledge their external dependence for both raw materials supply and their industrial processing. On the other side, there is a huge international pressure to multiply the output of the mining sector for a number of minerals, so mining countries are formulating strategies to leverage their critical minerals resources and expand their role in the global value chains for critical minerals. This workshop focuses on the experience of countries from Africa and South America, and explores questions related to national mineral policies targeting critical and strategic raw materials, trade objectives, and international agreements.
Full workshop H description

Open plenary discussion: "Mutually beneficial"? Creating value in cross-country cooperation

February 21, 16.00 Room Giovanni Agnelli

Murtiani Hendriwardani (Intergovernmental Forum on M

inerals, Metals and Mining), Harmony Musiyarira (Namibia University of Science and Technology), Paul Ekins (International Resource Panel), Stéphane Bourg (OFREMI), tbc (CBMM), tbc (European Commission, DG INTPA), tbc; moderated by Claudia Baranzelli, OECD

In the opening plenary discussion, stakeholders from different nations, organizations, and backgrounds will discuss their views on what they consider mutually beneficial agreements on critical raw materials supply, and potential new forms of collaboration.

Keynote conversations

These 45-minute events are moderated discussions between three experts.

February 22, 14.30	Room Giovanni Agnelli

Industry responses to supply chain risks

Joseph Herzog (CM Aerospace, former GE), Hiroko Shinkai (Hitachi, Ltd.), tbc; moderated by Luis Tercero, Fraunhofer ISI

The conversation will cover questions such as: How do industries react to current supply risks? How does the current international competition for resources influence them? What are examples of industry responses and why were they taken? What are outlooks for the future?

February 22, 10.00	Room Giovanni Agnelli

Can we make do with less?

Diego Marin (European Environmental Bureau), Tae-Yoon Kim (IEA), Astrid Wynne (Techbuyer Europe); moderated by Dieuwertje Schrijvers, WeLOOP

Criticality mitigation strategies focus almost exclusively on the supply side – but what about the demand side? How can we reduce demand by circular economy, material efficiency, sufficiency, and/or new economic approaches?

Cross-sectional topic: Skills needed for the future

Led by Jan Eggert (EIT RawMaterials), David Peck (TU Delft/UCL) and Eleonora Brighenti (Dana Motion Systems) in collaboration with the session Chairs

One of the topics we will explore during the conference is the impact of new policies and increased domestic sourcing on required skills and competencies. This will encompass not only the technical skills required for advancing mining and recycling technologies but also the workforce needed to effectively implement these innovations and ensure compliance with new regulations. We will delve into questions surrounding the adaptation of these new skills into existing educational frameworks and identify areas where up-skilling and re-skilling may be necessary to meet evolving demand. During the conference, we aim to consolidate insights on such required skills from the various workshops and sessions, creating a comprehensive overview of the findings.

Scientific sessions – Oral presentations

Each session will consist of four 15-minute presentations, followed by a 30-minute discussion session with the presenters, which will be moderated by the Session Chairs.

Session 1: Emerging raw materials policies and their impacts

Chaired by Rod Eggert (Colorado School of Mines), Weiqiang Chen (Chinese Academy of Sciences), and Karen Hanghøj (BGS and UNECE Expert Group for Resource Management)

The global landscape of raw material strategies is evolving rapidly as nations seek to master the green transition, secure their supply chains, maintain economic stability, and address sustainability challenges. This session aims to explore the diverse approaches, their associated challenges and opportunities, and how they impact stakeholders and market dynamics. Topics of interest include categories of critical and strategic raw materials and the effects of these classifications, ambitions to strengthen economic security, undertakings to increase transparency and sustainability and their effects, and how new policies influence resource security, innovation, sustainability, and global collaboration. We welcome contributions from a broad range of stakeholders, including researchers on policies from academia, think tanks and private institutes, international organizations, government representatives, and affected stakeholders.

Thursday February 22 -- 11.00

Global race to secure mineral supply chains: Collaboration, Competition, or Inequity?

<u>Kriti Shah</u> (India ZEV Research Centre, ITS, UC Davis), Shivani (India ZEV Research Centre, ITS, UC Davis)

With the rapid deployment of both electric vehicles and renewable energy technologies, the demand for critical minerals like Lithium, Cobalt, Nickel, Graphite and Manganese has risen at an accelerated scale. As the spatial distribution of these minerals is wide yet concentrated, various countries worldwide are now reliant on a few minerally endowed nations. While many Global South countries have recognized the role of critical minerals in their clean energy transitions, there are two distinct themes emerging: 1. Producer countries (mineral endowed such as Chile or Zambia) have prepared critical mineral strategies which are essentially industrial policy approaches in the short to medium term. 2. Consumer countries (import dependent, such as India) are still in the early stages of developing a comprehensive strategy to secure critical minerals, causing them to lag behind Global North countries such as the US, UK and other EU nations. In theory, resource-rich countries should have the opportunity to control these value chains, but much is defined by economic and geopolitical power. This has resulted in increased geopolitical tension, supply chain insecurity, and changing foreign policy.

Our study identifies ten G20 member countries and the European Union because of their role in global critical mineral supply chains. Based on how they define critical minerals, we analyzed their national plans and strategies, along with their international collaborations to build secure and resilient critical mineral supply chains. Through the analysis, we found several common and differing themes at the cross-section of countries based on their economic development status (i.e., advanced or emerging) and their resource endowment (producer or consumer). Emerging economies are still evolving in their roles in global mineral value chains. They are yet to: a) Ramp-up mining and processing; and b) Develop their own critical mineral strategies to enable resource-security and manage their energy transitions.

On the other hand, most advanced economies began collaborative efforts to secure critical minerals in 2009. The first major agreement with an emerging economy was signed in 2020, between the European Union and Namibia, after which there have been a series of mineral-related economic partnerships amongst various countries. We further analyzed policy actions taken by different countries as a response to their critical mineral strategies, via trade, international cooperation, and protectionism, among others. Based on this, our study answers three key questions: (i) what is the nature of critical mineral-related international collaboration and agreements? (ii) what is the distinction between collective strategies and approaches towards critical minerals by advanced and emerging economies?; (iii) how does this impact the shared global priority to build secure and resilient mineral supply chains for an equitable energy transition?

Thursday February 22 – 11.15

Critical Minerals: Geopolitics, Security, and Balancing State-Market Dynamics

<u>Vlado Vivoda</u> (Rabdan Academy, UAE), Simon Lacey (World Economic Forum)

In this era of rapid technological change and geopolitical flux, critical minerals have become pivotal for national security, economic prosperity, and technological advancements, from renewable energy to military applications. This paper scrutinizes global raw materials policies, emphasizing their impacts on national security and the delicate balance between state control and market freedom. Using diverse case studies, the paper explores how nations adjust their strategies in response to the growing scarcity and strategic importance of critical minerals. It delves into the dynamics of state versus market, investigating how governments manage the balance between ensuring mineral security, fostering market efficiency, and protecting national interests. A particular focus is placed on the role of international trade obligations, including WTO rules, Free Trade Agreements (FTAs), and bilateral trade agreements. The principles of non-discrimination, avoidance of quantitative restrictions, and least trade restrictiveness of technical regulations are examined for their impact on raw materials policies and practices. The paper argues for a balanced and resilient approach, highlighting the need for innovative policies, international cooperation, and a redefined role for the state in the critical minerals sector. The aim is to contribute to the ongoing discourse on raw materials policies, providing insights and actionable recommendations for policymakers, industry stakeholders, and the academic community.

Thursday February 22 – 11.30

National strategies to secure critical raw materials for high-tech industries of Korea

<u>Min-Ha Lee</u> (KITECH, CISAC, Stanford University)

While Europe is progressing on the details of the Critical Raw Materials Act which released in March 2023, a month earlier, the Korean Ministry of Trade, Industry and Energy (MOTIE) had announced new national strategies for securing strategic minerals for Korea in February 2023.

The Korean government has selected 33 core minerals such as copper and tungsten that needs managing in terms of economic security. Among them, it will intensively manage ten strategic core minerals such as lithium, nickel, and rare earths which are essential to production of semiconductors, secondary batteries, and electric vehicles, will be managed first and foremost.

The necessity for securing these minerals is motivated by the rapid increase in demand for them due to global carbon neutrality pledges and industrial paradigm shifts, growing uncertainties caused by high supply concentration and increased resource weaponization, and the need to secure key minerals for a sustainable development of the domestic high-tech industry as well as to lower dependence on foreign sources for core minerals.

Therefore, Korea's national supply of strategic minerals shall be stabilized by reducing import dependence on them from 80 to 50 percent, and increasing recycling rates from 2 to 20 percent by 2030. New national strategies include an increase of international resource cooperation, the expansion of stockpiles, and the establishment of an early warning system.

The author will introduce recently announced national strategies for securing critical raw materials to support high technology industries of Korea. The strategic plans of 10 core strategic minerals and total 33 minerals are assessed as being critical for future of Korea.

Thursday February 22 -- 11.45

Current landscape and future prospects of the lithium in Bolivia

America Rocio Quinteros-Condoretty (LUT University)

Renewable energy sources and their associated technologies, notably electric vehicles, play an important role in mitigating the impacts of climate change. Nevertheless, these technologies required a heightened demand for mineral resources such as lithium. At present, Bolivia stands as the global leader in lithium resources estimated at 23 million tonnes. Bolivia distinguishes itself as a pioneer country in following a different lithium mining approach by keeping lithium mining under full state control, through the State-Owned Enterprise (SOE) Yacimientos de Litio Bolivianos (YLB) allowing foreign investment only for the industrialization of lithium. Therefore, this paper investigates the dynamics generated within a lithium SOE operating in a mineral-rich developing country, with a specific focus on the Bolivian case, to unpack the main components generated by the Paris Agreement towards lithium battery production and electrical vehicles. This research is an empirical qualitative case study that explores the primary achievements and challenges of the Bolivian industrialization project of lithium. For this, qualitative data were collected through semi-structured interviews with different actors. The paper discusses the present status, and future perspectives within the Bolivian context, concluding by highlighting regulatory and managerial implications.

Session 2: Forecasting critical raw materials supply and demand

Chaired by Constanze Veeh (DG GROW, European Commission), Paul Lusty (Fastmarkets), and TaeYoon Kim (IEA)

This session seeks to delve into forecasts on critical raw material supply and demand, shedding light on the equilibrium between the availability and necessity of essential raw materials. We aim at presentations of study results, time frames, perspectives on scenario modelling, as well as insights on pivotal parameters and their consequential impacts on predictive analyses. Another topic of interest includes ways to enhance the availability of reliable data and harness the potential of digital tools to enable better market projections. We look forward to submissions from international organizations conducting forecasting, academics in the field, commercial providers, consulting companies, and others.

Thursday February 22 -- 11.00

Combined assessment of energy and material supply risks: a multi-objective energy system optimization

<u>Gianvito Colucci</u> (MAHTEP Group, Department of Energy "Galileo Ferraris", Politecnico di Torino), Valentin Bertsch (2), Valeria Di Cosmo (3), Laura Savoldi (MAHTEP Group, Department of Energy "Galileo Ferraris", Politecnico di Torino)

This work proposes a methodology to compare energy and material supply risks (SRs) using energy system models (ESMs) with multi-objective optimization (MOO) to analyze possible trade-offs between them. Indeed, on the one hand, the transition to renewable energy technologies is decreasing the fossil fuel import dependency that many countries have been suffering until today; on the other hand, such technologies are much more mineral-intensive than fossil-based ones. They may therefore be affected by possible bottlenecks along the entire supply chain, from raw materials extraction and processing to components assembly. All these steps have been considered "critical" worldwide in an increasing number of analyses, and policymakers are starting to be concerned, promoting new devoted policies. In this regard, ESMs represent suitable tools to test their effectiveness, but some research gaps exist concerning critical raw materials (CRMs) and technology supply chain assessments. Despite the number of studies evaluating future material requirements increases, such studies are usually done ex-post starting from already available energy transition scenarios and only consider geological availability as a criticality issue. A few studies propose instead ex-post SR assessments, while to the authors' knowledge, no endogenous analyses are present that include material criticality terms in the optimization, meaning that current global and regional energy scenarios are not affected by potential risks concerning CRMs supply chains. That makes this work among the first-of-a-kind assessments of energy and material SRs in a multi-objective energy system optimization. The proposed methodology involves the consistent definition of the just-mentioned SRs for a reference energy system (that is described in terms of technologies and commodities) as two separate objective functions to be used in a MOO, that include risk indicators both at commodity and technology level. The adopted material commodity SR is based on well-established criticality methodologies, while an energy commodity SR was consistently derived from literature. Then, for each technology included in the analyzed energy system, the commodity SRs are aggregated to calculate material and energy technology SR indicators, by using specific material and energy consumptions. The trade-offs between system material and energy SRs, costs, and CO_2 emissions were studied through MOO optimization for a case study developed within the open-source TEMOA framework, providing insights about technology competitiveness in terms of energy security.

Thursday February 22 -- 11.15

Meeting an escalating Lithium-Ion Battery demand: Global Graphite Supply-Demand Scenarios

Francis Isidore Barre (IMPACT, NILU, Industrial Ecology Programme, NTNU), Romain Guillaume Billy (Industrial Ecology Programme NTNU), Fernando Aguilar Lopez (Industrial Ecology Programme, NTNU), Daniel Beat Müller (Industrial Ecology Programme NTNU)

The decarbonization of the transportation sector relies on electric vehicles (EV), mainly equipped with Lithium-Ion Batteries (LIB). The primary anode material in LIBs is graphite, usually a mix of natural (from mines) and synthetic (graphitized from a carbon precursor, usually needle coke) graphite. The rapid penetration of LIBs and increased graphite demand can disrupt the natural and synthetic graphite value chains and increase supply risks.

A parametric material flow analysis model was developed to describe and quantify the flows in the graphite value chain and its use in LIBs. Several demand and supply scenarios were developed for the period 2020-2050. Demand parameters comprise vehicle ownership, size of vehicles, EV penetration, battery chemistries, recycling technologies and the share of natural versus synthetic graphite in batteries. Parallelly, a model of petroleum refineries was developed to quantify the maximum theoretical supply of needle coke in the different scenarios and compare it with the demand. Uncertainties were calculated with Monte Carlo simulation.

The range of the demand for graphite ore and needle coke varies greatly between the scenarios, with 1.3 to 25.7 Mtons/year of graphite ore and 3.9 to 22.3 Mtons/year of needle coke in 2050 in the six selected scenarios. The maximum theoretical supply for needle coke varies from 3.6 to 39.1 Mtons/year depending on EV penetration and flexibility in refineries. The study revealed that the dependence of LIB production on the extraction of hydrocarbons leads to supply constraints for synthetic graphite: in scenarios with fast EV penetration, less petroleum is required by the transportation sector, and the supply of needle coke is limited. On the other side, graphite ore is abundant, but the lack of infrastructure and development time makes it unlikely to see its supply keep up with the galloping demand. The contribution of recycling to substitute primary production is limited: little scrap is available in the short term and recycling rates are constrained by the lack of understanding of the ageing mechanisms of graphite in LIBs.

Supply risks can only be mitigated by combining the most efficient recycling techniques with societal changes, such as lower vehicle ownership and smaller vehicles and batteries. If there exist large uncertainties on the development of alternative battery chemistries, the role of non-petroleum carbon precursors or the potential of graphite recycling, this study highlights that the criticality of anode materials should benefit from wider attention from both the scientific community and policymakers.

Thursday February 22 -- 11.30

Unlocking the resources of end-of-life ICEVs: contributing platinum for green hydrogen production

Yanan Liang (Institute of Environmental Sciences (CML), Leiden University), Rene Kleijn (Institute of Environmental Sciences (CML), Leiden University), Ester van der Voet (Institute of Environmental Sciences (CML), Leiden University)

Green hydrogen, produced by electrolysis of water using renewable electricity, is an attractive alternative to fossil fuels in applications where direct electrification is impractical. Proton exchange membrane (PEM)-water electrolyzers are recognized as a promising technology for achieving high purity and efficient hydrogen production, and their installation is expanding. As a result, the demand for materials used in the manufacture of PEMs has climbed. These include the coatings on the bipolar plates and the cathode material, platinum (Pt). Conversely, Pt, which presently serves primarily as a catalyst material for internal combustion engine vehicles (ICEVs), is expected to become a potential resource as ICEVs come off the road. Here, we simulate the Pt requirements for rapid scale-up of PEM electrolyzers under the IEA-NZE scenario. We also compare these requirements with the availability of Pt derived from scraped catalysts used in ICEVs. Our results show that (1) PEM electrolyzers will increase Pt demand dozens of times over the next decade; (2) ICEV catalysts will cumulatively scrap ~2500 tons of Pt over the next 3 decades; (2) the surplus of Pt from ICEV catalysts can meet the increasing demand for Pt for green hydrogen production from 2030 onwards. These findings offer fresh insights on how to exploit the potential of these urban mines to meet the challenges associated with the energy transition.

Thursday February 22 -- 11.45

Enhanced composition model towards more reliable decision making enabling recoverability assessment

Kirsten Remmen (Empa), Manuele Capelli (Empa), Matthias Rösslein (Empa), Joana Francisco Morgado (Empa), Susanne Rotter (Technische Universität Berlin), Nathalie Korf (Technische Universität Berlin), Katharina Kippert (Technische Universität Berlin), Stewart Charles McDowall (CML, Leiden University), Deepjyoti Das (Chalmers University of Technology), Maria Ljunggren (Chalmers University of Technology), Patrik Wäger (Empa)

The effective management of raw material supply and demand requires reliable and complete information, as well as foresight on Secondary Raw Material stocks and flows throughout their life cycles. Therefore, having knowledge about the availability and recoverability of Secondary Raw Materials is crucial, especially for Critical Raw Materials (CRMs) as defined by the EU. The Horizon 2020 project ProSUM led to the creation of the Urban Mine Platform (www.urbanmineplatform.eu), a valuable resource that includes end-of-life vehicles (ELV) and other Secondary Raw Material composition data sets. As a part of the Horizon Europe project FutuRaM, we are extending the existing composition data model, initially established during the ProSUM project and expanded upon in a JRC report concerning ELV composition. Through the application of a combined top-down and bottom-up approach, the model is being broadened to incorporate more in-depth information. This expansion focuses specifically on the materials and alloys used. Furthermore, additional emphasis is placed on strengthening the data sets and the data model for electric vehicles.

The objective of this work is to create generic composition datasets for vehicles, including their components, materials, and elements. Within the FutuRaM composition data model, the aim is to link each element of interest to a specific material defined within the project. Consequently, these datasets will provide not only information on CRM content but also comprehensive details about used materials, particularly metal alloys. This approach allows for a more detailed assessment of recoverability, going beyond the limitations of the current mass-based indicators. Therefore, the updated dataset has a potential to support policy interventions, with regard to element-/material-specific indicators. Additionally, the model is designed to facilitate straightforward updates, seamlessly incorporating new data, such as potentially emerging information from upcoming product-centric reporting such as the Digital Product Passport or other databases. Furthermore, the use of ontologies to structure the existing composition data is explored by extending the defined taxonomy with additional relationships and concepts to provide a more descriptive representation of the domain.

In this contribution, we will showcase the FutuRaM composition model using ELV as an example and demonstrate how future scenarios can be incorporated. We will illustrate how this approach could support informed decision making regarding the recovery of Secondary Raw Materials and CRMs from waste, thus contributing to advancing the understanding of resource management for industry, policymakers, and researchers.

Session 3: New forms of sustainable value creation from CRMs

Chaired by Anders Sand (Boliden), Brian Baldassarre (JRC), and Patrick Wäger (Empa)

This session aims to provide insights into novel and/or unconventional forms of value creation from extraction and production related to critical raw materials. These may include new and early-stage ideas, as well as established processes. Focus is placed on a wide range of topics, including but not limited to: innovative business models, technical innovations in the mining and recycling sector, sustainability and circularity aspects, alternative forms of value creation through material byproduction and valorization from wastes, and substitution. We invite contributions from academic and research institutions, as well as innovative industry players, start-ups, and collaborative projects.

Thursday February 22 – 15.45

Circularity to reduce criticality from a primary supply perspective: micro to macro strategies

Eva Marquis (University of Exeter), Karen Hudson-Edwards (University of Exeter), Frances Wall (University of Exeter), Carol Pettit (University of Exeter)

Circularity strategies are advocated as a mechanism to enhance critical raw materials (CRM) security in Europe (European Commission, 2023). They can potentially reduce import reliance and thus decrease supply risk by having domestic/localised cycling of key metals and materials. Gaustad et al. (2018) and Cimprich et al. (2023) explore how circularity strategies can alleviate criticality in commercial (downstream) settings.

Circular Economy (CE) principles-based systems may initially appear to contradict continuation of a primary raw materials extractive sector. However, there is a growing body of research examining the development of CE practices in the mining industry, in order to increase resource efficiency by understanding better potential co- and by-products, more efficient extraction and processing, and use/re-use of waste products. Thus, there are multiple ways CE principles could apply to metals and minerals production, with variable scales of application from micro (components, products, individual enterprises), meso (eco-industrial parks, regional-level) and macro (entire economy). A set of CE principles have been developed through our research in the Met4Tech Centre (Wall et al., 2022) and these are being explored using novel geo-models of mining/production systems for critical minerals in the UK and Zambia.

Demand for many CRMs is increasing rapidly as production of EVs, renewable energy and other digital technologies ramps up to meet climate change targets. For many energy-transition metals, some not previously extracted at scale, there will be an intensification in mining and thus an increase in mine waste generation (Valenta et al., 2023). Such mining intensification and associated waste can strain environmental and social systems and increase risks to project development and by extension CRM supply. Adopting more circular approaches can help alleviate these pressures, at both micro and macro scales.

In this contribution, we provide a review of circularity practices proposed at different scales in the extraction of critical metals and discuss the potential opportunities and challenges arising from this approach.

Thursday February 22 – 16.00

Market strategies for scaling solar module recycling

Dr Akanksha Tyagi (Council on Energy, Environment and Water), Neeraj Kuldeep (Council on Energy, Environment and Water), and Arzoo Kumari (Indian Institute of Technology Bombay)

Clean energy technologies such as solar, wind and batteries are the basic building blocks of a net-zero future. IEA's net-zero analysis shows that solar capacity must increase at least 20 times between 2020 and 2050. Therefore, the production of minerals that go into these modules, such as silicon, copper, and aluminium, has to increase significantly, necessitating increased exploration. However, analysis shows that for metals such as copper, the availability of global reserves has remained constant over the last seven years. Furthermore, the current production of metals such as copper is already more than 2% of the global reserves. These insights suggest that alternate avenues are needed to meet the rising demand. Recycling the waste solar module to recover various materials, also called urban mining, is one such strategy. It's a fact that as solar deployment increases, the world will also be witnessing vast volumes of waste modules which have reached the end of their useful life. Hence, recycling modules, and generally, a truly circular economy, will solve the dual issues of resource adequacy and environmental pollution.

Solar module recycling is still an emerging industry which needs active collaboration between producers, recyclers, and policymakers. Some of the challenges grappling the sector are nascent recycling technologies, waste volumes (including reverse logistics), policy guidance and so on. The recyclers understand the explicit revenue potential of this industry but are sceptical of the various challenges and risks. The sector needs innovative market strategies, such as business models, to guide investment decisions.

This research work intends to abridge this decision-making gap. Based on the extensive stakeholder discussions with technology providers (recyclers, academia, start-ups) and manufacturers, as bulk consumers of solar projects, we have identified the bottlenecks to commercialise solar module recycling. We supplement this information with an extensive literature review and key information interviews (KII) with the operational recycling facilities to compile the best practices and learnings across the globe. These learnings are used to arrive at some market strategies that the key stakeholders can refer to for enabling a recycling industry. These include innovative business models, financing mechanisms, plausible partnerships and collaborations, and fiscal and non-fiscal support from the government. Such information shall inform decision-making by the industry and accelerate sectoral progress.

Thursday February 22 – 16.15

The politics and sustainability of critical metals

Sampriti Mahanty (University College), Frank Boons (University of Manchester, Maastricht University), Brian Baldassare (Joint Research Centre, European Commission), Riza Batista Navarro (University of Manchester)

Over the last few years, there are numerous critical metal policies that have been released that indicate policy response in managing the supply of critical metals. In parallel, there is an increasing body of literature (both academia and grey) that indicates the need to focus on the sustainability and responsibility of critical metals among many other sectors. On the surface, the policy response to secure critical metals and the literature on sustainability beg for similar outcomes i.e., securing an uninterrupted supply of critical raw materials either through primary extraction or through routes of circulation. However, we observe a pattern wherein policies focussing on critical metals and the sustainability of critical raw materials are in some ways divergent. We use evidence from critical metal policies and academic literature using a mixed methods approach combining text mining and insights from experts to draw insights pertaining to this divergence. Drawing from our analysis we outline the case for a sustainable and responsible circular economy of critical metals as a way forward.

Thursday February 22 – 16.30

Reducing primary critical raw materials through battery reuse & recycling in mining electrification

Maria Ljunggren (Division of Environmental Systems Analysis, Chalmers University of Technology), Harald Helander (Division of Environmental Systems Analysis, Chalmers University of Technology)

Widespread and rapid adoption of batteries to replace internal combustion engines in road-based vehicles is viewed as central for mitigating climate change impacts. Such a shift is ongoing also in the mining sector, driven by commitments to net zero carbon emissions, better working conditions and energy cost savings. But supply risks related to upscaling material extraction and battery production capacities have become urgent issues for business and policy, why circular strategies are being suggested to relieve supply risks.

This study investigates the potential of reusing lithium-ion batteries and recycling critical materials when electrifying underground mining machines through the example of a battery-as-a (BaaS) service offered by a mining machine manufacturer. In the BaaS, the manufacturer maintains battery ownership and manages both reuse and collection for recycling in close collaboration with the battery manufacturer and recycler. A standardized design allows for reusing batteries in high performance machines in machines with lower requirements. Using dynamic material flow analysis, this multiple reuse and recycling setup (RU) is analysed from the introduction in 2020 to full electrification assumed in 2050 and compared with business as usual (BAU) without reuse before recycling.

The analysis shows that, initially, reuse is low since batteries are still in use, but increases as more become available for reuse. Eventually, the demand for reuse batteries saturates since fewer are required in reusing machines and the surplus is recycled directly, resulting in a moderate displacement of in total 13% of primary batteries. In contrast, the displacement of primary critical metals can eventually reach significant levels. With high recycling efficiency, the recycled content increases from 0 to more than 80% at the end of the period in both RU and BAU, although somewhat later in RU since recycling is delayed by reuse. However, early in the period when the high electrification growth rate is assumed, the recycled content of cobalt in primary batteries in RU is too low to reach the targets in the EU Battery Regulation in time. With lower recycling efficiencies, this delay also holds for nickel and lithium targets.

In sum, the BaaS for electrification of mining machines with a combination of reuse and recycling can reduce both primary battery and primary critical metal demand at varying levels over time. Studying both supply and demand of reuse batteries as well as supply and demand of secondary critical metal over time is crucial for estimating the interdependence of reuse and recycling potentials. For policy makers, balancing targets for use of recycled materials and extended battery lifetimes is a challenge. For a company relying on extensive reuse, recycled content targets could undermine its business.

Session 4: Emerging sectors and technologies

Chaired by Patrice Christmann (KRYSMINE), Min-Ha Lee (KITECH), and Magnus Ericsson (RMG Consulting)

This session delves into emerging sectors and technologies within along the critical raw materials field. It encompasses a wide array of topics, ranging from newly evolving products to their associated processes – for example, in sodium-ion batteries, superconductors or green steel. Beyond these, the exploration extends to the application of CRMs in less visible sectors in the debate on CRMs, like pharmaceuticals, cyber security or agriculture. Moreover, our focus extends to integrating CRMs in rapidly evolving domains, exemplified by the fusion energy, hydrogen economy, quantum computing, space technology, and water electrolysis. We invite contributions from diverse participants, including pioneering companies in emerging sectors, technology start-ups, researchers working in the intersection of CRMs and perspective technologies for the future sustainable economy, and all other stakeholders working in this advancing field.

Thursday February 22 – 15.45

Circular Economy Research and Innovation (R&I) on Strategic Technologies

Brian Baldassarre (European Commission, Joint Research Centre), Alejandro Buesa (European Commission, Joint Research Centre), Paola Albizzati (European Commission, Joint Research Centre), Malgorzata Jakimów (European Commission, Joint Research Centre), Hans Saveyn (European Commission, Joint Research Centre), Samuel Carrara (European Commission, Joint Research Centre)

To develop renewable energy, digital, space and defence technologies, the European Union (EU) needs access to critical raw materials of which a large share is currently imported from third countries. To mitigate the risk of supply disruptions, the Critical Raw Materials Act proposes to diversify sources of imports, while increasing domestic extraction, processing, and recycling. The circular economy is therefore positioned as a key element of the EU strategy to deploy strategic technologies for navigating the sustainability transition in a complex geopolitical landscape. In line with this position, the present study analyses the intensity of circular economy research and innovation (R&I) in the supply chains of strategic technologies. The focus is placed on four critical products containing raw materials having high supply risks: lithium-ion battery cells; neodymium-iron-boron permanent magnets; photovoltaic cells; hydrogen electrolysers and fuel-cells. The R&I analysis is based on the identification of scientific articles, patents, and innovation projects on the subject, with a global scope, in the period between 2014 and 2022. The analysis is enriched by connecting to parallel work on the subject, conducted by Joint Research Centre (JRC) as well as academic institutions, industry, and policy stakeholders. This is functional to provide insight into: where circularity efforts R&I have been placed in terms of different products and supply chains; which countries are undertaking these efforts; how the EU is positioned and how much funding was deployed so far; what are the current gaps and trends going forward. Main insights include the following: 1) circularity R&I for critical products is not balanced, with a prominent focus placed on Li-ion cells on a global level 2) the EU has followed this trend in terms of number of innovation projects and public spending; 3) Next to EU efforts, China and the USA focus intensely on circular economy R&I as well. This study contributes with evidence to advance scientific research and policymaking on the role of a circular economy to achieve open strategic autonomy and climate neutrality in the EU.

Thursday February 22 – 16.00

Next Generation batteries adoption: a survey-based study on users and experts' perspectives

<u>Alessandra Manzini</u> (Cleopa Gmbh), Laura Martinez (Cleopa Gmbh), Pauliina Harrivaara (Cleopa Gmbh)

The survey-based study explores adoption attitudes of users and experts towards electric vehicles (EVs) and next generation batteries for achieving low carbon mobility. Two surveys were deployed inviting 50 users and 50 experts to answer questions on adoption, development, and use of next generation batteries. Surveys were conducted during the 'first stage' of the living lab process for circular design of 2BoSS battery (2boss.eu). 2BoSS project aims to develop and validate a Si-Li2S battery technology made of cobalt free Li2S-based cathode and a graphite-dendrite free silicon-based anode in a circular economy framework. The aim of the 'first stage' is to understand the 'current state' and setting the benchmarks together with stakeholders, users, and experts, concerning the current preferences of customers, the current problems for the commercialization especially of Sulfur Batteries and the barriers that are preventing a full transition to EVs. Results show users' sensibilities, consumers choices on EVs and get insights on their knowledge and expectations for batteries and future energy scenarios. The study dived into the energy storage emerging technologies and their potential uses, assessing advantages and disadvantages with the expert's participants. The experts' survey results highlighted drawbacks of current predominant Lithium-ion Batteries (LiBs) and explored opinions on the potential benefits, challenges, and prospects for sulfur batteries compared to other emerging technologies. To maximise the rigor of the study results were compared with a broader literature review studies on adoption of next-generation batteries. Concluding remarks indicate intersecting areas of the different surveyed perspectives and areas where the knowledge transfer should be improved.

Thursday February 22 – 16.15

A descriptive study of innovativeness of Rare-Earth-Elements recycling sector based on patents

<u>Marinella Favot</u> (Area Science Park), Riccardo Priore (Patlib - Area Science Park), Marco Compagnoni (University of Trento)

Rare Earth Elements are key chemical elements in the twin transition i.e., green and digital. Europe has listed REEs as Critical Raw Materials since 2011 for their economic importance and supply risk. Recovery REEs from waste electric and electronic equipment (WEEE) is an alternative solution to primary mining. In this paper we investigate the innovativeness of the recycling sector in recovery REEs from WEEE by analysing the patent applications. Our research is based on the well-established

OECD methodology “ENV-TECH” using IPC and CPC codes. We selected with key words, the patents which are strictly related to recovery REEs from WEEE. The study reveals that the time trend of patent applications is quite stable with over 100 applications per year since 2011. The increase of almost 1,5 times between 2010 and 2011 is mostly due to the Chines export restriction of REEs that had an impact on the prices of virgin REEs, making recycling REEs from waste, economically convenient. The West group of countries has 203 patent applications, compared to the East countries (exclude China) with 261 applications. In the West group the US is the key player with 130 applications, followed by Canada (30) and Australia (20). In Europe only Poland and the UK play role, but still marginal. In the East group, China plays a central role with 64% of the total applications. The meso-level analysis underlines the importance of private companies compared to the university and individual as applicants, showing a large interest of the private sector. More precisely, the Japanese companies are by far the leaders in this sector while the most important universities are based in China.

The quite stable trends of patent applications in the field of recovery REEs from WEEE, compering to the increased demand of such minerals worldwide, spots the fact that large investments on this field are still lacking. Finally, we focused on the typology of treatments. We investigated the main treatments: hydrometallurgy and pyrolysis. The first technology is mainly investigated by CEA (a French research centre), while the second one is mostly studied by multinational companies, and it is more promising if we consider the total number of patent applications.

In conclusion, the twin transition, digital and green, require a large quantity of REEs. Extracting these elements from urban mining can be a partial solution to decrease the European dependency from external supply. However, the recycling sector needs the support from the governments both in terms of regulation to address the collection of WEEE containing REEs as well as financial support in research studies and industrial plants. Government direct investments or national incentives in this field could help this promising sector that can partially diminish the dependence from virgin source and therefore from China being the major international player.

Thursday February 22 – 16.30

Helium resource supply and demand shifts: Material flow analysis

Ankesh Siddhantakar (School of Environment, Enterprise and Development, University of Waterloo), Komal Habib (School of Environment, Enterprise and Development, University of Waterloo), Steven B. Young (School of Environment, Enterprise and Development, University of Waterloo)

Helium (He) is an industrial gas and a critical raw material (CRM), as identified by the USA, EU, and other nations. Helium is a unique natural resource with growing demand in healthcare and electronics -- and shifting global supply including recent shortages. However, there is little extant research on the element, its resource criticality, life cycle or environmental footprint. This study evaluates the global flow and stocks of helium and quantifies material resource losses in the economy.

Helium is extracted from a small number of natural gas reservoirs mostly in United States, Qatar, and Algeria where it is present in economic quantities. Following separation from hydrocarbon natural gas, helium is stored and transported as cryogenic liquid (liquid helium boils at 4.2 K (-268.95° C)), then distributed as liquid or compressed gas. Given its tendency to diffuse, effuse, and boil off, helium logistics are complex and time constrained. Roughly 30% of refined helium finds end-use as a cryogenic liquid coolant in magnetic resonance imaging (MRI) machines in healthcare. Other major uses are in research laboratories and semiconductor manufacturing. Global helium production in 2019 was 160 million cubic metres, only 27 kt.

In this study, we mapped 2019 global and regional helium stocks and flows using material flow analysis (MFA). As a noble gas, helium does not change its form or mix over its life cycle, thus providing ease of tracking through the global supply chain. An original database was compiled on helium processes and supply chains including a list of major helium companies and sites. Flows to eight end-use categories were quantified and stocks were modelled for helium resident in MRI machines and smaller industries. Our results indicate that helium presents a classic linear economy model: most helium being used is lost within one-year of extraction and the gas literally exits the Earth's atmosphere. Notably, up to 50% of helium is lost between extraction and use.

From a supply-demand perspective, there is waning role of the USA in global helium production and trade resulting in increasingly complex helium resource pathways, including a shift to Asian markets. As helium is a small yet global industry, and difficult to handle without losses, development and commercialisation of new helium sources is challenged and dependant on access to complex helium-specific equipment, infrastructure, and technical expertise. With growing international demand, risks of shortage remain, and resilient systems are crucial to efficient supply management.

Session 5: New data and tools

Chaired by Peter Buchholz (DERA), Tatiana Vakhitova (Ansys), and Anthony Ku (Xiron Global)

In the session "New Data and Tools for Critical Raw Materials," diverse contributions are sought to explore the forefronts of this field. This session seeks abstracts encompassing a range of topics, including tools for market monitoring, carbon footprint assessment via digital platforms, the integration of artificial intelligence and blockchain for CRM management, digital technologies for supply chain modelling, the significance of product passports, novel data processing tools, and the role of AI-powered resources like ChatGPT in advancing the understanding of critical raw material dynamics. We extend this invitation to data providers, field researchers, and entities showcasing practical instances of digital tool implementation within the CRM landscape.

Friday February 23 – 11.15

Capabilities and limitations of AI Large Language Models (LLM) for materials criticality research

Anthony Ku (Xiron Global Ltd)

Generative AI chatbots such as ChatGPT are built upon large language models (LLMs). These tools have attracted significant attention due to their ability to compile general search results, generate narrative text, and assist in data analysis and visualization. While the number and range of use cases for which these tools have demonstrated capabilities continues to grow rapidly, concerns have arisen about the accuracy and completeness when used in a research context. For example, in early 2023 there were reports of "hallucinations" where the chatbot returned fictitious results and references. This study explores the capabilities and limitations of LLMs for use in materials criticality research. Experiments were performed with several chatbots based on different underlying LLMs to explore the quality and extent of data coverage (e.g., accuracy, resolution, timeliness), the ability to recognize uncertainty and reconcile divergent data, and new directions that might be uniquely enabled by this technology.

Friday February 23 – 11.30

Deconstructing nickel trade: a high-resolution material flow analysis of a critical supply chain

Marceau Cormery (Norwegian University of Science and Technology), Romain Guillaume Billy (Norwegian University of Science and Technology), Fernando Aguilar Lopez (Norwegian University of Science and Technology), Barbara Reck (Center for Industrial Ecology, Yale School of the Environment), Daniel Beat Müller (Norwegian University of Science and Technology)

The global nickel cycle has historically been dominated by its use in stainless steel, while most of the future demand will be driven by the lithium-ion batteries needed to electrify the transport sector. As the criticality of nickel is increasing, historical trade patterns are being challenged by the emergence of new actors and tensions.

Here, we developed a trade-linked material flow analysis model of the global nickel system in 2021, combining trade data from the UN Comtrade database with country- and facility-level production data for upstream nickel mining and processing facilities. An algorithm was developed to detect outliers, estimate the missing mass flows, and reconcile the unbalanced mirror statistics between reporting countries. This approach increases the robustness of the data and allows us to analyze the trade relationships of different nickel-containing commodities between countries.

We quantified the global nickel cycle and identified the most important countries in the international nickel trade network at the different stages of the supply chain. Upstream processes, such as mining and refining, are dominated by a few countries, such as Indonesia, the Philippines, Russia, New Caledonia, Canada, and Australia. Downstream processes involve an interconnected network of many countries, with a stronger presence of China and Western economies. Some countries, such as Norway (matte refining) and the Philippines (mining) are heavily specialized in one process, while China has a strong presence in all stages of the supply chain.

Such a trade-linked cycle is a powerful tool to better understand critical supply chains: the higher resolution enables powerful trade network analyses. As a first application, we used our model to highlight the supply risk of class 1 nickel—the quality required for batteries and other strategic applications—to Europe following the war in Ukraine. Indeed, the EU relies on Russia for its imports of class 1 nickel, while Russia is in a stronger position as it also exports to non-NATO countries such as China. Such asymmetries in critical materials trade networks increase the risk of supply disruption. These effects can be better quantified with high-resolution trade-linked material flow accounting models.

Friday February 23 – 11.45

The Economic Value Dissipation Potential method applied to a lithium-ion battery recycling process

Jair Santillán-Saldivar (BRGM), Emmanuelle Cor (Univ. Grenoble Alpes, CEA), Antoine Beylot (BRGM), Elise Monnier (Univ. Grenoble Alpes, CEA), Stéphanie Muller (BRGM)

Multiple methods in life cycle assessment (LCA) address resource depletion and raw material criticality as a way to quantify the impacts of human activity on mineral resources availability and accessibility; recently, resource dissipation has been discussed in the community as a complement. The dissipation of resources is a phenomenon occurring along the life cycle of a product or service for which the value or function of resources are no longer accessible due to technical and/or economic constraints. Dissipative flows can be associated to dissipation compartments corresponding to their final destination (environment, landfills, tailings, final disposal facilities, etc.). It becomes necessary to link resource dissipation evaluation with LCA approaches in order to get accurate indicators related to mineral resource accessibility and support decision making in circular value chains.

The aim of this contribution is to test a novel impact-assessment method: the Economic Value Dissipation Potential (EVDP), which evaluates the environmental performance of a product or system through the estimation of potential economic losses associated to resource dissipation. It integrates a Recoverability Function (R) that estimates resources in life cycle inventories outputs that are no longer accessible, and a Value Function (V) that determines the economic value loss associated to them.

The EVDP method is applied on a case study of lithium-ion battery recycling based on hydrometallurgy. The objective is to quantify the potential for value loss mitigation of this circular economy strategy that maintains the value of several resources in the Technosphere. Eight raw materials, representing 75.3% of the battery mass, are the focus of the method application: aluminum, cobalt, copper, iron, graphite, lithium, manganese and nickel. For impact assessment, the EVDP characterization factors for resource dissipation are applied to a dedicated structure of the Life Cycle Inventory (LCI) of the process, in which the dissipation compartments of selected resources were identified.

Results show that the recycling of one kg of battery allows the avoidance of the 3.79 USD eq. in dissipative losses. The biggest contributors to the impact reduction are associated to Co recovery due to its high price and economic importance, and Al, due to its great mass in the analyzed process. These results are compared to other environmental impact categories in LCA and other dissipation indicators available in the literature. This application of the EVDP method reveals the need of a high level of detail in the LCI description to better assess the impacts of using critical raw materials (e.g. the determination of their dissipation compartments). Further testing is suggested to operationalize the EVDP method, it could be considered as a complement to traditional LCAs to support decision making in eco-design approaches and criticality assessments.

Friday February 23 – 12.00

Leveraging supplier material data to inform metal scarcity assessments in the automotive industry

Felipe Bitencourt de Oliveira (Chalmers University of Technology, Volvo Car Corporation), Anders Nordelöf (Chalmers University of Technology), Maria Bernander (Volvo Car Corporation), Björn Sandén (Chalmers University of Technology)

In the face of emerging challenges such as geopolitical shifts and climate change, industries worldwide face increasing pressure to ensure resource sustainability. The automotive industry, known for its significant dependence on diverse metals, is no exception. As it shifts towards electrification and a greater reliance on electronics, understanding metal compositions and potential scarcity becomes crucial. To expedite such assessments and facilitate proactive industry responses, an innovative data extraction method was developed. By leveraging material composition data from the automotive industry's International Material Data System (IMDS), we created a streamlined approach that automates the extraction process, offering a significant reduction in manual data retrieval efforts. Utilizing an automated algorithm, our approach links to the IMDS database, extracting comprehensive component lists for vehicles and detailing the materials and their constituent substances. These lists not only support life cycle assessments but also provide insights into potential metal scarcities in the industry.

In our assessment, two vehicle gliders, i.e., vehicles excluding powertrains, configured with different equipment levels revealed significant supply risks associated with gold, bismuth, molybdenum, copper, lead, and specific rare-earth metals (REMs). The gliders' extensive metal demand significantly contributes to supply risks in vehicle manufacturing. Notably, equipment level variations largely influenced short-term supply risks for certain metals. The analysis of metals across the gliders' subsystems and components revealed distinct patterns; for instance, entertainment and communications equipment harbor large REM quantities, while mirrors and electrical systems notably contain gold, silver, and copper. Moreover, some metals are concentrated in a few components while some are dispersed across thousands, impacting recycling and substitution opportunities.

Our findings underscore the imperative to consider metal demands beyond powertrains when gauging the automotive industry's supply risk exposure. They also highlight how industry trends, like new requirements for safety and comfort, digital connectivity and communication, amplify these risks. By bridging the IMDS with automated data processing tools, our method offers a new frontier in assessing the environmental impacts and metal scarcity risks in the automotive industry. In the era of digital transformation, this approach can significantly enhance the reliability, speed, and comprehensiveness of assessments, steering the industry towards more sustainable resource use.

Session 6: New ideas on critical raw materials

Chaired by Yulia Lapko (Politecnico di Milano), Akanksha Tyagi (CEEW India), and Patrick d'Hugues (BRGM)

This session serves as a platform for the exploration and dissemination of pioneering concepts and research in the critical raw materials field. We invite contributions that push the boundaries of innovation, presenting fresh perspectives and novel approaches that defy conventional categorizations. This session is the perfect avenue for topics that don't neatly align with the predefined themes of other sessions, giving voice to ideas that might otherwise go unheard. We encourage the submission of abstracts from less represented disciplines, as well as cross-disciplinary research endeavors that bridge the gaps between traditionally distinct fields. We encourage the presentation of innovative ideas and research that challenge existing paradigms.

Friday February 23 – 11.15

How are critical raw materials different from a producer country's perspective?

Marianna Ottoni (School of Environment, Enterprise and Development, Faculty of Environment, University of Waterloo), Komal Habib (School of Environment, Enterprise and Development, Faculty of Environment, University of Waterloo), Steven B. Young (School of Environment, Enterprise and Development, Faculty of Environment, University of Waterloo)

Critical raw materials (CRM) producer countries are those that hold large shares of critical mineral reserves and are processing these materials not only to meet domestic needs but also to export to consumer countries. Producer nations will have different priorities and criteria that influence their determination of "criticality", the methodology to assess raw material's criticality and, hence, their CRM lists. Despite the urgency of issues related to CRM in the current context of realizing a low-carbon society in future, there is a lack of comprehensive studies that deepen this discussion through the lens of CRM-producer countries. This study asks: What criteria do producer countries use to define the CRM? How does a producer country evaluate and determine its CRM? What are the materials listed as critical by producer versus consumer countries? For this purpose, we considered several CRM producer countries. From this sample, Canada, as a global supplier of various CRM, was chosen to be evaluated in terms of its selection of criticality factors, criticality assessment method, and listed CRM. Finally, a comparison of the CRM lists of producer countries versus consumer countries was conducted to highlight the differences and similarities for each context. The criticality factors highlighted in the Canadian Critical Minerals Strategy refer to materials that are either essential for economic security with supply threatened, required for a low-carbon economy, or a source of highly strategic critical minerals for its partners and allies. In addition to "common" CRMs like Ni, Li, Co, W, and graphite that consumer nations employ in manufacturing and high-tech industries, we find that Canada has identified, from a producer perspective, other minerals (U, P, Cu, Zn) that are not commonly listed as CRM by consumer countries. The approach of Canada (and Australia) appears to centre on the definition of "economic importance", which, differently from consumer countries, these nations have defined in terms of production for export, jobs in mining and minerals, and associated benefits to communities and the national economy. As a contribution to the literature on CRM, this study offers a different perspective to assess the criticality of materials and, hence, consider effective solutions for dealing with CRM worldwide.

Friday February 23 – 11.30

The Dark Sides of Sustainability: extractivism, global asymmetries and perspectives on transitions

Luíza Cerioli (University of Kassel)

At the Extractivism.de project, we grasp, through interdisciplinarity and transregionality, extractivist societies and their future perspectives in a context of energy transition and multipolarity. Extractivism is a development path in which growth is envisioned through rent redistribution from raw materials exploration. This creates and sustains global asymmetries between suppliers and buyers, influencing how societies, political coalitions and institutions organize themselves in the Global South while fuelling social contestation.

This paper defines the dark sides of sustainability. As the North seeks decarbonization, an intensification of extractivist activities for the needed raw materials is promoted as an attractive alternative for the South. Often, green transition narratives toss socio-economic growth while

idealizing experiences from pre-capitalist times and overlooking the development needs of extractivist societies. While crises like the Ukraine war and the COVID-19 pandemic have exposed the importance of energy security and the need to push forward for renewables and diversification in many countries, policies are still over-concentrated on the domestic level. However, we argue that transition policies cannot be detached from international relations and geopolitical shifts. Grasping energy transition as an inherently global endeavour should push for a change in the nature of North-South and South-South relations, linking green projects with development needs, particularly in the Global South.

We argue that there is a window of opportunity for change simultaneously with a significant risk of intensifying the current unequal division of labour. Decarbonization demands capital, technology, new resources, training, and labour force readiness. While the North has the money, technology and know-how, it is short on land, workforce and access to many mining resources. Most needed new resources are in the Global South; however, they have fewer incentives and access to technology for advancing sustainability projects. Also, they do not have the domestic market needed for a stable decarbonization. Suppose the relations between suppliers and buyers do not fundamentally change, taking a much more complex and multifactorial shape that connects energy security partnerships with sustainable development. Thus, extractivism will just surge in a post-fossil age, intensifying global inequalities and hardening social, political and economic contexts for local citizens, expanding the extractivist frontiers, intensifying environmental catastrophes and upholding the Global South positional of the political periphery. We call for a critical assessment of this dark side of the sustainability phenomenon, arguing that alternatives for developing countries to escape the extractivist trap and promote inclusive economic growth and welfare must combine domestic and international politics.

Friday February 23 – 11.45

Technology-level supply disruption probabilities of RES and energy storage technologies

__Steffen Schlosser__ (German Aerospace Center, Institute of Networked Energy Systems), Tobias Naegler (German Aerospace Center, Institute of Networked Energy Systems)

The energy transition to net zero emissions requires a large-scale installation of renewable energy sources (RES), e.g. wind power plants, and energy storages. State-of-the-art RES and energy storage technologies require various metallic resources: bulk materials such as steel and copper mainly for the peripheries, but also potentially critical metals, e.g. for permanent magnets, PV active layers, and battery cells.

Many metals in clean energy technologies are subject to potential geopolitical risks. A method for assessing the Supply Disruption Probability (SDP) of individual materials based on the concentration of supplier countries and their political stability has been developed by the European Commission. However, there is not yet an established method for the aggregation of material-level SDP to product level, although a number of different approaches have been proposed:

1. Mass weighted average of material level SDP
2. Cost weighted average of material level SDP
3. Arithmetic mean of material level SDP

4. Maximum of material level SDP

The aim of this study is to compare the above aggregation methods of material-level SDP on the product level for the case of different RES and energy storage systems with respect to technology SDP ranking and the contributions of the constituent materials on the overall product level SDP.

Our investigation reveals that the choice of the aggregation method has a decisive influence on the final technology-level criticality in two ways. First, the ranking of the RES and energy storage technologies with respect to their SDP is determined by the aggregation method. Accordingly, the aggregation methods tested here do not provide a uniform picture of which a technology has a particularly high SDP or not. Second, the contribution of the considered materials to the product level SDP changes drastically for different aggregation methods.

Since it is favorable to install low-criticality technologies on a broad scale, a good knowledge about how to define the product level criticality is crucial, especially when using criticality assessments for recommendations on the future energy system. The results highlight that the choice of method for aggregating criticality values from the raw material level to the product level strongly influences the results. This indicates that there is a need for further research at this point.

Friday February 23 – 12.00

From catch-up to forging ahead through (green) windows of opportunity: China and the REEs

<u>Mihaela Gaglioti Roibu</u> (Copenhagen Business School, Department of Organization, Sino-Danish Center), Stine Haakonsson (Copenhagen Business School, Department of Organization, Sino-Danish Center)

The green transition relies on regime shifts introducing radically new technologies and often changes in the use of materials. The current transition towards greener technologies, such as electrification and smart solutions, has major implications for how industries are organized and distributed. Industrial leadership structures are challenged as industrial solutions for green transition imply moving towards new technologies, innovations and not least materials. Applying the frameworks of sustainable transition and green windows of opportunity, this paper contributes to the conceptual development for understanding cases where established industrial organization is challenged by emerging market actors offering a new technological regime. The green windows of opportunity framework allow for this as it potentially complements the transition literature by bringing in the emerging market industrial development perspective. Resorting to China and its rare earths industry as an illustration, this paper looks to nuance the conceptual framework for understanding the role of technological development and catch-up processes. The paper zooms in on permanent magnets for which Chinese actors have evolved into global leaders in the downstream segments of the value chain. This Chinese industry has built its advantage by investing in basic and applied research. By exploiting a green window of opportunity offered by international and domestic dynamics, China has upgraded and quickly moved into downstream green-tech applications such as electric vehicles and wind turbines.

By asking the question: How did (green) windows of opportunity over time foster Chinese actors to become global leaders in the development and application of green technologies? By applying the conceptual framework of windows- and green windows of opportunity, this paper identifies the drivers of recent shifts in the technology path and engages in the discussion on how the interplay between investments into basic research and industrial policy have contributed to change the geography of the global supply chains for green transition. The paper proceeds as follows: Section 2 provides an overview of the literatures related to green transition and green windows of opportunity. In Section 3 the geography and development of rare earth elements is introduced. Section 4 gives an in-depth analysis of China's active role in becoming a leader in rare earths production. This is in Section 5 the windows of opportunity framework is discussed by using the case of permanent magnets. Finally, Section 6, presents the conclusion and avenues for further research.

Scientific Sessions - Posters

Session 1: Emerging raw materials policies and their impacts

Poster 1.01

A European strategic research and innovation agenda for a sustainable raw materials supply and use

Tobias C. Kampmann (Vinnova), Pontus Westrin (Vinnova), Dina Carrilho (FCT), Jorge Sotelo (AEI), Raquel Fernandez Reyes (AEI), Doroteja Zlobec (MIZS), Ana Luísa Lavado (GSI), Olga Kergaravat (ADEME), Nela Roy (ANR)

Ten years have passed since the ERA-MIN Research and Innovation Agenda was published (ERA-MIN agenda 2013). The landscape has changed considerably since then, and the experience from the ERA-MIN programme has brought new insights towards innovating the innovation system.

It is of key importance to define a new Strategic Research and Innovation Agenda (SRIA) as a document that outlines the priorities, goals, and strategies for research and innovation activities within a particular field, industry, or organization. The SRIA will provide a roadmap for how research and innovation efforts should be directed to achieve specific objectives, solve challenges, and take advantage of opportunities.

The aims for the new SRIA within the field of non-energy, non-agricultural raw materials, are two-fold:

- Identifying critical technological and structural challenges within the EU, related to the supply of raw materials for the green and digital transition.
- Addressing needs for research and innovation to tackle the challenges, as well as prioritizing among strategically important core targets.

The work towards a new SRIA revolves around our formulated mission of sustainable raw materials supply and use for the green and digital transition, and is structured into six thematic areas:

- Resilient primary and secondary raw materials supply
- Efficient use of raw materials in design and production
- Sustainable use and reuse of products
- Effective policy development and governance
- Maximizing societal benefits
- World-class innovation capacity

Poster 1.02

Organizing Innovation: Policy-Making Processes in China´s Rare Earths Industry

Mihaela Gaglioti Roibu (Copenhagen Business School, University of Chinese Academy of Sciences, Sino-Danish Center)

Rare earth elements (REEs) are a strategic sector in China, whose development has been supported by the government through numerous policy initiatives since the setup of the industry in 1958. As of 2022, China performed 63% of global rare earths mining and controlled 85% of the global supply of processed elements. On the side of those countries that import RE products from China, concerns about dependency issues and risk of supply disruption are increasingly growing. As a matter of fact, we are now witnessing a surge in conversations and policy initiatives concerned with industrial policy and addressing value chain disruptions in the Global North. Moreover, in the context of an increasing policy attention towards climate change, the risk of not being able to access the volumes of resources necessary to satisfy the demand coming from green technology, poses a threat to national security. Selected raw minerals are now categorized as ´critical´ and prioritized by experts and policymakers around the world, with rare earths as the most notable example.

In this paper, we want to analyze the empirical case of China´s REE industry and its advantage in the rare earths value chain. We want to understand how different stakeholders in China interact to contribute to the development of policy for the domestic rare earth industry. There is a broad consensus in the literature on a top-down approach coming from the Chinese government. However, we wish to challenge this argument by investigating the dynamics behind the policy-making processes that regulate the rare earths sector in China. We argue that there is complementarity between top-down and bottom-up interests, whereby actors at the meso- (government) and micro- (firms) level interact to inform the development of industrial policy. We conduct empirical research by adopting a qualitative approach that involves participant observation and interviews with relevant stakeholders at the government and business level. The data collected will guide us in exploring a process that we believe characterized by complexities that go beyond the top-down approach widely accepted in the literature.

The results of the paper will endeavor to broaden our understanding of policymaking processes in strategic industries. We argue that there are lessons to be drawn from China with regards to the development of the REE industry, and the country´s technological catch-up and innovation in green technologies more recently. In addition, it aims to contribute to our knowledge on the strategies adopted at the firm-level to prevent potential disruptions and strengthen the resilience of GVCs for critical minerals, against the backdrop of growing support deriving from industrial policy at the government level.

Poster 1.03

Varieties of Policy for (Strategic) Natural Resources: The Case of Rare Earth Elements in China´s National Innovation System, a Systematic Literature Review

Mihaela Gaglioti Roibu (Copenhagen Business School, University of Chinese Academy of Sciences, Sino-Danish Center)

The realization of the importance of having a rapid and unimpeded access to some selected resources, has triggered national governments to frame a discourse around the criticality and strategic importance of certain minerals. In particular, there is a need to secure access to strategic raw materials necessary for the manufacturing and development of existing and new technologies, especially when it comes to the ones related to decarbonization. Probably the most strategic of these resources are rare earth elements (REEs) – a group of seventeen minerals with unique conductive and magnetic properties whose value chain is almost entirely controlled by China.

Research in the Social Sciences has seldom devoted its attention to inquiring the role of the RE industry in China´s path to development and innovation. Therefore, this paper is informed by the following research question: what is the relationship between industrial policy and the advantaged position that China holds in the rare earths value chain? With a theoretical framework that finds its grounds in the framework of National Systems of Innovation and natural resources economics, we conduct an extensive systematic literature review and analysis of secondary data (e.g. policy documents) to shed some light on the role played by these strategic resources in China´s industrial policy and innovation system. We believe that by owning a competitive advantage in the production of strategic minerals, it is possible to achieve innovation in certain emerging strategic industries. We argue that rare earths, as critical resources, occupy an important role in Beijing´s state-led economic model, with industrial and innovation policy often shaped around them. In fact, the empirical case of the rare earths in China constitutes an example of how owning a competitive advantage in the production of strategic minerals can strengthen the value chains of certain emerging strategic industries, e.g. green technologies. Through this work, we wish to contribute to our understanding of the role that an advantaged position in the value chain of certain strategic minerals has for a country´s overall innovation goals and to what extent it shapes, or it is shaped, by industrial policy. In particular, the aim of this paper is to provide an overview - with a critical perspective - on the current status of research in Social Sciences on REEs and to how they are connected to China´s National Innovation System and economic growth.

We provide a thorough overview on the state of art of literature around rare earths published in English on Western academic journals. We argue that there is a lack of interest in trying to understand how China has integrated its comparative advantage in the RE industry in its broader aspirations with regards to economic development, whereas we believe it is relevant to understand what has been and what currently is the role played by rare earths in China´s National System of Innovation.

Poster 1.04

Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU

Samuel Carrara (European Commission, JRC), Silvia Bobba (European Commission, JRC), Darina Blagoeva (European Commission, JRC), Patricia Alves Dias (European Commission, JRC), Alessandro Cavalli (European Commission, JRC), Konstantinos Georgitzikis (European Commission, JRC), Milan Grohol (European Commission, DG GROW), Anca Itul (European Commission, JRC), Tedoro Kuzov (European Commission, JRC), Cynthia E. Latunussa (European Commission, JRC), Lorcan Lyons (European Commission, JRC), Giorgia Malano (European Commission, JRC), Thibaut Maury (European Commission, JRC), Angel Prior Arce (European Commission, JRC), Julien Somers (European Commission, JRC), Thomas Telsnig (European Commission, JRC), Constanze Veeh (European Commission, DG GROW), Dominic Wittmer (European Commission, JRC), Catriona Black (European Commission, JRC), David Pennington (European Commission, JRC), Michalis Christou (European Commission, JRC)

In order for the European Union to achieve the ambitious targets it has set for the energy and digital transitions and its defence and space agenda, it needs undisrupted access to critical raw materials and to many products which contain them. This foresight study presents a systematic and detailed analysis of the complete supply chains, from raw and processed materials to components, assemblies, super-assemblies and systems, for 15 key technologies across the five strategic sectors (renewable energy, electromobility, energy-intensive industry, digital, and aerospace/defence) responsible for the delivery of these targets.

The study assesses supply chain dependencies and forecasts materials demand until 2050 in the EU, other economic regions and the world. It also assesses the EU’s materials needs and vulnerabilities now and in the future. As such, it provides a forward-looking basis to help identify strategic raw materials for key technologies and applications, to identify bottlenecks and to pinpoint the segments of supply chains which need strengthening and how. This study contributes scientific evidence to underpin the Critical Raw Materials Act, in tandem with which it was published.

Poster 1.05

Export Restrictions to Trade in Raw Materials: Essential Security Interest or Protectionism?

Daria Boklan (National Research University Higher School of Economics)

Export Restrictions to Trade in Raw Materials: Essential Security Interest or Protectionism? WTO Law Perspective.

Today's crisis of the multilateral trading system showed that the spirit of trade liberalization and multilateralism on one hand and essential security interests on the other hand are very much complimentary to each other. Protection of one can lead to the enhancement of the other interest. For a multilateral system to be sustainable, it is important to have several escape clauses which can allow countries to protect their security concerns. However, when these escape windows are too wide or ambiguous, defining their ambit and scope becomes challenging yet crucial to ensure that they are not open to misuse. It explains why the WTO members have remained relatively cautious about the invocation of so called "security exception" provisions enshrined in the WTO agreements since the very creation of the multilateral trading system. The members have known that the use of this exception - whose interpretation could be a subject of dispute in itself – could lead to the weakening of the multilateral trading system. They also realized that this escape window is too wide – and once opened – it can allow members to escape the obligations they have undertaken as the WTO members. They recognized that invoking this exception could set a wrong precedent that other members could follow to justify blatant violations of multilateral trade agreements. One of the GATT's drafters stated that having a wide security exception which allows members to escape from their obligations is dangerous because that would permit anyone to 'justify anything under the sun'. However, "security" falls short of a universally accepted definition. Therefore, the main question that should be addressed by the WTO members and Panels is whether scope of the security exception should include export restrictions on trade in raw materials. Will such approach be an effective legitimate tool to protect state's holding raw materials interests or on the contrary such approach will lead to illegal protectionism?

This paper provides comparative analysis of different approached used by the panels regarding both trade in raw materials and security exception and points out the risks they are bearing.

Poster 1.06

Evaluation of the potential for supply risk mitigation achievable through the EU CRM Act

Jair Santillán-Saldivar (BRGM), Anish Koyamparambath (Université de Bordeaux, CNRS), Guido Sonnemann (Université de Bordeaux, CNRS), Daniel Monfort Climent (BRGM)

Methods to assess raw material criticality are key tools to support the transition of technologies towards a sustainable development. Specifically, the European Union (EU) has been regularly providing lists of critical raw materials to pilot strategic sectors in the EU economy. The most recent milestone is the Critical Raw Materials Act (CRM Act) that provides benchmarks for strategies to mitigate the criticality of raw materials in 2030: increasing recycling, reindustrialization with focus on mining and refining operations and, redistribution of supply mixes. This contribution aims to provide a prospective assessment of the impact of these public policy objectives in the supply risk of critical raw materials.

The GeoPolRisk method is applied in comparative criticality assessments and used within life cycle assessments to estimate the supply risk of a resource from the perspective of an economic agent; it considers global production and trade information to calculate characterization factors tailored to different sourcing scenarios and measures potential supply risk in monetary units. Based on the objectives in the CRM Act, we employ the GeoPolRisk method to estimate the potential supply risk mitigation attainable within the capacity limits of the EU. We use a linear programming model and "geopolrisk-py", an open-source python library that operationalizes the GeoPolRisk method, to calculate the potential for supply risk mitigation of critical raw materials in the EU.

Results show that supply risk mitigation strategies for a first group of resources are limited to new or improved recycling technologies due to a restricted international market and limited reserves in the EU (REE, Graphite, B, Mn, Ti); among this group, some CRMs are well recycled (Mn) while others are not (B, Graphite). Current practices in primary sourcing and/or recycling in the EU for a second group (Cu, Pt, Ni, Pd) require only moderate improvements to attain the CRM Act objectives. A further assessment of the cases of Li and Co shows the need for mixed strategies: increased primary production and recycling, and redistribution of current supply mixes. Examples of these initiatives are currently visible in the EU; however, might not be sufficient to attain the goals for 2030.

The analysis of the list of critical raw materials for the EU is limited by the amount of public information required for the assessment; specifically for the case of rare earth elements, the application could improve if more detailed production and trade data becomes available. Moreover, application of the method at intermediate points in the supply chain could further reveal bottlenecks associated to the transformative industry. Results obtained with the GeoPolRisk method should be used in parallel to other indicators focused on socioeconomic and environmental aspects of resource management to inform government bodies on the feasibility of the proposed strategies and better steer current efforts.

Poster 1.07

Critical raw material supply for E-mobility: potential self-sufficiency of the European Union

Maarten Koese (Leiden University Institute for Environmental Sciences), Michael Parzer (Leiden University Institute for Environmental Sciences), Benjamin Sprecher (Technical University Delft, Faculty of Industrial Engineering), René Kleijn (Leiden University Institute for Environmental Sciences)

The European Union aims to reduce transport emissions, necessitating a shift to sustainable mobility. Electric vehicles are a crucial component of this transition, but their widespread adoption poses challenges due to their critical raw material (CRM) requirements. The EU is now very dependent on other countries for the supply of these materials. Still, the European Commission has proposed a target of 10% self-supply of the European CRM demand in their Critical Raw Materials Act (2023).

In this paper we will explore to what extent the raw material reserves and resources in the EU can supply the demand for raw materials for E-mobility, and whether the goal of at least 10% self-supply in 2030 is reachable. We will do this for six CRM crucial for E-mobility: cobalt, copper, lithium, nickel, graphite and rare earth elements (REEs).

Mapping and quantifying CRM sources in Europe reveal promising deposits for these minerals. Our analysis indicates that for lithium, nickel and copper the planned extraction in Europe is sufficient to meet at least 10% of the demand in 2030, as the EU's proposed target dictates. The production of cobalt, natural graphite and REE, however, will not reach 10% of the demand in 2030. For REE there is no European production expected at all.

This paper also shows the practical and theoretical self-sufficiency of the EU in fulfilling CRM demand from E-mobility. The practical self-sufficiency is based on the planned extraction of the six assessed materials in Europe, compared with the demand under a High Development Scenario (HDS). The theoretical self-sufficiency illustrates the potential of European sources in fulfilling the EU's CRM demand for E-mobility. Our results indicate that the theoretical self-sufficiency is higher than the practical self-sufficiency. The EU could thus supply a lot more of their own CRM demand in theory, but extraction is a limiting factor.

This means that, to achieve these targets and increase the EU's self-sufficiency, CRM extraction in Europe needs to be increased. Considering the growing awareness for strategic autonomy, more CRM extraction within Europe is crucial. This requires accelerating the permitting process for mining projects. At the same time responsible mining practices are important to balance the supply of CRM from Europe with environmental and social sustainability concerns. Moreover, circular economy practices, like reducing demand and increasing recycling efforts are necessary to contribute to supply resilience and secure the availability of materials for the E-mobility sector in Europe.

Poster 1.08

Insight Global Value Chains from Material Lifecycles: A Case of Neodymium

Qiance Liu (University of Southern Denmark), Xin Ouyang (University of Chinese Academy of Sciences), Gang Liu (Peking University)

The global neodymium (Nd) industry, essential for sustainable technologies like electric vehicles and wind energy, operates within the intricate dynamics of Global Value Chains (GVCs). Traditionally, economic methods like backward and forward GVC participation measurements have been limited by sectoral integration and tracing assumptions, hindering accurate representation.

To address these challenges, this study introduces a Material-Value-Technology (MVT) assessment framework, merging Material Flow Analysis (MFA), text-mining patent analysis, and trade data. Focusing on Nd, the research uncovers detailed sectoral involvements and evolutionary trends, highlighting the pivotal role of technological innovation.

The findings reveal distinct contributions of selected regions and countries within the Nd industry. The study reveals distinct regional roles, emphasizing China’s dominance in production, Japan’s expertise in high-value products, Europe’s manufacturing stronghold, the US’s innovation leadership, and the Rest of the World’s resource contributions.

The research highlights the growing importance of material cycles in GVC evolution, especially for critical materials, providing a foundation for policymakers, innovators, and researchers. The developed MVT framework offers a versatile approach applicable to various critical materials, enabling a comprehensive understanding of GVCs from detailed sector and product perspectives, essential for navigating the complexities of the modern industrial landscape.

Session 2: Forecasting CRM supply and demand

Poster 2.01

Resource demand for a GHG-neutral aviation sector via implementation of synthetic kerosene

Lorenzo Cremonese (Ptx Lab Lausitz), Anja Paumen (Ptx Lab Lausitz), Harry Lehmann (Ptx Lab Lausitz)

The aviation sector is responsible of about 3% of the worldwide GHG emissions. From an emission reduction standpoint, aviation belongs to the hard-to-abate sectors, meaning that profound changes and diversified measures are required in this sector to ultimately reach neutrality in 2050 (e.g. negative emissions). If it is true that green energy stored in high-tech batteries and hydrogen could – if available at scale – cut emissions for low-distance air travels, to date kerosene remains the only viable aviation fuel for the vast majority of national and international flights. As appointed by the RefuelEU Aviation regulation and other international climate legislations, alongside biofuels, a relevant share of future aviation fuels must be covered by sustainable, power-based synthetic kerosene (e-kerosene or syn-kerosene) produced via Power-to-Liquid technologies (PtL). Different ways of producing e-kerosene exist, each characterized by a different material footprint in terms of material and their amount required. For the rollout of e-kerosene production and availability at scale, an enormous amount of raw material and renewable energy will be required. For the former, this includes minerals, non-mineral raw materials, and water. An accurate assessment of the future demand of these materials based on climate targets, blending quotas, traffic scenarios and PtL production systems is still missing. Raw material is required at the installations and machineries located at each stage of the production chain: from RE generation and CO2 collection, through hydrogen and syngas/methanol production, until refining. In the Project "Resource demand and availability for a GHG neutral aviation sector", the PtX Lab and its partners are investigating the raw material footprint of the e-kerosene production chain through combining the different technological alternatives available at each process or production components (e.g., RE generation system, electrolyzers technology, etc.). The aim is to identify the impact that different production pathways (i.e., combinations of the different available processes and technological components) have on the resource demand side, so to integrate and deepen previous studies such as the six development scenarios and associated raw material consumption presented in the RESCUE Project (UBA, 2020) . This evaluation takes into account the present and expected criticality grade of mineral and non-mineral materials, as well as the environmental impacts of their respective supply chains. The study wants to elucidate unknowns around future sustainable e-kerosene production systems under the perspectives of raw material availability, and provides guidelines for a rapid kick-off of an efficient, viable and long-lasting kerosene production industry. Insights for outlining appropriate defossilization strategies for the aviation sector will also be shared and discussed with decision- and policymakers.

Poster 2.02

Six perspectives on the abiotic resource demand of the German energy transition

Maya Yavor (Chair of Sustainable Engineering at the Technical University of Berlin), Vanessa Bach (Chair of Sustainable Engineering at the Technical University of Berlin), Matthias Finkbeiner (Chair of Sustainable Engineering at the Technical University of Berlin)

The shift towards renewable energy sources, which is essential for reaching climate targets, is diminishing the reliance on fossil energy carriers. However, it also entails a substantial resource demand and carries multifaceted impacts or risks. Therefore, this work had two main objectives. Firstly, it sought to acquire a holistic understanding of the resource requirement for the German energy transition, and secondly, it aimed to pinpoint hotspots in the material demand indicated by six different resource assessment methods recommended by the UNEP/SETAC life cycle initiative. This involved the determination of a bill of materials by combining several data sources and the application of six resource assessment methodologies. The findings show that sand and gravel (370 million metric tons), iron (160 million metric tons), and crude oil (142 million metric tons) are the most consumed materials along the transition path. Among six methods, platinum emerged as the primary hotspot in three (SOP, ADP u.r., ESSENZ), while LIME2 highlighted titanium as the top concern, CEENE identified nickel, and ADP e.r. pointed to indium as the biggest hotspots. Each method addresses distinct questions within the field of resource assessment, thus the outcomes. Simultaneous use of multiple methods provides comprehensive insights into hotspots from diverse angles.

Poster 2.03

Geopolitical Risk in Supply Chain of Manganese: Potential Vulnerabilities Due to Conflict in Gabon

Anish Koyamparambath (Université de Bordeaux), Jair Santillán-Saldivar (BRGM), Aina Mas Fons (Université de Bordeaux), Steven Young (University of Waterloo), Guido Sonnemann (Université de Bordeaux)

Manganese holds significant importance in industrial applications, particularly steel, which is used to create essential alloys. More recently, it has played a growing role in the cathode chemistry of lithium-ion batteries. Manganese production is concentrated in a select few regions: South Africa, Gabon, China, Australia, and Brazil. Recent research on critical raw materials for the European Union (EU) highlights the EU's high reliance on manganese imports, with a 96% dependency on manganese ore and 66% on refined manganese. For instance, France imports over 50% of manganese ore from Gabon, with the remainder from South Africa and other producers. The 2023 coup d'état in Gabon impacted the national production of manganese, and this situation underscores the potential risks associated with its supply, particularly for France and, by extension, the EU. Studies have highlighted that sourcing from regions affected by conflict raises critical questions, including raw material unavailability and the ethical considerations surrounding sourcing. This study examines supply and conflict risks connected to Gabon as a manganese source. Utilizing the GeoPolRisk and ConflictRisk methods, this study assesses the repercussions of conflict and discusses ramifications to the steel and battery industries. A qualitative approach, utilizing information from primary sources and recent news articles, is adopted to construct probable scenarios. The findings are examined in reference to ResponsibleSteel standard requirements on responsible sourcing of alloy materials and discussed in alignment with the implementation of the EU's Critical Raw Material (CRM) goals. We aim to validate the feasibility of CRM goals, pinpoint hotspots in the risk profile, and offer insight into the solutions to mitigate the distinct risks identified in the scenarios.

Poster 2.04

Problem shifts of nickel demand and supply growth

Eric Young (NTNU), Daniel Beat Muller (NTNU), Romain Billy (NTNU)

Nickel has historically been a major metal with established supply chains, mainly to produce stainless-steel. However, the demand for nickel is rapidly increasing due to its use in lithium-ion batteries for electric vehicles, creating pressure on the different stages of the supply chain of this critical raw material.

This work considers different scenarios for supply and demand of nickel in batteries and non-battery applications up to 2050. Using a demand-driven supply-constrained dynamic material flow model, we analyse how the growing demand for nickel to batteries can be met in the future, the potential bottlenecks in the supply chain, and the consequences on GHG emissions from different nickel mining and refining production routes.

We did not identify major risks of supply disruption for nickel. However, our results show large variation in characteristics of production routes. And that the production routes that are faster to develop, like nickel pig iron (NPI) smelting, are also the ones that have the highest carbon footprint. Therefore, a fast transition to electric vehicles using nickel-rich chemistries is likely to lead to an increase in GHG emissions from nickel production and/or to capture some of the production used in other sectors, mainly stainless-steel.

Policies are currently being developed to address this issue. For instance, the new EU battery regulation aims at limiting the carbon footprint of batteries and increasing their recycled content. Unfortunately, such measures might shift, bury or even increase the problem by incentivising competition for “green” nickel in certain applications, instead of addressing the underlying issue - a rapidly increasing overall demand for nickel is likely to be met with carbon intensive production routes. We show that a targeted reduction in the carbon footprint of batteries can potentially be achieved at the expense of other product categories or world regions, which does not help mitigating global emissions. Furthermore, recycled content targets for batteries could encourage the use of stainless-steel scrap to produce recycled nickel for batteries, a less efficient use from a systemic perspective than recycling steel to steel and could lead to an overall increase in emissions.

This work highlights the potential for modelling global element cycles with demand-driven supply-constrained dynamic material flow analysis models to uncover systemic impacts and risks of problem shifts associated with fast transitions.

Poster 2.05

Corporate raw material criticality assessments - a systematic review

Natalie Otterbach (Chair of Circular Economy, TUM Campus Straubing for Biotechnology and Sustainability, Technical University of Munich), Magnus Fröhling (Chair of Circular Economy, TUM Campus Straubing for Biotechnology and Sustainability, Technical University of Munich)

Businesses play an essential role in the debate on raw material criticality. They address the entire value chain, encompassing material selection, mining, product design, usage, and end-of-life strategies. Consequently, powerful levers for risk mitigation can be activated by establishing criticality methodologies as systematic decision-making tool within companies. So far, raw material criticality assessments and reviews have focused on an overall, global, or national scope, rather than on corporate scope (e.g., Graedel et al., 2016; Helbig et al., 2021; Jin et al., 2016). Previous reviews, like Schrijvers et al. (2020), provide an extensive overview of the methodological structure of criticality assessments in general. However, the goal and scope of an assessment determines the methodological choices and respective results (Schrijvers et al., 2020).

As such, this study strives to furnish researchers and industry experts with an in-depth analysis and overview of existing corporate raw material criticality methodologies, in order to integrate the existing knowledge into more advanced and applicable corporate methodologies. Thereby, our study can facilitate identifying the raw materials of strategic relevance, suitable risk mitigation strategies and essential success factors for an effective integration into corporate processes of the respective business.

To achieve this aim, a systematic review of corporate raw material criticality methodologies is combined with semi-structured qualitative interviews with experts from industry. Industry requirements and experiences can be used to examine the status quo from a practical perspective and to identify the greatest potential and need for further development.

As a result, a framework is developed which provides a comprehensive overview of the main methodological choices and specifics within corporate criticality assessments, covering goal and scope definition, considered dimensions, indicators, data sources, aggregation methods, visualisation, and communication, as well as risk mitigation measures. Combining the scientific and industry perspective, moreover, allows to highlight the research demand from the perspective of the main target group, also integrating developments in the corporate context. Overall, a profound basis for further and new developments of corporate raw material criticality methodologies is created.

Poster 2.06

Present and future supply risk estimation of materials for photoelectrochemical water splitting

Martin Hillenbrand (University of Bayreuth), Roland Marschall (University of Bayreuth), Christoph Helbig (University of Bayreuth)

The goal of a sustainable energy future has amplified the importance of Green Hydrogen – an energy carrier that promises a cleaner environment without the emission of greenhouse gases. However, the production capacity of Green Hydrogen through electrolyzers remains constrained due to limited supply of renewable power, necessitating advanced research and technological innovations. One such potential alternative is photoelectrochemical (PEC) water splitting, which converts energy from solar radiation directly into the chemical splitting of water into hydrogen and oxygen.

This study delves into the supply risks associated with various materials currently under research for PEC water splitting. Utilizing Raw Material Criticality Assessment methods, we evaluate the present and future supply risks of selected PEC materials to determine their viability for large-scale Green Hydrogen. Recognizing the nascent stage of extensive PEC installations, our analysis differentiates the supply risk between present and future scenarios.

Our findings indicate that, in the present, Ta3N5 presents the lowest supply risk. However, projections suggest that alpha-SnWO4 will have an even lower supply risk score in the future, hinting at a potential shift in the research landscape which is currently dominated by other materials including BiVO4 and Fe2O3. These materials, however, show higher supply risk scores in our assessment. Additionally, we quantify the potential surge in demand that would accompany the large-scale deployment of the most promising PEC materials.

Poster 2.07

Disaggregating prospective macroeconomic scenarios to quantify xEV battery raw materials needs

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Quantify Electric vehicle (xEV) battery material needs: a dataset and methodology to disaggregate macroeconomic scenarios.

Although many energy transition scenarios are proposed for the European Union (EU-27) region a robust approach to quantify the raw materials (RM) needs for such transitions to happen is still lacking, despite their critical role. Whereas mainly grey literature or institutional reports propose quantification the broad scope or underlying hypothesis rarely allows for grasping details for the EU-27 mobility sector. We will propose a FAIR(Findable, accessible, interoperable, reusable) framework to quantify the RM (i.e. at least Li, Co, Ni, Mn, Graphite) needed for xEV, for energy storage technologies (ESS), of mobility and freight from existing macroeconomic scenarios.

When investigating demand for ESS, xEV could represent up to 80% of the storage demand but as electrochemical storage is composed of a disparate set of chemistries or technologies, what are the possible RM demands? Reckoning the need to secure our critical RM supply, the EU has initiated several policies, including the Battery Regulation Act and the Critical Raw Material Act, all of them targeting specific materials. As relative goals (e.g., collection or recycling rate, in %; % of EU processing capacity per raw materials) have been set, there is also a need for a methodology to infer absolute values for RM needs for xEV.

This research plans to gather historical data and prospective hypotheses to draw RM demand pathways for passenger mobility and freight. Using the current EU mobility pattern and prospective scenario, we plan to produce a dataset, a disaggregation methodology (i.e., along with hypothesis) and software to quantify the RM necessary to achieve the transition proposed for the mobility and freight sector. From published scenarios giving values such as energy consumption or activity (i.e. in passenger kilometre or ton kilometre), the current state of the fleet and the targeted evolution is input, the model will compute the fleet which fits the best to the values given in the macro-economic scenario. Additionally, hypotheses on battery size and chemistry share of ESS will allow us to quantify the raw material needed.

The result of this research should provide the material necessary to understand the industrial capacity needed to underpin the value chain of energy storage, from the manufacturer to the recycler. It will allow future assessment of the security of supply, the benefits of circular economy strategies and the impacts of key parameters on RM circularity and demands.

Poster 2.08

Technological Innovations in lithium-ion batteries waste management

Elza Bontempi (INSTM and Chemistry for Technologies Laboratory, University of Brescia), Matteo Scaglia (INSTM and Chemistry for Technologies Laboratory, University of Brescia), Antonella Cornelio (INSTM and Chemistry for Technologies Laboratory, University of Brescia), Alessandra Zanoletti (INSTM and Chemistry for Technologies Laboratory, University of Brescia)

It is predicted that 2 million metric tons of waste batteries will be generated worldwide by 2030. To face this problem and to avoid the risk of strategic metals' low availability, technological innovations are mandatory. This work presents a recently proposed strategy for waste batteries management, in accordance with the targets of the European Commission's proposed Regulation on Batteries and Waste Batteries.

The new technology is based on microwave use, with the aim to substitute classical pyrometallurgical approaches in lithium-ion battery recovery processes.

Poster 2.09

Battery materials demand and end-of-life management in Europe's e-mobility transition

Wu Chen (SDU Life Cycle Engineering, University of Southern Denmark), Juan Tan (Center for Minerals and Materials, Geological Survey of Denmark and Greenland), Rui Zhang (Research Institute of Artificial Intelligence, Zhejiang Lab), Jakob K. Rasmussen (SDU Life Cycle Engineering, University of Southern Denmark), Jakob L. Karlsson (SDU Life Cycle Engineering, University of Southern Denmark), Burak Sen (SARGEM, Sakarya University), Jakob K. Keiding (Center for Minerals and Materials, Geological Survey of Denmark and Greenland), Xin Ouyang (University of Chinese Acad), Qiance Liu (SDU Life Cycle Engineering, University of Southern Denmark), Gang Liu (6, SDU Life Cycle Engineering, University of Southern Denmark)

The carbon neutrality target in Europe necessitates electric cars (EVs) deployment but also results in potential resource constraints for batteries. Most previous studies on the material implications of car electrification have not explicitly considered the lifetime difference between EVs and batteries, particularly together with dynamics in battery technology and recycling pathways. Here, we developed a product-component dynamic material flow analysis model for 32 European countries (EU28, Norway, Iceland, Switzerland, and Turkey) and explored the supply-demand gaps of lithium, cobalt, manganese, and nickel under various scenarios. We found that realizing 100% electrification in Europe causes significant amount of cumulative demand (2021-2050) for primary lithium (2798 kt), cobalt (386 kt), manganese (332 kt), and nickel (2606 kt), signalling supply risks for all materials except nickel even combining strategies of battery technology. Among other factors, deploying battery technology, especially advanced LFP battery technology, is found the most critical to relieve resource pressure. We also reveal a trade-off effect for second-life use of EV batteries: it may worsen critical materials demand-supply gaps but can mitigate demand and carbon impact for prospective surging energy storage systems. Our product-component model can be used for other product systems and suggests the need for a systems framework to maximize the synergies among material, energy, and climate strategies in the e-mobility transition.

Poster 2.10

Evaluating strategies for managing resource use in lithium-ion batteries for electric vehicles

Fernando Aguilar Lopez (Norwegian University of Science and Technology), Romain Guillaume Billy (Norwegian University of Science and Technology), Daniel Beat Müller (Norwegian University of Science and Technology)

The exponential increase in lithium-ion battery (LIB) demand for electric vehicles (EVs) has sparked material supply concerns, which makes the understanding of the LIB system and its drivers a pertinent issue. To understand the uncertainty and sensitivity around these drivers, we introduce the MATerIaL Demand and Availability (MATILDA) model. We investigate resource use within the global LIB cycle in the context of EVs and the potential secondary material supply generated by alternative scenarios. Using this dynamic, multi-layer material flow analysis model, we conducted a detailed, time-explicit sensitivity analysis to broaden our understanding of the critical factors affecting resource supply. We identified potential problem shifts between Co, P, Ni, and Li and evaluated alternative strategies to mitigate their criticality over time. We show that social paradigm shifts such as using fewer, smaller vehicles as well as technological developments can play an important role in enabling a sustainable transition.

Poster 2.11

Limited lithium supply is likely to slow down the electrification of the transport sector

Brent McNeil (Norwegian University of Science and Technology, Materials Transition), Romain Guillaume Billy (Norwegian University of Science and Technology), Fernando Aguilar Lopez (Norwegian University of Science and Technology), Evi Petravatzi (British Geological Survey), Daniel Beat Müller (Norwegian University of Science and Technology)

Most scenarios for climate change mitigation rely on a fast decarbonisation of the transport sector based on a transition to battery electric vehicles (BEV) using lithium-ion batteries (LIBs). Different LIB chemistries exist, all requiring different proportions of critical raw materials which can to some extent be substituted by one another. However, all these chemistries use comparable amounts of lithium.

Despite the geologic abundance of lithium, the rate of extraction and processing may fall short of the increasing demand for the electrification of the transport sector. Tensions on lithium supply have already contributed to a price increase of more than 400% in 2021. Continued supply constraints could limit the speed and scale of the electric mobility transition and therefore threaten climate targets.

To analyse potential lithium shortages, we modelled future demand and supply scenarios. Demand scenarios are based on the open-source model MATILDA, which considers several global electrification pathways using parameters such as electrification speed, population, vehicle ownership, size of cars and batteries, battery chemistries, and recycling technologies.

Supply scenarios were defined from an assessment of geologic, economic, environmental, and social constraints related to lithium production. Lithium resources were classified into ten groupings, based on world regions and deposit types. For each grouping, three future supply scenarios were defined: "Probable", "Optimistic", and "Breakthrough", assuming increasing levels of social acceptance for mining and confidence in the development of new extraction technology.

Our results show that in the next decade, lithium supply is very unlikely to keep pace with rapidly increasing demand. Consequently, this could limit the speed and scale of the transition to electric mobility. This shortfall will be very difficult to mitigate because of the long time required to increase mining capacity. Recycling cannot be scaled quickly enough to close the gap due to the long lifetime of cars. Lithium-free technologies, such as sodium-ion batteries, are unlikely to reach the automotive mass market in the next few years but will be needed to ease lithium demand. On the contrary, new solid-state and lithium-metal batteries require even more lithium than current chemistries. The identified supply gap can only be closed through a reduction in final demand for electric transportation, which means fewer vehicles per capita and/or limitations regarding the size of cars and batteries.

In the long term, the size of the supply gap is more uncertain, and shortages can be avoided under certain conditions. Deep societal changes, close-to-perfect recycling, and a diversified portfolio of battery technologies are required to limit demand. At the same time, considerable efforts to increase raw material production will be needed to meet Net Zero scenarios.

Session 3: New forms of sustainable value creation

Poster 3.01

Comprehensive investigation on unconventional lithium resources: when geothermal energy helps Europe

Marcella Balordi (RSE), Nunzia Bernardo (RSE), Cristina Guardamagna (RSE)

Lithium is the most important metal for batteries (LIBs). The proliferation of new technologies for energy transition, particularly in electric mobility or energy storage, has significantly increased the demand for lithium. The European demand for lithium will grow up to 30 times by 2050 to cope with the spread of electric vehicle batteries and energy storage. Despite the development of alternative energy storage technologies, such as sodium-ion or zinc-ion batteries, LIBs remain the best-performing batteries.

Lithium is a relatively rare element in the Earth's crust. It can be found in hard rocks, where its main mineral sources include spodumene, petalite, lepidolite, and amblygonite. Continental and geothermal brines can be also significant for lithium recovery. Australia, Brazil, China, Canada and Zimbabwe are the major producers of lithium-derived hard rock, while brine deposits are mainly found in Chile (Salar de Atacama), Argentina (Salinas Grandes), USA (Clayton Valley) and Bolivia (Salar de Uyuni).

Geology is a key factor for the distribution of lithium in the Earth's crust; Europe is relatively poor in lithium and so alternative sources need to be found to ensure a secure domestic supply. It is also crucial to define new methods of extraction and refining with low social, economic and environmental impact, to maximize the potential of the alternative sources of this CRM.

Li is a lithophilic element; it forms silicates or oxides and is associated with the Earth's crust. It concentrates in hydrothermal fluids and can be found in volcanic areas, very common in Italy due to the geo-structural and geodynamic setting.

This study represents a comprehensive investigation of the mining potential of geothermal fluids covering both the geological and geochemical aspects.

The first part discusses potential lithium sources by collecting and comparing literature data related to well and geothermal fluids, at a global, European, and Italian level. This study reveals that lithium in Italy is in very high concentrations, exceeding 200 ppm in areas near certain volcanic districts.

For the geochemical aspects, laboratory activities are presented, focusing on the analysis of natural geothermal brines to identify the chemism of geothermal fluids.

Finally, the main methods and technologies to selectively extract lithium from continental and geothermal brines are presented together with preliminary extraction tests conducted in our laboratories, by using innovative materials.

Poster 3.02

"Circular Economy approach for value creation in the Cobalt supply chain"

Juan Pablo Mardones (British Geological Survey, University of Exeter Business School), Evi Petavratzi (British Geological Survey), Markus Zils (University of Exeter Business School), Mickey Howard (University of Exeter Business School)

Cobalt is a critical raw material (CRM) with risks to supply in several aspects of its value chain, for example product concentration (extraction and refining stages), feedstock availability within the timescales needed to meet net zero targets, environmental, social and governance challenges, price volatility and many more. Given the rising global demand for batteries, electronics and magnets, among other applications, the supply of cobalt is expected to continue to play an important role in emerging technologies. According to the IEA [1], the projected total demand for cobalt will reach 284 kt in 2030 and 525 kt in 2050 under the Announced Pledge Scenario (APS). In 2021, the total global mine production of cobalt was 131 kt [2], which means that production will need to double in the next seven years to meet the projected demand. This would require a rapid scale up of global primary production as well as an expansion of secondary supply.

Governments of major economies have in recent times produced or are working towards CRM strategies, aiming at improving primary and secondary supply. Except from the case of the EU CRM

Act [3] and the EU Battery Regulations [4] that set mandatory recycled content targets for cobalt use in batteries (e.g. 16 % by 2031), concrete goals for the deployment of the Circular Economy (CE) of CRM are not given. Even in the case of the European Union, clarity around the processes required to achieve these material requirements are lacking. This is due to a systemic understanding gap of the linear and the future reverse supply chains of CRM. Bearing in mind the core principles of CE, for example eliminating waste and pollution and circulating products and materials, CE provides additional advantages through lower exposure to energy transition setbacks, security of material supply, ESG concerns associated to mining, and extraction of the retaining value of the CRM.

The objective of this PhD project is to develop a systemic understanding of the embedded flows of cobalt products and their fate when reaching the end-of-life. The project will explore value leakages and assess value creation opportunities in the supply chain of cobalt from a CE perspective, with a focus on examining value loops streaming from secondary flows such as material recycling and resource recovery from end-of-life products as well as tailings. The project will provide new data that can be utilised to develop tailored CE policy, together with quantitative targets associated with secondary cobalt supply.

Poster 3.03

The global challenge of magnesium in demand of a low carbon competitive environment

Martin Tauber (International Magnesium Association)

The global magnesium supply base needs to undergo a green transformation both in global primary production and in secondary & recycling value chains. Also new agreements are necessary to stabilise global supply through geopolitical decentralisation and ways of trade. Up-grades and new market applications for magnesium need to utilize the full potential of the material. The green demand of raw materials needs to be synchronised with policy and technical developments avoiding unnecessary and uneconomical substitution.

Session 4: Emerging sectors and materials

Poster 4.01

Resilience of Space Economy in the context of global competition for critical materials

Yulia Lapko (Politecnico di Milano), Alessandro Paravano (Politecnico di Milano), Paolo Trucco (Politecnico di Milano)

Space Economy has received increasing attention over the last five years as the number of space assets in the orbit has quintupled. The technological downsizing and cost reduction of space assets has led to a flourishing of new businesses. The introduction of new digital technologies has transformed the Space Economy into a cross-technological realm, attracting a growing number of users, interested in leveraging space assets to monitor land, water, air. Despite the benefits generated by space assets, they require nearly all strategic and/or critical materials. There are only a few studies that provide implications for vulnerability of the Space Economy, highlighting its uncertain competitive position at material markets due to niche utilization of critical materials. This study aims to provide more in-depth examination of the resilience of Space Economy, its capacity to tolerate the supply chain disruptions associated with critical materials. We determine in more detail the concept of resilience in the context of material criticality and analyse the Space Economy through the developed framework. The obtained results provide valuable implications for other sectors employing critical materials.

Poster 4.02

2BoSS A battery technology based on silicon, sulfur, and biomass derived carbon

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2BoSS innovation is a Si-Li2S battery technology made of a cobalt free Li2S-based cathode and a graphite-dendrite free silicon-based anode which is under development within the 2BoSS project (https://2boss.eu/). Besides improving performance and safety, as well as minimizing the use of Critical Raw Materials (CRMs), a key advantage of the battery technology here proposed is the easier recycling of its raw materials. 2BoSS batteries are designed to use no metal collector and to incorporate no metal additive at the cathode, anode, and electrolyte, which will allow a more effective and economical separation of the two key raw materials: silicon and lithium.

2BoSS is validating effective lixiviation strategies to separate and regenerate the battery key elements and defining its upscaling.

Batteries are an essential component of portable devices and electric vehicles, and their rapid growth requires both to secure the availability of the used raw materials and to develop effective and economical strategies for their recycling. Lithium-ion batteries are the current dominating technology, but they have several intrinsic limitations that hinder their sustainable production, such as a moderate specific energy capacity and durability, a strong reliance on several CRMs, and the complex and costly recycling of these CRMs related to their dispersion and intermixing with other metals.

The proposed technology offers a higher energy density and theoretical capacity, use of abundant materials and increased safety compared to traditional lithium-ion batteries. 2BoSS technology solves the challenges consumers, industrial users and society at large are facing in terms of safety, reliability, environmental and social sustainability of electrification of mobility. With our battery innovation the future of EVs is in line with key customer requirements and with all the upcoming regulations, especially Critical Raw Materials Act target objectives, circularity of design and valorization of recycled materials.

Poster 4.03

Applying criticality methods to the agri-food sector: case study integrating mineral, land and water

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The dependence of agri-food systems on resources can threaten the food supply security of populations. These systems require various resources to meet the food needs of populations, such as mineral resources like phosphate rock, but also other abiotic resources like water or land. However, agri-food supply chains have been overlooked from criticality studies. In addition, water and land resources have rarely been taken into account in existing criticality methods.

The aim of this study is therefore to apply criticality methods to an agri-food system, including criticality metrics for water and land. Two contrasting bread supply chains (BSC) (A and B) are used as an illustrative case study. They differ by agricultural practices, milling and baking processes, as well as transport distances.

The criticality assessments were integrated into the Life Cycle Assessment of the two BSCs by using the supply risk (SR) indexes of two renowned criticality methods for mineral, land and water resources. The two criticality methods chosen were that of the Yale University (Graedel et al., 2012) and that the Joint Research Centre (JRC) (Blengini et al., 2017) as they are recognized for their scientific robustness, transparency, applicability and high level of acceptance (Hackenhaar et al., 2022). They also both cover numerous mineral resources, and the Yale method has been adapted to water following the developments of Sonderegger et al., (2015). The two methods have been adapted to develop land SR indexes at country level by adapting each parameter of the original SR index for mineral resources to the land context. The JRC method was also adapted to water using the same methodology.

The results indicate that fertilisers contribute the most to the mineral SR of agricultural products due to phosphate, that land SR is due to agricultural production and forestry for energy and packaging, and that water SR is mainly related to electricity production, in particular in the case of electric furnace. A comparison of the two BSCs shows trade-offs between resources SRs: BSC A has a lower land SR than B, because BSCA has a lower wheat yield and uses wood for baking, so it requires more land per kg of bread. However, BSC B has a higher water SR than BSC A, because BSC B uses more water for its energy needs (hydro-electricity), particularly during the baking phase. Furthermore, the Yale and the JRC methods can provide different results due to differences in scope, resource coverage or modelling choices.

This study shows the interest and feasibility of applying criticality methods to the agri-food sector. Indeed, it allows to determine the main critical resources over the products life cycles and to identify those least vulnerable to SR. Yet, disparities between criticality methods were observed. Therefore, applications to other case studies and with other criticality methods would boost further investigations on food systems criticality.

Session 5: New data and tools

Poster 5.01

New digital tools are needed

Alexandra Pehlken (OFFIS), Lisa Dawel (OFFIS), Maria Davila (OFFIS)

The strategy of the European Circular Economy strategy as part of the European Green Deal seeks to minimize the environmental impact of production and consumption, while promoting economic growth, innovation, and job creation. How do we measure the environmentalt production and consumption within open loop supply chains?

The concept, known as "Design for Sustainability," emphasizes the creation of products that last longer, are easier to repair, and inherently more recyclable. Enhancing resource use efficiency across sectors and curtailing waste generation will undoubtedly be a pressing challenge for the EU manufacturing industry in the coming years.

Today's product engineering tools, unfortunately, are not fully primed for this paradigm shift. While they often emphasize cost-efficiency and other performance metrics, they typically overlook the imperatives of sustainable design. Traditionally, manufacturers have not viewed their products as part of their ongoing supply chain—once sold, products seldom return to their origin. However, a transformation is underway. Manufacturers are increasingly recognizing used products as valuable resources in their supply chain.

The pressures surrounding resource acquisition, especially given that a large proportion of raw materials are imported from non-EU countries, cannot be ignored. Recognizing this, the European Union's Critical Raw Materials (CRM) initiative is addressing the sustainable and secure provision of essential raw materials crucial for industries ranging from electronics to renewable energy.

Today, there is – besides Life Cycle Assessment- neither a standard process nor hardly any digital support tool available to guide the manufacturer to design products for a reuse, recyclability right from the beginning, including the involved critical materials. As it is nearly impossible for manufacturers and consumers to overlook all necessary and important developments for sustainable resource management, digital tools play a crucial role in advancing the European Circular Economy strategy.

The proposed session discusses the main KPIs to serve as a benchmark for the sustainability of a product and assesses digital shadows as a solution for the stated problem. This tool is not just aligned with recycling and sustainability goals but also serves to reduce risks linked to dependencies on raw materials.

The research presented here is a component of a broader initiative aimed at creating a robust tool: a sustainability digital shadow. Our current research dives deep into the prospects of employing digital shadow for the principle of "Design for Sustainability" within the manufacturing domain (case study ESP- Electronic stability program within the EU Project CIRC-UITS). The objective is to discern how these digital counterparts can be most effectively harnessed to drive sustainable design and, by extension, foster a more resilient and circular manufacturing ecosystem.

Poster 5.02

Materializing the Risks in Raw Material Supply by the Event Analysis

Hiroki Hatayama (AIST), Shinsuke Murakami (The University of Tokyo), Yurie Anzai (AIST)

Critical raw materials are identified by considering the supply risk in various aspects. In evaluating the degree of those risks for different materials, the development of data and subsequent indicators enables the broader aspects of supply risk to be taken into account. On the other hand, the lack of data can be an obstacle to incorporating the severe risk factors into the criticality assessment. For example, a natural disaster risk has not been incorporated into the criticality assessment so far although it is recognized as a major cause of past supply disruption events. Furthermore, it would become more complex when reflecting differences in risk by supplier regions. To support the proper identification of critical raw materials, much room for discussion is left on developing the risk data and processing them for supply risk evaluation.

This study proposes a methodology to evaluate the supply risk associated with supplier countries for three risk factors: natural disaster, industrial accident, and labor strike. We employed three approaches to obtain the past event data relating to those risks: 1) meta-analysis of past supply disruption events, 2) web-scraping from mining news, and 3) exploitation of existing database. We then analyzed these data to measure the degree of which supplier countries are associated with each risk factor. Finally, the risks of natural disaster, industrial accident and labor strike in different countries are evaluated as risk scores. Whereas the criticality assessment has been using country indicators such as the World Governance Indicator and the Policy Perception Index, we found that there is naturally no correlation between those existing indicators and the risk scores evaluated in this study. The result indicates the potential and necessity to develop the criticality assessment to consider broader supply risk issues, for which it is essential to accumulate the objective knowledge and data across the supply chain of raw materials.

Poster 5.03

Unlocking the Potential of Secondary Raw Materials: A Web Tool Based on UNFC Criteria

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The recovery of secondary raw materials, especially critical raw materials, from various waste streams has become imperative for a sustainable and resource-efficient future. There are many approaches to evaluating recycling and recovery projects, usually focusing on technical feasibility. The environmental impact is in general evaluated using a life cycle analysis (LCA). However, there is a lack of a consistent approach to determining the potential of a project to recover valuable components from waste streams as secondary raw materials, as is the case with primary raw materials. In addition to the economic viability, it should capture both environmental and societal impacts.

To effectively assess and classify the feasibility and viability of recovery projects, a systematic approach is essential. The United Nations Framework Classification of Resources (UNFC) provides such a context, as it is a principles-based classification system for determining the environmental-socio-economic viability and technical feasibility of resource development projects. However, there is no guidance on how the UNFC can be used for secondary raw materials projects. We introduce the "Structured Anthropogenic Resource Assessment (SARA)" webtool, developed as a part of the Future Availability of Secondary Raw Materials (FutuRaM) project, as an innovative solution that supports project developers, authorities, investors and in consequence decision-makers in conducting a holistic project classification according to the principles of the UNFC. At its core, SARA relies on the UNFC criteria, which comprise three essential categories: the degree of confidence in estimates (G-axis), technical feasibility (F-axis), and environmental-socio-economic viability (E-axis). This tool offers a structured, user-friendly interface with customizable inputs, ensuring that project developers can efficiently and accurately assess their projects. With the help of seven coordinated steps, the user is guided through the menu to end up with not only the UNFC code reflecting the maturity of the project but also the basis for reporting with an overview of the project's opportunities and barriers. By enhancing transparency and facilitating informed decisions, this tool plays a pivotal role in the responsible utilization of secondary raw materials, thus contributing to the circular economy and sustainable resource management.

This paper begins with an introduction to the SARA webtool, explaining why it is essential for secondary raw material projects. Through an interactive demonstration, we will then discuss the user-friendly interface, the power of customizable inputs, and the seven coordinated steps that guide users assess the feasibility and viability of secondary raw material projects. It will provide insight into how this tool enables the determination of the project's maturity level according to the UNFC while providing a roadmap for decision-making throughout the project development cycle.

Poster 5.04

Recent updates and features of the IRTC Decision Tool

Dieuwertje Schrijvers (WeLOOP), Tamara Schmidt (WeLOOP), Alison Vandromme (WeLOOP), Alessa Hool (ESM Foundation)

Within the context of the International Round Table on Materials Criticality (IRTC), a web-based tool has been developed to help inform companies about their decisions related to raw material value chain risks.

The tool is based on a cause-and-effect model that links typical criticality indicators, such as concentration of supply, by-product dependency, environmental impacts, and social concerns to potential damages experienced by a company. The tool suggests potential mitigation measures tailored to the specific sources of risk and provides information on potential hurdles in their application.

A prototype of the IRTC Decision Tool was launched during the Raw Materials Week in 2022. In the meantime, new materials, semi-finished products, strategic sectors, indicators, and updated data have been added, and the scientific publication that describes the scope and limitations of the tool has been finalized. This presentation provides an overview of recent updates and developments around the tool.

Poster 5.05

Toward Prospective Dynamic Criticality Assessment Using System Dynamics Modelling

Jessie Bradley (Delft University of Technology), Willem Auping (Delft University of Technology), Rene Kleijn (Leiden University, the Netherlands), Jan Kwakkel (Delft University of Technology), Benjamin Sprecher (Delft University of Technology)

Metal supply chains are part of complex systems that are constantly evolving over time. These metal supply systems are often evaluated through static snapshots in current material criticality assessments. Such assessments are useful for identifying short-term challenges and opportunities but fail to capture certain risks and possibilities of longer-term developments such as the energy transition. For capturing such dynamic complexity, System Dynamics (SD) modelling is a valuable tool. SD models provide insights into future demand projections, but also into the ability of supply to keep up with demand, through the inclusion of feedback loops, delays and accumulations. Existing SD models of global metal supply chains have a high level of aggregation. In contrast, we are developing a model that includes geographical and sectoral disaggregation, which allows for prospective dynamic criticality assessment. With this model we can explore regionally and technologically specific supply chain losses, recycling rates, product lifetimes, sustainability impacts, and supply risks, based on changing sectoral shares and regional concentration of primary and secondary production over time. We can use the model to test the impacts of various disruptions, such as geopolitical disturbances, societal crises, and radical innovation, as well as the impacts of various policies and strategies for improving supply chain sustainability and resilience. Using the model can highlight trade-offs and interferences between these strategies, which is essential for making informed decisions that balance environmental, economic, and social considerations. We combine the model with Exploratory Modelling and Analysis (EMA) by exploring a large number of possible futures that include various structural and parametric uncertainties. The resulting methodology provides a comprehensive approach to understanding the potential future developments and criticality of global and regional metal supply systems, and what can be done to improve their sustainability and resilience.

Poster 5.06

Criticality: From raw materials to energy systems

Michaela Schicho (Fraunhofer Institute for Systems and Innovation Research ISI), Luis Tercero (Fraunhofer Institute for Systems and Innovation Research ISI)

The discussion on raw material criticality has gained in volume and detail over the last two decades, with a variety of investigations for different materials, applications, and stakeholders. These past efforts enable putting numbers on the abstract concept of security of supply.

In order to use this quantification as an indicator in large-scale decision-making, the concept of criticality needs to evolve to characterize entire systems made up of multiple materials and technologies deployed to different degrees. Such an assessment at the system level would help to better address trade-offs between alternatives to reach societal, policy or industry goals.

Herein, we propose an approach allowing for a quantitative criticality assessment of entire systems and demonstrate its usability using scenarios for the energy transition in Germany. Previous work in energy systems analysis describes cost-optimized transformational pathways towards the decarbonization of said energy system. Using the proposed methodology, we evaluate selected scenarios in terms of security of raw material supply. The methodology consists of conventional supply risk analysis on the raw material level, and two subsequent aggregation steps yielding merit numbers at the technology and system level.

Poster 5.07

Raw Material Radar: Responsible Mining in West Africa with Blockchain & IoT

Luca De Marco (FBK), Massimo Vecchio (FBK)

The Raw Material Radar (RMR) project seeks to address a significant challenge in the raw material sector, particularly within the European Union. The EU faces vulnerability to shortages of critical raw materials (CRMs), exacerbated by the Conflict Minerals Regulation, which obliges EU importers to ensure responsible sourcing of 3TG minerals (tungsten, tantalum, tin, and gold) to avoid conflict-affected regions. A transparent, trustless solution is essential to enhance regulatory compliance and fair trading of CRMs.

The primary issue with CRMs is the difficulty in distinguishing sustainable extraction from unsustainable practices, especially in supply chains originating from Africa. Lack of traceability and control tools makes it hard for stakeholders to verify environmental and social standards compliance.

The RMR project aims to revolutionize CRMs supply chains by integrating cutting-edge, cost-effective technologies. It plans to introduce a platform that leverages IoT and blockchain, providing a legal alternative for Artisanal Small-scale Mining (ASM) and enabling automatic, transparent tracking of CRMs shipments. This approach eliminates the need for centralized third-party authorities, promoting responsible sourcing and equitable distribution of benefits.

The consortium behind RMR includes diverse partners, such as a mining consultancy ECTerra, a research institute Fondazione Bruno Kessler (FBK), a technology foundation Hub Innovazione Trentino (HIT), and a technology company Minespider Germany GmbH.

RMR combines IoT tracking hardware with sophisticated software to automate data collection, improving accuracy and reducing human errors. The software integrates with Minespider's blockchain-based due diligence system, creating a transparent and indisputable tracking system for CRMs from mining to final destination.

Containers are sealed with IoT tracking devices after material assessment, allowing continuous monitoring of their status and location. All relevant information is securely stored in a blockchain-based infrastructure. The system offers auditing features, producing certifiable documents in compliance with the EU Conflict Minerals Regulation to promote transparency in the RM market.

RMR aims to create transparent and responsible tantalum supply chains using blockchain and IoT sensors. The goal is to increase ASM transparency and legalize ASM activities, ensuring compliance with the Conflict Minerals Regulation. Blockchain guarantees traceability and transparency, while IoT devices interact with the blockchain, ensuring data trustworthiness without intermediaries. Additionally, the project focuses on stakeholder engagement, social development, vocational training, and community building for its success.

Poster 5.08

Recycling of Lithium-ion batteries to meet sustainability challenges of mobility electrification

Kim LUU (WeLOOP), Dieuwertje SCHRIJVERS (WeLOOP), Naeem ADIBI (WeLOOP)

The importance of batteries has been increasing recently due to the electrification of the transportation sector and their use in energy storage for renewable energy. The lithium-ion batteries (LIB) are among the most mature and mainstream technologies. The production of conventional lithium batteries requires critical raw materials (CRM), such as cobalt, lithium, and natural graphite. One of the most efficient ways to mitigate the criticality of raw materials is recycling, which is now a hot topic with the European Commission battery regulation coming into force.

Recycling processes have many associated economic, environmental and social issues, making monitoring the sustainability of the recycling processes for lithium batteries essential. Through its various projects on LIB, WeLOOP has developed a state-of-the-art on LIB recycling processes, their maturity in the market, the main actors, and the capacities needed in France and Europe to meet the EC targets. WeLOOP also evaluated their environmental impacts via Life Cycle Assessment (LCA), developed several LCIs (Life Cycle Inventories) for different recycling processes (conventional and innovative), and tested modelling the recycled materials through these different recycling methods using parametrized economical allocation.

LCIs for recycling processes are crucial for assessing the recycling benefits and impacts. They also allow the application of the CFF formula in mandatory carbon footprint declarations for EV batteries to determine the impact of recycled versus mining extraction. Throughout this exercise, WeLOOP has built an LCA database for EoL processes and recycled materials but also a platform called BATTERS collecting and listing all LCIs available by different actors to help LCA practitioners and manufacturers to identify LCIs for innovative processes or technologies and encourage companies to work with new innovative actors to improve the sustainability of batteries.

Poster 5.09

Building a Sustainable Future for Tin: Exploring the Tin Code and other sustainability initiatives

Mayra Diaz del Olmo Oliveira

Justification

The demand for responsibly sourced minerals is increasing, which requires responsible practices throughout the supply chain. Tin is a vital metal for a decarbonised and digitalised future holding together almost all of our electronic and electrical infrastructure.

In the 2010s, responsible sourcing expectations for tin changed due to concerns over "conflict minerals" and armed groups in the DRC and neighbouring areas. The Dodd-Frank Act mandated reporting for US companies on minerals sourced from the DRC and surrounding countries. The EU Responsible Minerals Regulation expanded this to cover conflict and high-risk areas globally. Now, the industry faces broader expectations for social, human rights, and environmental impacts under new EU frameworks like the EU CSDDD.

This initial focus on conflict minerals catalysed the tin sector to act proactively. In 2018, the Tin Code was launched, providing the first comprehensive framework for transparent sustainability reporting and improving sustainable practices in the tin industry.

Methodology

The Tin Code is a progressive global sustainability reporting framework designed for tin companies of all sizes covering exploration to mining, smelting and recycling. Companies that participate in the program complete a self-assessment questionnaire and submit supporting evidence for each standard. An independent assessor then reviews the evidence and assigns one of the six progressive performance ratings. Companies are expected to achieve third-party verification of each of the standards. ITA has enabled this through the implementation of the Assurance program which uses ISAE 3000.

Results

The Tin Code has had a positive impact on the tin industry. For instance, it has helped to enhance transparency and accountability among major tin producers and within the supply chain achieving 59% of global tin production reporting against the same standards. As a result, companies have improved their governance and raised awareness of global sustainability expectations. The Tin Code has inspired other practical sustainability improvements in producing areas including through; the Indonesia Tin Working Group, a multistakeholder project to improve OHS and environmental reclamation of Indonesian tin mining, including ASM, Tin Life Cycle Assessment (public) providing information on the environmental footprint of refined tin, and the ASM Handbook.

Implications

The Tin Code offers a valuable model for promoting and progressing towards sustainable practices in the tin mining industry. Companies demonstrate their commitment to responsible sourcing and sustainability. By implementing the Tin Code, companies can mitigate environmental, social, and governance risks, which will improve operational stability and confidence in the industry. Through its collaborative approach, it has the potential to transform the tin mining industry towards a more sustainable future.

Session 6: New ideas on critical raw materials

Poster 6.01

Method proposal to assess biomass feedstock criticality in the context of bioeconomy

Siddharth Goel (International Institute for Sustainable Development), Tom Moerenhout (Columbia University Center on Global Energy Policy, International Institute for Sustainable Development Switzerland, 3), Christopher Beaton (3)

Globally, state-owned enterprises (SOEs) are among the largest oil-, gas, and coal producing companies, and are major players in energy-intensive industries in many countries (Benoit, 2019), making them an important grouping for efforts on energy transition. The role of SOEs is often overlooked, but they can play an important role in filling the investment gap in critical mineral supply chains. The diversification of their business models towards clean energy can also support broader decarbonization efforts in emerging economies.

SOEs are particularly important in developing economies, where they are often the dominant actor in certain energy sub-sectors or regions (Kane & Christiansen, 2015), helping support socio-economic development, as well as promoting national priorities, such as energy access. Although there are concerns regarding the governance of SOEs, which need to be addressed to improve transparency and sustainability of the mineral supply chain, their involvement in critical mineral supply chains can help mineral-rich nations secure more revenues from their deposits and help importing countries secure access.

Japan has effectively utilized state-owned institutions to bolster the overseas exploration and production of critical minerals (Goel et al., 2023). The Japan Organization for Metals and Energy Security (JOGMEC) supports private companies through investments, equity financing, and loan guarantees to secure mineral access. Interestingly, JOGMEC was renamed from “Japan Oil, Gas and Metals National Corporation” in 2022, to support Japan’s efforts to achieve carbon neutrality by 2050. Its example could provide lessons for fossil-fuel driven SOEs in other countries to pursue diversification efforts. For example, Coal India Limited (CIL), India’s largest coal miner, has announced plans to purchase overseas critical minerals assets.

Even in mineral-rich countries, state-owned firms are playing a prominent role to secure more revenues and provide greater state oversight over the governance of supply chains (IGF, 2023). Some Latin American countries make use of SOEs for the mining of critical minerals such as Codelco (copper) in Chile. SOEs can have inherent advantages for investing in critical mineral extraction and processing, which can involve higher risk, significant capital requirements and long investment timeframes.

The IEA estimates that there is a 55% gap to meet the required investment needs for four key critical minerals to achieve net-zero emissions by 2050 (IEA, 2023). Given SOEs are owned by governments, they should be leading efforts to diversify into renewable energy. However, a study by the International Institute for Sustainable Development found that only 13% (7 out of 56) of the fossil fuel SOEs in G20 countries surveyed indicated in their annual reports that they had invested in renewable energy. Investing in critical minerals provides a unique opportunity for SOEs to support energy transition efforts.

Poster 6.02

Price contributions of raw materials to clean energy technologies

Steffen Schlosser (German Aerospace Center, Institute of Networked Energy Systems), Tobias Naegler (German Aerospace Center, Institute of Networked Energy Systems)

The energy and transport transition requires a large-scale installation of renewable energy sources (RES), e.g. wind and PV, as well as storage technologies and the electrification of vehicles. These technologies use bulk materials as well as smaller material fractions, some of which are classified as potentially critical. In general terms, “criticality” implies that there is a significant likelihood of short- to mid-term supply bottlenecks and/or a high economic importance of those materials. Supply bottlenecks, in turn, are expected to affect raw material prices and – as a consequence – prices for those technologies in which these raw materials are used.

Energy system transformation strategies are often developed using cost-optimizing energy system models. Therefore, cost assumptions for RES technologies play a central role in the development of such scenarios. However, it is usually implicitly assumed that the necessary raw materials for the transformation are available in unlimited quantities, i.e. that there are no bottlenecks in the raw material supply that could result in higher technology costs.

In this study, we therefore first examine the share of the costs of a wide range of raw materials in the total costs of central energy and transport technologies. We do this by building, on the one hand, on an extensive database on the specific demand for raw materials in energy and transport technologies. On the other hand, we use the assumptions on investment costs of the technologies in question as they are used in energy system modelling and optimization.

In this way, it is possible to show for which technologies price increases on the raw material side can contribute to an increase in technology costs and to what extent. This makes it possible to identify which raw material price developments should be given special attention in the future in order to take potential raw material bottlenecks into account already in the development of (cost-optimal) transformation strategies for the energy system.

Poster 6.03

Unconventional Sources of Critical Metals

Olga Ulanova (Irkutsk National Research Technical University)

The global shift to a carbon-free energy system is set to drive a huge increase in the demand for critical metals.

Rare earth metals are important components of many modern electronic devices including electric vehicle batteries, the magnets inside wind turbines, and copper electricity cables. Rare earth metals are also called “industrial vitamins” because even small amounts of them in alloys and other compounds improve their properties.

Today, this presents an urgent need to locate new sustainable sources of these critical metals.

A potentially rich source of these metals could be unconventional resources include underground, geothermal, oil field brines, and sea water, as well as mine water of mining industry.

Mining enterprises, in particular, those on the territory of the Siberian platform, produce large amounts of pumped water, which cannot be recycled because of its high mineralization and, thus, is discharged as liquid waste either back into the ground or onto the surface. The environmental impact of liquid waste is much higher than that of solid one because of higher migration ability and, thus, larger areas of affected soil. However, groundwater is often a valuable raw material and a source of critical metals. Brines are unique groundwaters.

Central Asia is also rich in industrial groundwater, which is natural underground brines containing individual components or their compounds in quantities that, according to technical and economic indicators, ensure their cost-effective extraction and processing. For example, Kazakhstan: brines of salt lakes of the Aral Sea region, oil reservoir waters of Karachagan. Turkmenistan: brines in Karabogazgol, formation brines and mineralized waters of the North Caucasus region.

The industrial value of brines from Siberia, Kazakhstan, and Turkmenistan, North Caucasus is caused by the high contents of rare elements (lithium, rubidium, cesium, strontium, yttrium, niobium, molybdenum, thorium, zirconium etc.). The absolute concentrations of these elements in brines exceed the lower limits of the mining cut-off tens of times. Today, rare earth metals are a part of the strategic reserve of many countries.

The study was focused on the evaluation of the prospects of the hydromineral resources as unconventional source of rare elements and the exploration of the technological processes for the selective extraction of rare metals from natural and industrial multi-component brines aimed at decreasing their negative environmental impact. The environmental and economic efficiency was proved for processing complex brines and the integrated selective extraction of rare metals from sodium chloride brines and calcium chloride brines based on the ion exchange sorption, eluent chromatography, flotation, crystallization, and freezing techniques. The basic technological schemes were developed for the rare metal extraction from pit water and brines.

Poster 6.04

Criticality of agricultural products: combining criticality methods and food security metrics

Lazare Deteix (ITAP - University of Montpellier - INRAE - Institut Agro, Elsa - Research Group for Environmental Lifecycle & Sustainability Assessment), Thibault Salou (ITAP - University of Montpellier - INRAE - Institut Agro, Elsa - Research Group for Environmental Lifecycle & Sustainability Assessment), Eléonore Loiseau (ITAP - University of Montpellier - INRAE - Institut Agro, Elsa - Research Group for Environmental Lifecycle & Sustainability Assessment)

Food systems depend on many resources, including abiotic resources such as minerals, land and water. However, agricultural products (e.g. cereals, meats, fruits etc.) are themselves raw biotic resources that can be subject to supply risks (SRs), and whose accessibility can threaten food security. Countries' agricultural supplies are exposed to increasingly frequent risks (Cottrell et al., 2019). These risks can be geopolitical, climatic or economic. To provide decision-support tools, the food security research field has developed metrics for assessing the risks to countries' agricultural supplies (Wassénius et al., 2023). These methods are mainly based on import diversity, a central parameter in criticality methods (Schrijvers et al., 2020). Yet, they do not take into account other criticality parameters. The aim of this study is therefore to combine food security metrics and raw material criticality assessment to assess the SR of agricultural products by country. The proposed developments will shed relevant light on the criticality of the whole agri-food sector. The SR is first quantified on the basis of a FAO's index, which assesses the vulnerability of a country's agricultural supply as a function of structure and diversity of supply, between imports and domestic production. The model is extended by taking into account the geopolitical and economic risks following the recognised criticality method of the Joint Research Center (JRC) of the European Commission (Hackenhaar et al., 2022). These risks are assessed by indexes often used in criticality, i.e. political stability and price volatility. However, agricultural products are also highly sensitive to climate, whose risk is assessed by the occurrence of extreme events. Finally, to refine the SR index, the JRC recycling and substitution indexes are also adapted to the agricultural products context. The second dimension of the JRC criticality method, economic importance, is assessed by the apparent consumption of the agricultural product in the country. Agricultural product SR indexes are calculated for 108 products across 153 countries. The focus is on some of the world's most widely consumed products (cereals, fruit and vegetables, meat). The results make it possible to compare countries and products. For example, rice SRs are higher than that of wheat for European countries, and African countries have higher wheat SRs than North Americans. Yet, strategies for reducing food SR will vary from one product and country to another. This study shows the interest of extending criticality methods to agricultural products. This expands the existing metrics for food security and provides additional results to the single analysis of food self-sufficiency. The SRs developed do not take into account the dependence of food systems on other resources (e.g. mineral resources for fertilisers). One avenue of research would thus be to combine the developed SRs with classic criticality metrics for minerals.

Poster 6.05

A systematic literature review of the existing methodologies for criticality assessment

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Critical raw materials (CRMs) have a crucial role worldwide. The economic and social impact they have in a vast array of industrial sectors is huge. Through the years, a lot of methodologies and models have been developed to assess criticality of raw materials. Each of them considers different thresholds and mechanisms to assess if a material is either critical or not critical. Furthermore, each of them considers different ranges of parameters as concurring in defining the criticality of a raw material (e.g., unavailability risk, environmental impacts, social impacts, etc.). The result is that there is not just a lack of univocity in assessing when a material is critical or not, but also in defining what criticality itself is when referred to raw materials. For example, in some cases it is just referred to the unavailability risk, while in others it is referred to also economic impacts, or social sustainability, etc. In this work, a systematic literature review is conducted, aiming at considering all the existing methodologies to assess raw materials criticality. The aim is investigating all the existing approaches to criticality assessment. Particular attention is given to analysing how assessment models change according to their scope (global level, country level, and micro-level) and when they are referred to a particular industrial sector. Emphasis is also placed on the consideration of environmental sustainability aspects in the definition of criticality. In the discussion and the conclusions, an evaluation of possible future evolutions of the state of the art of raw materials criticality assessment is conducted