FINANCEMENTS CIRCET

APPEL A MANIFESTATION D'INTERET 2026

1. Contexte et stratégie du programme CIRSET

Le programme CIRSET *(Circular Economy for Sustainable Resources in the Energy and Digital Transitions*) s'inscrit dans la volonté de l'I-SITE Lorraine de soutenir une recherche interdisciplinaire, ambitieuse et tournée vers les transitions énergétique et digitale. CIRSET mobilise des expertises variées pour traiter les enjeux liés à l'économie circulaire, en particulier la valorisation responsable des ressources et leur gestion dans les contextes des transitions en cours.

CIRSET s'appuie sur les synergies entre sciences de l'ingénieur, procédés, géosciences, sciences sociales, matériaux, énergie et environnement. Son objectif principal est de structurer une communauté scientifique autour de problématiques interdisciplinaires fortes, soutenues par une stratégie scientifique cohérente. CIRSET vise également à stimuler la formation par la recherche en impliquant les étudiants de Master, des doctorants et des jeunes chercheurs postdoctorants dans des projets ancrés dans les enjeux sociétaux contemporains.

Dans le cadre de son programme interdisciplinaire CIRSET, cet appel à manifestation d'intérêt (AMI) vise à stimuler des initiatives de recherche autour de la circularité des métaux pour les transitions énergétiques et digitales. Ces transitions reposent sur une consommation croissante de métaux aux propriétés spécifiques indispensables aux technologies bas carbone, aux infrastructures numériques et aux équipements électroniques avancés.

Parmi l'ensemble des thématiques relevant de la circularité des métaux, CIRSET porte un intérêt particulier à la chaîne de valeur des déchets électroniques (DEEE), depuis leur collecte et leur caractérisation jusqu'aux procédés de recyclage et de raffinage permettant la valorisation circulaire des métaux qu'ils contiennent. Les déchets électroniques constituent en effet un gisement urbain en forte croissance, concentrant une grande diversité de métaux, dont plusieurs présentent un caractère critique et/ou stratégique (cuivre, cobalt, nickel, lithium, terres rares, métaux du groupe du platine, gallium, indium, etc.).

La maîtrise de cette chaîne de valeur représente un enjeu majeur pour la France et l'Europe, à la fois sur les plans industriel, économique, environnemental et géopolitique. Aujourd'hui, l'Union européenne demeure fortement dépendante d'importations extraeuropéennes pour l'approvisionnement en métaux critiques, souvent issues de chaînes de production exposées à des risques géopolitiques, à des tensions sur les marchés et à des impacts environnementaux et sociaux significatifs. Dans ce contexte, le recyclage des déchets électroniques apparaît comme un levier stratégique de sécurisation des approvisionnements, de réduction des vulnérabilités et de renforcement de la souveraineté industrielle européenne.

Au-delà de la sécurité d'approvisionnement, la valorisation circulaire des métaux contenus dans les déchets électroniques contribue directement aux objectifs de sobriété matière, de réduction de l'empreinte environnementale et de décarbonation des filières industrielles. Comparé à l'extraction primaire, le recyclage permet de limiter la consommation d'énergie, les émissions de gaz à effet de serre et les impacts sur les écosystèmes, tout en favorisant le développement de compétences, de technologies et de filières industrielles à forte valeur ajoutée sur le territoire européen.

Dans cette perspective, CIRSET encourage des approches transdisciplinaires afin de lever les verrous scientifiques, technologiques et organisationnels qui limitent encore la pleine valorisation des métaux issus des déchets électroniques. Les projets attendus devront contribuer à une meilleure compréhension, maîtrise et optimisation de la chaîne de valeur des DEEE, au service d'une économie plus circulaire, résiliente et durable pour les transitions énergétiques et digitales.

2. Objectifs du programme

CIRSET poursuit plusieurs objectifs :

- Développer des projets de recherche interdisciplinaires autour de la valorisation responsable des ressources minérales pour les transitions énergétiques et digitales.
- Renforcer les coopérations entre laboratoires de l'Université de Lorraine et éventuellement avec des partenaires extérieurs.
- Soutenir des projets ayant déjà un cofinancement et entrant dans la stratégie de CIRSET.
- Stimuler des projets de recherche à fort impact pouvant ouvrir vers des financements européens

3. Présentation des Work Packages (WP)

Le programme CIRSET est structuré autour de plusieurs workpackages (WP) thématiques complémentaires (Figure 1) dont les descriptions détaillées sont données en annexe. Chaque WP constitue un axe scientifique prioritaire, animé par deux personnes référentes qui seront les points de contact pour les porteurs de projets.

WP1 – Ressources pour les transitions énergétiques et digitales

Responsables : Alexandre Tarantola (GeoRessources), Michel Cathelineau (GeoRessources)

Ce volet de travail examine le cycle complet des matériaux, depuis la prospection et l'extraction jusqu'à la transformation, au contrôle et à la minimisation de l'impact environnemental. Il se penche sur les ressources primaires et secondaires en métaux de base et critiques, leur potentiel et les nouvelles méthodes d'extraction minière visant à réduire l'impact environnemental, social et de gouvernance. Une attention particulière est accordée à l'amélioration des connaissances sur les cycles géochimiques des métaux critiques et au développement de nouveaux outils pour l'acquisition et le traitement des données qui leur sont liées.

WP2 – Stratégies pour une exploitation responsable des ressources dans le contexte de l'économie circulaire

Responsables : Alexandre Nominé (IJL), Catherine Sirguey (LIEC)

Ce WP est consacré à l'étude des impacts environnementaux et sociaux de l'exploitation des ressources primaires et secondaires. Il comprend un diagnostic complet de l'impact global des matières premières, l'exploration de nouvelles méthodes d'exploitation et la conception d'outils d'aide à la décision pour une gestion durable des ressources.

WP3 – Valorisation des ressources primaires et secondaires pour les transitions énergétiques et digitales dans le contexte de l'économie circulaire

Responsables : Sandrine Hoppe (LRGP), Alexandre Chagnes (GeoRessources)

Ce volet vise à développer des procédés innovants pour l'extraction de métaux à partir de ressources primaires et secondaires. Il s'attaque aux défis posés par l'augmentation de la demande mondiale en métaux et la complexité croissante des minerais et des déchets des transitions énergétiques et digitales, en mettant l'accent sur l'amélioration des techniques d'extraction et de recyclage.

WP4 – Relever les défis de l'économie circulaire grâce à des approches innovantes de formation et de transfert de connaissances.

Responsable : Stéphanie Fleck, Romain Pierronnet

Ce WP est dédié à l'innovation dans les programmes d'enseignement supérieur et de formation, ainsi qu'à la médiation et au transfert de technologies. Il vise à développer les compétences de demain, à sensibiliser le public et à encourager les changements nécessaires pour faire face aux transitions énergétiques et numériques

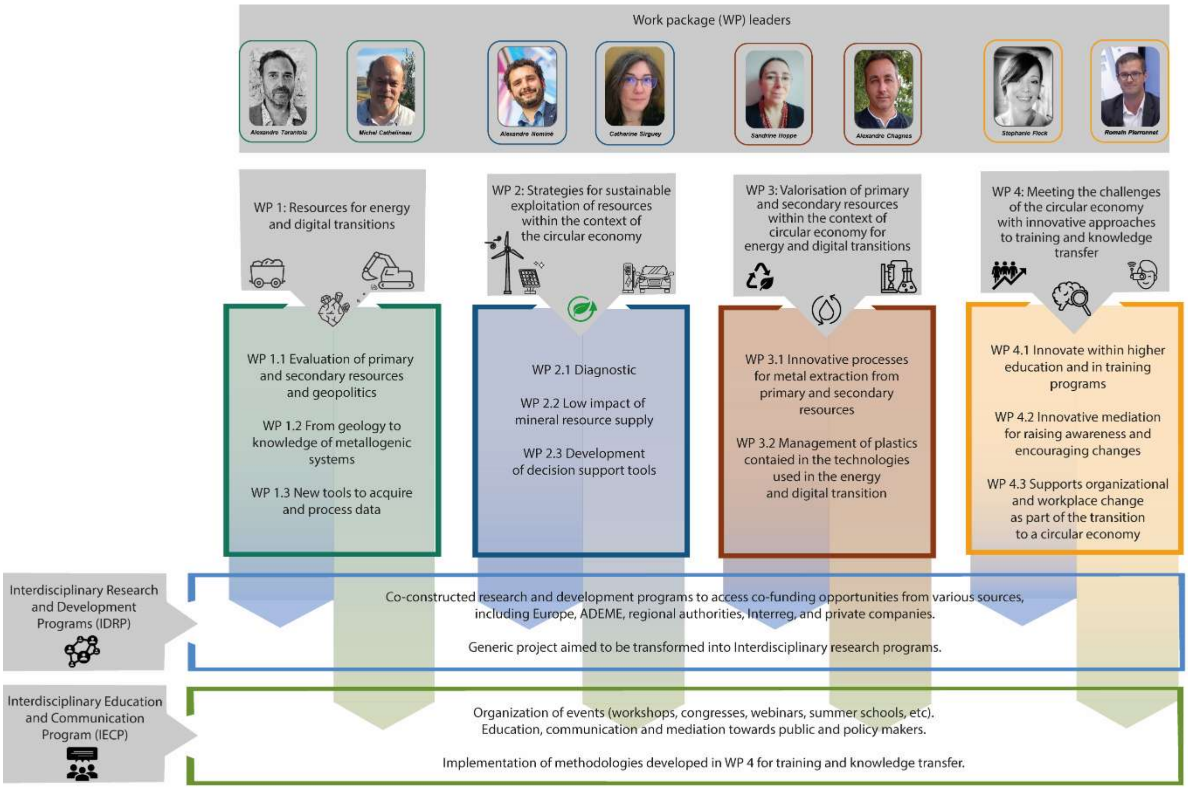

Figure 1 : Description des WP du programme CIRSET.

4. Appel à manifestation d'intérêt

CIRSET lance un appel à manifestation d'intérêt (AMI) pour identifier et soutenir des projets de recherche interdisciplinaires en lien avec un ou plusieurs WP dont la durée sera comprise entre 1 an et demi et deux ans et demi. Cette AMI permettra de définir de nouveaux projets pour les WP, les programmes de recherche interdisciplinaires (IRDP, *Interdisciplinary Research and Development Program*) ou les Programmes interdisciplinaires sur la formation et la communication (IECP, *Interdisciplinary Education and Communication Program*).

Appel à manifestation d'intérêt 2026

Enveloppe du financement CIRSET : 80-150 keuros/an en personnel (postdoc) + 10-21 keuros/an de fonctionnement. **Cofinancement exigé** : Un cofinancement d'au moins 30 % est demandé. Des cofinancements en cours d'acquisition pourront être pris en compte, à condition qu'une part du cofinancement soit déjà acquise au moment du dépôt du projet. **Nombre de projets financés** : 1 **Durée** : 1 an et demi à deux ans et demi Le projet sera évalué par le comité scientifique à mi-parcours. Formulaire en pièce jointe à remplir et à renvoyer à : alexandre.chagnes@univ-lorraine.fr et olga.chernoburova@univ-lorraine.fr selon le calendrier fourni dans ce document.

Les projets retenus devront :

- Avoir comme porteur un permanent de l'I-SITE Lorraine.
- Présenter un caractère fortement interdisciplinaire.
- Être cofinancés à hauteur d'au moins 30 %. Des cofinancements en cours d'acquisition pourront être pris en compte, à condition qu'une part du cofinancement soit déjà acquise au moment du dépôt du projet. Les cofinancements non acquis lors du dépôt devront être confirmés au plus tard six mois après le démarrage du projet.
- S'intégrer dans les thématiques stratégiques de CIRSET.
- Impliquer au moins deux laboratoires de l'Université de Lorraine appartenant à deux disciplines croisées (définies par les sections CNRS) ayant un objet commun.

En complément, CIRSET propose un appel pour le financement de stages de Master, sous une forme de gratification, pour soutenir des mémoires s'inscrivant dans les axes du programme. Ces gratifications visent à initier de nouvelles dynamiques de recherche, susceptibles de déboucher sur des projets structurants à moyen terme.

5. Organisation de l'AMI

L'appel à manifestation d'intérêt du programme CIRSET est organisé en deux étapes successives, afin de favoriser l'émergence de projets interdisciplinaires.

Étape 1 : Manifestation d'intérêt (phase simplifiée)

La première étape consiste en une soumission simplifiée, dont l'objectif est :

- d'identifier les personnes ou équipes souhaitant manifester leur intérêt pour le dépôt d'un projet interdisciplinaire dans le cadre du programme CIRSET ;
- de recenser et faire connaître les thématiques et idées de projets envisagées.

À l'issue de cette première phase, le comité d'évaluation de CIRSET procédera à une présélection des manifestations d'intérêt sur la base des éléments soumis.

Le comité communiquera ensuite aux candidats présélectionnés :

- la liste des candidats retenus à l'issue de l'étape 1 ;
- le titre des projets correspondants.

Cette mise en visibilité a pour objectif de permettre aux candidats présélectionnés d'échanger entre eux, s'ils le souhaitent, afin d'explorer des rapprochements scientifiques et de faire émerger un projet transdisciplinaire commun, notamment par la fusion ou la complémentarité d'au moins deux propositions initiales.

Étape 2 : Dépôt du projet final

Les candidats présélectionnés à l'issue de l'étape 1 seront invités à soumettre un projet complet lors de la deuxième étape de l'appel.

Ce projet pourra être :

- soit une proposition collective issue de la première étape sans rapprochement avec d'autres porteurs de projets;
- soit un projet interdisciplinaire commun, élaboré conjointement par deux candidats ou équipes présélectionnés.

Les projets soumis lors de cette deuxième étape feront l'objet d'une évaluation finale par le comité d'évaluation de CIRSET, en vue de la sélection définitive des projets financés.

6. Critères de sélection

Les projets seront évalués sur la base des critères suivants :

- Qualité scientifique et caractère innovant.
- Interdisciplinarité réelle et intégration dans les WP.
- Potentiel de structuration et de valorisation.
- Adéquation avec la stratégie de CIRSET.
- Existence de cofinancements.
- Capacité du projet à servir de base à une future candidature à un programme européen.

Les porteurs de projets sont invités à prendre contact avec les responsables de WP listés ci-dessous pour affiner leur positionnement scientifique s'ils le désirent.

WP	Contact	Adresse e-mail
1	Alexandre Tarantola Michel Cathelineau	alexandre.tarantola@univ-lorraine.fr michel.cathelineau@univ-lorraine.fr
2	Alexandre Nominé Catherine Sirguey	alexandre.nomine@univ-lorraine.fr catherine.sirguey@univ-lorraine.fr
3	Sandrine Hoppe Alexandre Chagnes	sandrine.hoppe@univ-lorraine.fr alexandre.chagnes@univ-lorraine.fr
4	Stéphanie Fleck Romain Pierronnet	stephanie.fleck@univ-lorraine.fr romain.pierronnet@univ-lorraine.fr

7. Calendrier

09/02/2026	Publication de l'AMI
30/03/2026	Date limite de réception des manifestations d'intérêt (phase 1) **DOSSIER DE CANDIDATURE A SOUMETTRE AVANT CETTE DATE A :** **olga.chernoburova@univ-lorraine.fr**

20/04/2026	Communication sur les projets sélectionnés pour la phase 2
29/05/2026	Date limite de réception des projets finalisés (phase 2) **DOSSIER DE CANDIDATURE A SOUMETTRE AVANT CETTE DATE A :** **olga.chernoburova@univ-lorraine.fr**
08-12/06/2026	Présentation orale des projets présélectionnés en phase 2
03/07/2026	Communication sur des résultats pour un démarrage du projet en novembre 2026 au plus tard

ANNEXE : DESCRIPTION DÉTAILLÉE DES WP

WP 1: Resources for energy and digital transitions

Exploitation can no longer be envisaged without an integrated approach to the material cycle, from prospecting and extraction to processing, monitoring and minimizing environmental impact. It is this cycle that underpins the CIRSET projects.

WP 1.1 - Evaluation of primary and secondary resources and geopolitics

WP1.1 is a global reflection on the primary and secondary resources for base and critical metals, their potential at different scales and new methodologies for metal extraction for a lower ESG (Environmental, Social and Governance) impact. The decades require an unprecedented need for base and new metals, generally classified as critical metals, for the new technologies and a decarbonization development model. The industry's search for and exploitation of these metals face many challenges, including environmental, societal, and governance (ESG). Moreover, the mineral industry, whatever the resource it is interested in, is facing significant technological challenges: (i) the discovery of new primary resources is decreasing, their metal content is lower, and the need for rock excavation increases, thus increasing environmental issues and (ii) exploitation of primary or secondary resources with low or very low levels of valuable substances. For example, uranium contents of around one hundred ppm are currently being exploited, and this exploitation appears more profitable than high-grade ores, which are challenging to extract. After recovering major substances, mine tailings are also of great interest for strategic metals necessary to high-tech manufacturing: germanium is essential for optical fibers, gallium, indium, and cadmium for electronic devices and solar panels. All these elements are co-products of zinc and aluminum metallurgy.

Brownfield and tailings are complex ores with residues of exploited metals and material left with a concentration considered too low or of no interest in trace elements, including critical and precious metals. Their exploitation is complex because it could give access to necessary new resources and represent concentrated residues with potentially high environmental and social impact (pollution with reintroduction of more or less stabilized substances, new biotopes).

The scarcity of raw materials will necessarily lead to an increasingly circular economy in the following years and decades. In this context, the industry is responding to two significant pressures. Firstly, the economic conditions of the time and place drive the development of secondary resources and the recovery of contained values. Two ways may be implemented: either by extracting small volumes of noble materials that can be used directly (gold, silver, platinum, non-ferrous metals, etc.) or by eliminating from a large-volume material species that are detrimental to its use (amphoteric metals, sulphates in slag), the main benefit being that they don't have to be managed anymore.

It is crucial to consider the environmental impact of mining and re-processing operations. Protecting the environment and avoiding waste, often called "sustainable development", poses new problems for mining operations (whether active or abandoned). It generally requires scientific advances. In addition, several technological developments have led to the increasing use of rare earth elements (REEs) and rare metals (RMs) in various industrial processes. As a result of their extraction, manufacture, use and waste generation, the natural biogeochemical cycle of REEs and RMs is progressively disrupted by anthropogenic REEs and RMs, raising questions about their possible impact on human health and the environment. Most of the NCMs (Northern Contaminant Mixtures) have been reported to be toxic to humans (particularly Be and Nb): they can cause eye and dermal irritation, kidney disease and disruption of nerve transmission, as well as cancer, depending on the NCM in question; in particular, genotoxic effects have been reported for beryllium. Like many other artificial contaminants, EARs (exposure-activity ratios) and MRs (micro rubbers) can contaminate ecosystems and affect organisms living in water and sediments, so it is essential to determine their impact.

The new mines represent complex ore bodies that require (i) better integration of the mine into its local territory, (ii) better balance between profit logic and governance (increased regulation of mining) and (iii) more balanced interactions between a mine and the local communities surrounding it. Finally, the issue of resources (their extraction, marketing, transport, processing, etc.) is caught up in economic and political stakes that would benefit from being approached from the angle of international relations. Numerous latent and explicit power games can help explain the difficulties in transforming practices, with consequences regarding sovereignty for States, including France. This observation could thus be extended by work grounded in the field of political science and international relations, even to partners from the field of Economic Intelligence ("Institut des Hautes Etudes de Défense Nationale" or "Agence Innovation Défense").

WP 1.2 - From geology to knowledge of metallogenic systems

WP1.2 aims to improve the general knowledge regarding the geochemical cycles of critical metals. This situation mentioned above is encouraging increased exploration and necessary research into (i) the cycle of these metals and their concentration factors, (ii) whose mode of incorporation in trace amounts in major minerals (e.g. germanium in sphalerite, selenium in galena, rhenium in molybdenite), and (iii) distribution on the scale of deposits (grades from the mineral to the deposit) or provinces. The stakes in research into new metal deposits have largely shifted and evolved compared to our vision just thirty years ago. The development of sophisticated 'deposit models', essential for prospecting (e.g. Hodgson, 1989; Sillitoe, 2010), has largely been completed, and interest is now focused on building models of 'metallogenic systems': the aim is to gain a better understanding of the source-extraction-transport-trapping-preservation chain and to establish its spatial and temporal scope, and what is the systematics of the distribution of these elements between rocks and minerals, and their concentration in low-grade ores, mine tailings, residues from metallurgical extraction (red mud yielding from aluminum ore processing, iron metallurgy in Lorraine, IPB soil/terrils/residues in Andalusia, etc.), sludges from the automobile industry linked to galvanization processes for instance, or even flotation tailings. This understanding is essential to define the envelopes of metal distribution of metal grades at lower values than in the commonly exploited ores. The study of concentration or pre-concentration mechanisms in the carrier phases (magmatic stage for rare metals), the distribution and content of these elements (trace elements, germanium, indium, gallium, scandium) in ores and their link with hydrothermal alteration zones, precipitation sites and mechanisms (germanium, REEs), their subsequent hydrothermal remobilization and reprecipitation, the composition and thermodynamic parameters of hydrothermal fluids at the origin of these concentrations and the precipitation, the fractionation between the fluid (gas, liquid) and the solid phases. Furthermore, these trace elements are often used as tracers of source and fluid-rock interactions (titanium-germanium-aluminium,) and geothermometers (sphalerite, titanium-indium quartz) assuming fluid-mineral equilibrium, making them fundamental elements in support of classical stable isotopy. Methodological developments are required in the field of the localized quantitative analysis of trace metals (ppm to hundreds of ppm) in mineral and fluid phases, in particular by LA-ICP-MS: germanium in sphalerite, scandium in iron hydroxides, and tracers of metallogenic processes (halogens, for example, in point analysis in inclusion paleofluids), and the analysis of isotopic fractionation in deposition processes (germanium), source of fluids (^{18}O, ^{2}H, ^{13}C, ^{34}S, $^{3}He/^{4}He$, $^{4}He/^{20}Ne$), age and fractionation of gas/fluid phase/mineral (noble gases radiogenic and stable isotope geochemistry).

WP 1.3 - New tools to acquire and process data

WP1.3 aims to develop novel qualitative and quantitative tools inherent to these new issues (low concentration of the elements, scale transfer modelling, integration of data issued from several sciences, sources and scales). A problem with scale jump always appears when dealing with a thin section and a kilo of a rock sample. How do we go from a localized estimate to a distribution characterisation at metric or even kilometre scales? The representativity of the sampling and the scale transfer should be treated by geostatistics, as well as with continuous improvement of our ability to provide geochemical data in the form of maps (which preserve phase relationships) rather than discrete individual analysis and their correlation to provide complete cross-correlated information.

Newly developed portable spectroscopic tools (pXRF, pLIBS, pVNIR-SWIR, pRAMAN) represent numerous benefits: (i) direct qualitative and quantitative, providing accurate calibration for elemental mapping on the field, (ii) optimization of the sampling, therefore reducing the number of samples to be shipped. Combined with their lab equivalent, their use allows fast section scanning to localize the distribution of elements of interest.

There is a link between the process section and hydrochemical separation with the distribution of metals of interest and their speciation: mineralogy by quantitative SEM, XRF, and LIBS imaging to resolve the localization of carriers in the main minerals or independent micro-phases.

Development of numerical tools for data reduction on imagery for quantitative mineralogy (AMIX (software Brucker for SEM and µXRF) where we need to develop our databases for solid solutions, MARCIA (interactive in-house software, processing with optimized mineralogical map selection via elementary composition bracketing)).

In an exploration strategy, a perfect understanding of deposits depends on the knowledge of the succession of geological events and their relative and absolute chronology. There are two aspects of LA-ICPMS development here: (i) analysis of trace elements in the paragenetic continuum with trace elements on sulfides and (ii) direct age dating of ores by U/Pb (UO_2, Sn oxides, Nb, ...), but there are still developments on titanite, Rb/Sr on micas and other silicates. Here, the stakes are on standards and methodology to stay on top. Other Re/Os systems can also be considered.

Finally WP1.3 focuses on data processing: (i) Geostatistics for changes in scale, taking into account data complexity, (ii) Development of Advanced Methodologies: Analyze the diversity of environmental, geographic and socio-economic data, including their format, scale and accuracy, to build Datasets that support data learning (we aim to refine geostatistical methods to address the complexities of data across different scales, ensuring robust data interpretation and integration), (iii) Creating Data Generation Models and Adaptive Systems: Development of algorithms and generative Artificial Intelligence models capable of adjusting to environmental and socio-economic evolutions, this system will provide tailored advice for each region, enhancing local decision-making and strategy formulation, and (iv) Integrating Uncertainties into Decision-Making: Development of reliable decision-making models based on data collection and generation models, taking into account unknown variables and uncertainties for the integration of material recycling value chains.

The development of analytical and statistical tools to better understand critical metals in various types of deposits will help:

- Minimizing Environmental Impact: Decision-making models and generating uncertainties from environmental, geographical and socio-economic data will promote eco-responsible practices adapted to each territory, reinforcing circular value chains.
- Promotion of the Circular Economy: The recommendations resulting from the models and systems developed will encourage sustainable practices in the materials recycling industry.

References:

Hodgson C.J. (1989) The structure of shear-related, vein-type gold deposits - a review. Ore Geology Reviews 4, 231-273.

Sillitoe R.H. (2010) Porphyry copper systems. Economic Geology 105, 3-41.

3.2. WP 2: Strategies for sustainable exploitation of resources within the context of the circular economy

Achieving the UN's Sustainable Development Goals and implementing the Paris Agreement require technologies that use a wide range of minerals in large quantities. The availability of essential metals will depend on economic and commercial factors (metal prices, anticipated supply and demand) and social and environmental pressures. If exploited responsibly, mineral wealth can contribute to public revenues and provide livelihoods for many people while addressing climate challenges. However, if poorly managed, mining can lead to a myriad of negative consequences, including (i) significant greenhouse gas (GHG) emissions resulting from energy-intensive extraction and processing activities, (ii) environmental impacts, including biodiversity loss, water depletion and pollution, waste contamination and air pollution, and (iii) social impacts, including social disruption due to land-use change, land-use conflicts, impacts on indigenous populations or social vulnerability. These risks can then lead to supply disruptions, which could slow the pace of the transition to clean energy. Events such as the collapse of the Samarco tailings dam in Brazil in 2015 and the cancellation of the Rio-Tinto lithium mine project in Serbia in 2021 illustrate the risks of supply disruption and erosion of community trust that mining activities can cause.

The notion of transformative change, recently proposed (FRB 2021/ IPBES 2019) (Brondízio et al., 2019) in response to the need to preserve biodiversity and the services it provides, is defined as a fundamental and systemic reorganization of economic, social and technological factors, including paradigms, goals and values (Couvet, 2021). Applied to mining systems and associated activities, this concept leads to a rethinking of all sectors to meet the requirements of sustainable development. The supply of mineral resources may mean developing mining strategies with low environmental and social impact. In other words, it means providing humankind with strategic elements without destroying nature, restoring it wherever necessary, and helping achieve climate objectives, particularly regarding greenhouse gas emissions and carbon storage. It is, therefore, imperative to assess and manage the environmental, social and economic impacts of mineral production. To achieve this goal, WP 2 is organized into three tasks, as shown in Figure 5:

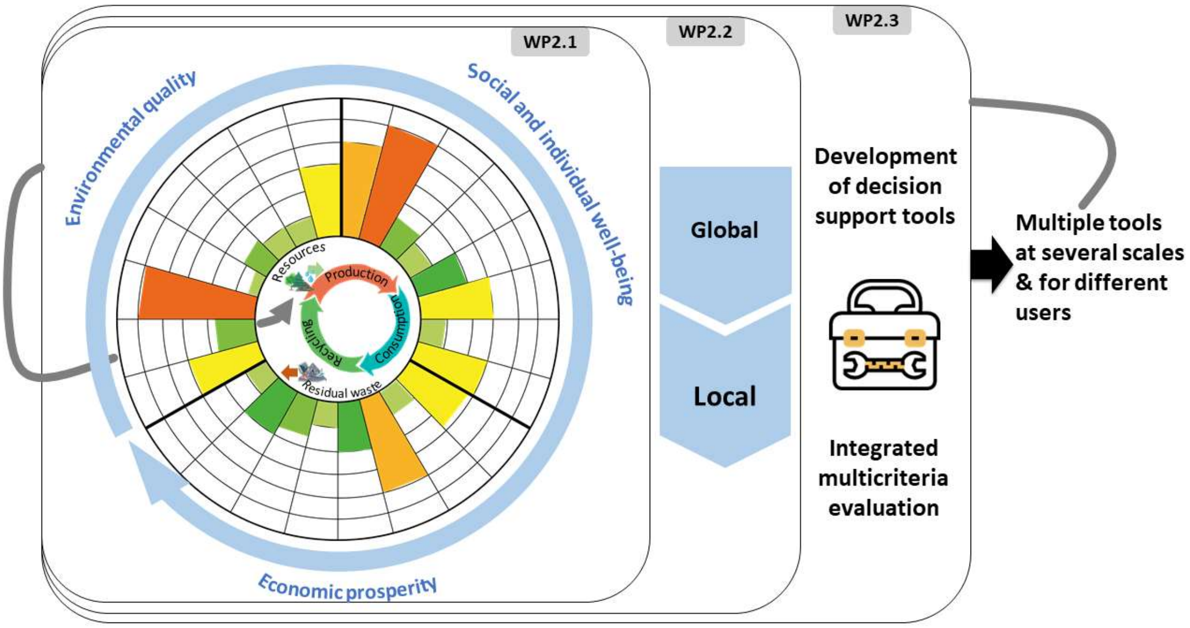

Figure 5: Schematic representation of activities covered by WP2.

WP 2.1 – Diagnostic

The first part of this work package (WP 2.1) delves into the comprehensive diagnosis of the global impact of raw materials. This initial stage sets the foundation for informed decision-making within multifaceted challenges spanning environmental, social, economic, and geopolitical dimensions (Table 1). Three key actions are to be undertaken within WP 2.1.

Global Indicators Data Acquisition. This action involves acquiring data for the identified global indicators outlined in Table 1, utilizing open databases from reputable sources such as academic papers, the United States Geological Survey (USGS), and other databases available to UL. Stakeholders will collaborate to compile comprehensive data sets encompassing environmental, social, economic, and geopolitical dimensions.

Indicator Refinement and Integration. Following initial data acquisition, this action focuses on refining and integrating indicators based on the results obtained from other work packages (WP) within the project. Data collected will be analyzed considering variations in impacts resulting from different types of deposits (WP1), extraction processes, and recycling methods (WP1 & WP3). The WP members aim to join the French and European community of researchers working on the Life-Cycle Assessment of metal production and the standardization of the impact assessment. Insights from other WP results will inform the selection and prioritization of indicators, ensuring a more comprehensive evaluation of raw material impact across various contexts. Additionally, local impacts studied in WP 2.1 will be considered for integration and comparison.

Automation for Continuous Monitoring. In this action, stakeholders will develop and implement automated systems for continuous data acquisition and monitoring of global indicators. Leveraging advanced technologies such as machine learning, data analytics, and remote sensing, stakeholders will establish real-time or periodic monitoring mechanisms. This allows timely detection of changes, trends, and emerging risks in raw material impact, facilitating proactive decision-making and adaptive management strategies. Additionally, stakeholders will analyse reputational risk by monitoring articles in the press and social media messages. By gauging public sentiment and media coverage, stakeholders can proactively address potential reputational risks and manage stakeholder perceptions effectively. Data transparency, being an essential criterion for correct estimations, risk prediction and building trust with stakeholders, will be addressed in this WP.

Table 1: Global key indicators studied in WP 2.1.

	Sub-criteria	Description	Source	Improvement within CIRSET	
Global Environmental Impact	CO_2 Footprint	CO_2 emmitted to extract and process a given materials	EcoInvent, Nuss et al...	- Refine the calculation at different step using LCA -Include the carbon footprint of the energy mix in the models and therefore have a geographical speading of the footpring.	Automation of Data mining
	H_2O consumption	The quantity of water needed to produce a given material			
	Emboddied energyy	Energy needed to produce a given material			
Ressources	Production	Yearly production of a given metal	USGS	Location of existing mines and prospects. Modelling of the reserves as a function of ores concentration (with WP1.1) Integrate in the model the contribution of recycling	
	Reserve	Estimated reserve of a given metal			
Economy	Price	Price of a given metal	LME, Argus metal		
	Volatility	Relative variation of the price over a given time period			
ESG risk	Environmental score	Measurment of the different impacts on the environment for the community (e.g. soil pollution)	Lebre et al.	- Include supplementary parameters	
	Social Score	Measurment of the different impacts on the social impact for the community (e.g. usage conflicts)			
	Govenmental Score	Measurment of the governmental risk			
Political risk	Reputation risk		Social Networks, press	Collection of the posts in the social networks and the press. - Feeling measurment	
	Geopolitical risk		UNO votes, Legal texts	Transform WP1 results on indicators	

WP 2.2 - Low impact of mineral resource supply

Work package 2.2 will involve exploring new ways of exploiting primary and secondary resources, including transforming current routes or creating new ones, such as metal agromining (van der Ent, 2021), with a view to transformative change. Based on emblematic local demonstrators, knowledge needs concern strategic priority elements such as Ni, Li, REE, Cu and Co. Examples of the first demonstrators studied could be the recovery of metals of interest from industrial waste contained in mine tailings (Koutra, 2023) or industrial wasteland (Kinnunen, 2019), the future lithium mine at Echassière or a future Ni agromine project in Malaysia. Ideally, work will cover the entire supply chain, from extraction, purification and alloy production to the production of finished products (Figure 6).

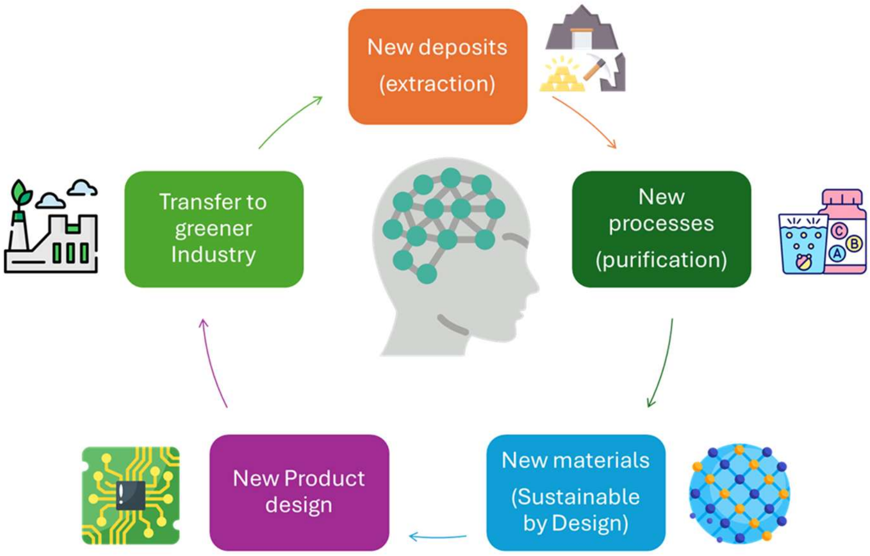

Figure 6: Consideration of the entire value chain in assessing the environmental, social-economic and political impacts of the extraction of metals of interest.

For each element, or each group of elements with similar properties, we need first to understand and model their fate and impacts in ecosystems, the effects on the functioning and conservation of organisms and communities, the mechanisms involved, and the interactions between different causes of disturbance (e.g. multi-pollution, climate change and ecosystem modification). Representative complex metallic forms used in industry (e.g. $LiPF_6$, Li-ion batteries) must also be considered. All aspects of the industry will be examined, including scientific, technological, social, economic and legal aspects. This knowledge can then be used to identify markers at different scales and to select indicators chosen not only for their ability to reflect the state of functions (environmental, social, economic or political) but also for their ease of use. These indicators will enable data to be collected and fed to the models developed in WP 2.3 and provide objective information on the real impact of mining practices and the effectiveness of prevention and restoration measures.

Secondly, new site restoration and requalification strategies will be investigated to support biodiversity, carbon storage, tailings recovery and pollution mitigation. This set of ecosystem services that degraded mine sites and brownfields can provide will preferentially use nature-based solutions. The diagnostic tools developed in WP 2.3 will then be used to assess the suitability of these solutions, which most often boil down to revegetation.

WP 2.3 - Development of decision support tools

Work Package 2.3 serves as the critical nexus for integrating the outcomes of WPs 1.3, 2.1 and 2.2, aiming to consolidate their findings into a robust Decision Support System (DSS). This DSS is envisioned to cater to diverse objectives, including augmenting public awareness, aiding policy formulation, facilitating corporate decision-making, and supporting developers - *of new* *metal extraction methods, new materials and new remediation methods* - and device designers (Figure 7).

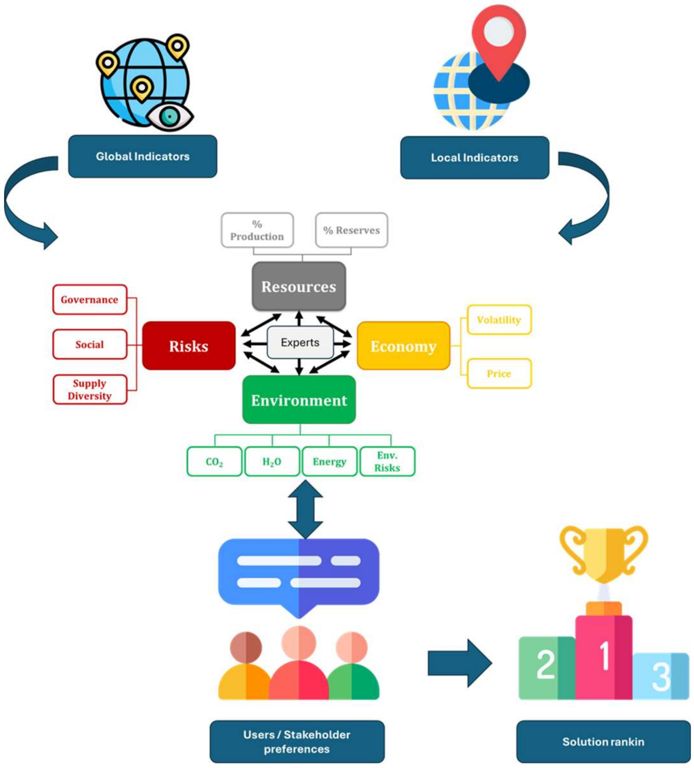

Figure 7: Schematic diagram of the decision-support tool developed in CIRSET WP2.

Our primary focus is seamlessly amalgamating the insights from the localized impact analysis and the global impact diagnostics. In particular, it will define a methodological framework incorporating a qualitative analysis matrix and a quantitative adjustment method for assessing ESG risks. This methodological framework will mobilize both existing industry standards (Initiative for Responsible Mining Assurance https://responsiblemining.net/) and new standards resulting from the work of WP 2.1 and 2.2. By synthesizing these diverse perspectives, we aim to craft a sophisticated algorithm that encapsulates the breadth and depth of our project's collective knowledge. This algorithm will serve as the foundational framework of the DSS, empowering stakeholders with comprehensive decision-making capabilities across various contexts and objectives.

The Decision Support System's iterative development and rigorous testing are central to our efforts. Collaborating closely with project partners and leveraging the resources of available platforms and fablabs, we are dedicated to architecting and implementing an intuitive and effective DSS algorithm. Real-world testing and validation exercises involving researchers, industry stakeholders, and policymakers will provide invaluable insights and feedback, enabling us to refine and fortify the system's functionality, accuracy, and user-friendliness.

In addition to catalysing practical application, this work package confronts several formidable scientific challenges inherent in decision support systems for raw material impact management. These challenges encompass the seamless integration of heterogeneous datasets, algorithmic complexity, uncertainty quantification, and scalability. By addressing these challenges head-on and leveraging cutting-edge methodologies and interdisciplinary expertise, we aim to advance the frontiers of decision support systems and forge new pathways towards more productive and sustainable resource management practices.

Work Package 2.3 will provide a comprehensive Decision Support System (DSS) and contribute significantly to WP4, IRDP and IECP, which is focused on innovative training, education and outreach activities. By synthesizing complex research outcomes into user-friendly tools and insights, we aim to empower educators, students, and the general public with a deeper understanding of raw material impact management. Our outreach efforts will disseminate knowledge, engage stakeholders, and foster dialogue, driving broader awareness and participation in sustainable resource management initiatives. Through these endeavours, WP 2.3 is pivotal in catalysing positive change and building a more informed and engaged community.

References:

Brondízio, E. S., Settele, J., Díaz, S., & Ngo, H. T. (Éds.). (2019). *The global assessment report of the intergovernmental science-policy platform on biodiversity and ecosystem services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Couvet, D. (2021). *Changement transformateur : De quoi parle-t-on ? Expliciter la notion, la décliner dans sa profondeur historique et géographique* [Journée FRB 2021] Agir en faveur de la biodiversité – Osons les changements transformateurs ! Paris, 30 septembre 2021.

Van der Ent A., Baker A.J.M., Echevarria G., Simonnot, M.-O., & Morel J.L. (Éds.). (2021). Agromining : Farming for metals. Extracting Unconventional Resources Using Plants. Second Edition (Springer). Springer Berlin Heidelberg.

Koutra, S., Bouillard, P., Becue, V., Cenci, J., & Zhang, J. (2023). From 'brown'to 'bright': Key issues and challenges in former industrialized areas. Land Use Policy, 129, 106672.

Kinnunen, P. H.-M., & Kaksonen, A. H. (2019). Towards circular economy in mining: Opportunities and bottlenecks for tailings valorization. Journal of Cleaner Production, 228, 153-160.

3.3. WP 3: Valorisation of primary and secondary resources within the context of circular economy for energy and digital transitions

WP 3.1 - Innovative processes for metal extraction from primary and secondary resources

Nowadays, the energy and digital transitions associated with developing new emerging countries significantly increase global demand for base metals. Moreover, a wide range of metals are highly sought after globally by the abovementioned transitions, which involve the rise of renewable energies, the manufacturing of electrical and electronic equipment, transportation, and various cutting-edge industries. The importance of these metals in our society is evident, and the fragility of their supply currently represents a real challenge for the French and European economies in the short term. Generally, advances in extraction techniques, material economics, substitution, and recycling (including eco-design) help mitigate the risk of critical metal shortages. However, the recycling rate of critical and high-tech metals from end-of-life materials is low compared to that of base metals due to increased material complexity.

Furthermore, the constant increase in metal demand (across all types) renders recycling insufficient and makes it necessary to supply the manufacturing industry from primary sources. These ores exhibit characteristics (grade, texture, composition) that are increasingly more complex and must be exploited, particularly in Europe, to minimize societal and environmental impacts in pursuing European mineral resource independence. Moreover, metal extraction through the general scheme of "mine-mineralogy-extractive metallurgy" always produces residues and effluents, the volume of which far exceeds that of the useful substance extracted, yet they are still valuable. In this context, CIRSET will develop its research, focusing on separations and transformations applied to valorising primary and secondary resources. These research activities range from characterizing the mineralogical, textural, and chemical properties of resources to developing physical, physicochemical, and chemical separation processes, including mechanistic understanding and modelling. This WP is divided into three scientific themes and covers the entire spectrum of metal extraction from primary and secondary resources, mineralogy, pyrometallurgy, and hydrometallurgy. Therefore, the leading scientific challenge of this WP is to achieve an understanding and description of the physical, chemical, and physicochemical phenomena involved in each operation of extractive metallurgy processes developed for specific applications (magnet, lithium-ion batteries and WEEE recycling for secondary resources, rare-earth elements, copper, cobalt, nickel, manganese, lithium, etc., extraction from primary resources for instance). The ultimate goal is to develop a methodological and scientific approach guiding the choice of effective physical separation methods (gravity or magnetic separation), physicochemical methods (flotation), chemical methods (hydrometallurgy), and thermal methods (residue stabilization/transformation) to design new flowsheets or improve existing flowsheets. These flowsheets could combine classical operations already developed in extractive metallurgy or new technologies relying on new chemistries.

Mineral processing

Research in the field of mineral processing in this WP will focus on the scientific and industrial challenges of our century in terms of metal extraction from primary and secondary resources. Conventional (rocks) and unconventional (mining residues, underwater resources, waste) ores are increasingly characterized by lower grades, finer textures, and weaker separation contrasts between their constituent materials. Priority will be given to developing integrated approaches to build upon detailed ore characterization to define processing schemes, extending to downstream stages of pyrometallurgy and hydrometallurgy. This approach optimizes processing schemes by considering the textural, chemical, and mineralogical variability of the ore. Furthermore, several fundamental research studies will be conducted to address the increasing complexity of deposits.

Firstly, research in surface physicochemistry, both experimental and theoretical, will significantly intensify to deeply understand the molecular mechanisms involved in flotation. This aspect, which has relied on molecular modelling for the last five years, will constitute a major research axis and be accompanied by acquiring appropriate tools. To meet the challenge of increasingly complex deposits, it is necessary to develop innovative flotation reagent formulations and, to achieve this objective, to understand the fundamental mechanisms involved in their adsorption. Additionally, the study of flotation of fine and coarse particles, presenting scientific, industrial, and technical challenges, will be intensified.

The research on understanding and modelling the hydrodynamic conditions within flotation machines will be addressed to develop new flotation equipment suitable for unconventional particle size ranges for flotation. This significant aspect will be coupled with the physicochemical approach to surfaces to create new flotation concepts such as micro- and nano-bubbles.

Similarly, pre-flotation flocculation will be studied as it will become a major research axis for mineral processing. This process effectively addresses the increasing fineness of ores that become too fine for conventional flotation processes. Pre-flotation flocculation increases particle size, thereby enabling the use of an effective conventional flotation process.

All these research trajectories will be applied to primary ores and secondary ores. This WP will also be dedicated to intensifying the application of mineral processing processes in recycling, where pyrometallurgy and hydrometallurgy play a predominant role.

Pyrometallurgy

The scientific activity in pyrometallurgy will study the chemico-thermal processes that govern selective separation processes in valorising mineral raw materials and transformed substances. Overall, the objectives will be to acquire new knowledge in materials and processes, to understand solid reactivity further, to determine the reaction pathways involved in the interaction of matter with chemical agents, and to design selective extraction processes. This topic will explore thermodynamic and kinetic approaches by elucidating the reaction mechanisms associated with pyrometallurgical operations such as high-temperature liquid-liquid extraction, chlorination, high-temperature electrometallurgy, etc. The study of reactivity and thermodynamic control will be the first step of each study to identify reaction products depending on the specific conditions of the system considered. The availability of reliable, accurate, and comprehensive databases facilitates these predictions. Coupling the kinetic monitoring of solid transformation with a protocol of in-depth analysis and characterization will complement the knowledge of the intrinsic reactivity of the solid and help achieve the desired objective. From the application perspective, the selective separation of salts from a specific group of metals will be ensured by using the difference in their thermodynamic properties or hydrometallurgy (solvent extraction).

Hydrometallurgy

Hydrometallurgical operations involve mature technologies already integrated into the extractive metallurgy industry. Still, they must be interconnected to improve overall process performance and newer technologies based on novel chemistries to reduce environmental impacts while remaining effective (development of new extractants/absorbents, new leaching media, etc.). This axis aims to hydrometallurgically treat metallic concentrates or pyrometallurgical residues from primary resources (mines) or secondary resources (industrial residues, mining residues, end-of-life materials) to produce metallic salts with properties compatible with market expectations. The unit operations implemented in this axis include leaching, liquid-liquid and liquid-solid extraction (using ion exchange resins, adsorbent materials, or (electro)-membrane processes), precipitation/crystallization, and electrometallurgy.

From a more fundamental perspective (beyond the design of new processes or the improvement of existing ones), understanding the physicochemical phenomena occurring in the aforementioned operations will be addressed to develop physicochemical models that can be integrated into process simulation tools (process control assistance, process optimization). This topic will focus particularly on developing process schemes that can incorporate new technologies for extracting and valorising metals contained in conventional deposits, new deposits (low-grade ores, industrial effluent neutralization sludges, pseudo-sterile and attack residues, brines), and spent materials (recycling), with a specific focus on the recycling of WEEE, lithium-ion batteries, and permanent magnets, for which many challenges remain to be addressed to ensure a controlled energy transition.

Integrating hydrometallurgical operations into a comprehensive process combining mineral processing and pyrometallurgical treatment to ensure complete process control is a challenge this WP aims to develop sustainably. This holistic approach is ideally suited to many applications. In most processes addressed, each unit operation affects the others, and the three main types of separation (mineral processing, pyrometallurgy, hydrometallurgy) each has their strengths and weaknesses. In this regard, it seems essential to develop integrated approaches that combine separations to compensate for the shortcomings of each type of separation. Furthermore, it would be wise to intensify the development of tools that assess the impact of modifying one operation on the entire process and its organization. This modelling (and understanding the physicochemical phenomena included in the models) will require a multiscale vision integrating molecular modelling (DFT, molecular dynamics), acquiring thermodynamic and kinetic data, and coupling physicochemical models with chemical engineering models.

WP 3.2 - Management of plastics contained in the technologies used in the energy and digital transition

With over 60 million tonnes produced worldwide, we now face record electrical and electronic equipment consumption. Thanks to the many advantages of the plastic/metal combination, this market is growing by an average of 5% a year. The metal parts are rightly recycled when this equipment is collected (around 20% of available equipment).

However, very little has been done to consider the associated plastic fraction[1], representing up to 40% of the weight of this equipment. As part of the CIRSET project, we want to implement a Circular Economy (CE) around waste from electrical and electronic equipment (WEEE), considering, in particular, the plastic part and asking ourselves what is the best approach and what CE levers are available that could lead to the recovery of this material.

WEEE consists mainly of rigid plastic parts (thermoplastics or thermosets) included in computers, smartphones, televisions, printers, refrigerators, washing machines, coffee makers, etc., frequently forming the "casing" of these appliances. The flexible parts, such as electrical cable sheaths, buttons and seals, are elastomers, a more general and technical term than "rubber".

Plastronics is another field that is becoming increasingly important in developing the digital transition. Plastronics is a concept that brings together plastics processing and electronics. It aims to integrate components directly into the plastic. This technique makes it possible to manufacture smaller, more solid components. However, the dissociation of the metal components from the polymer matrix is a problem in terms of recycling.

Finally, the development of renewable energies also calls for equipment combining metals and plastics (photovoltaic panels, batteries, etc.).

Figure 8 illustrates the life cycle of a product and shows that CE can enable various players, such as manufacturers, distributors, consumers, service providers, and end-of-life players, to take action.

[1] Plastics from waste electrical and electronic equipment (WEEE)

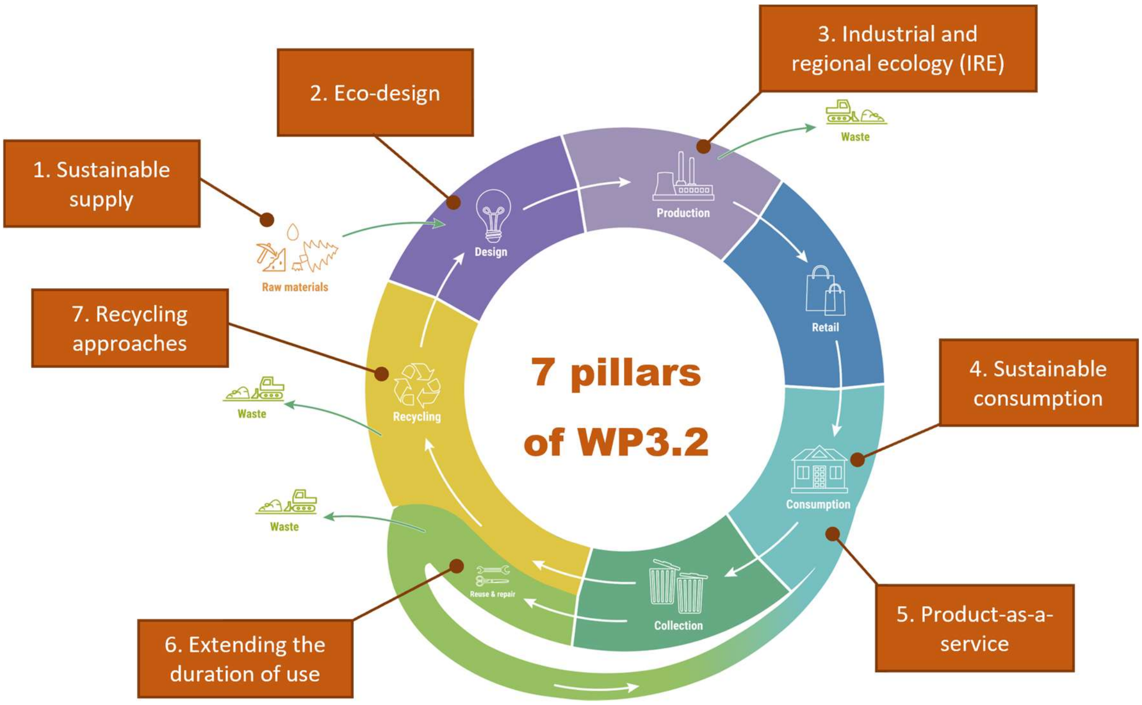

Figure 8: Life cycle of a product.

Which circular economy for WEEE?

For manufacturers and distributors, three levers can be activated: using more sustainable raw materials, a better product design and using secondary resources from another player.

As far as using more sustainable resources, many manufacturing sectors using plastics (packaging, textiles, transport, etc.) have seen more bio-sourced, bio-degradable or recycled materials. However, if we look at 3E applications, according to the European Bioplastics Association, less than 1% (around 100 thousand tonnes) of the plastics used come from this source. Regarding the use of recycled plastic, the fraction is even lower due to increased consumption of this secondary material by other sectors of activity and less pressure on the electronic equipment sector. In the CIRSET project, we will explore how new bio-sourced and recycled materials can be used to develop new 3E applications or replace already used materials.

From a product design point of view, in 2011, the ISO 14006 standard introduced the foundations of the eco-design principle. However, a few years later, pointed out that this measure did not affect manufacturers. More recently, the AGEC law has changed how EPR schemes are implemented. However, because of the weakness of the legal instruments and the lack of incentives for innovation, there are still few results for the plastics sector as a whole and virtually none for plastics combined with 3E. One of the cities' most attractive waste streams is printed circuit boards (PCBs), which contain many valuable metals. However, by now, they are separated by destructive operations. In this WP, we will develop new fields to explore opportunities to re-design 3E applications with close collaboration from local industries, such as Cimulec, the 2nd French PCB actor.

Finally, at the manufacturer level, the more valuated option is the establishment of an industrial and territorial ecology in a geographical perimeter. The main idea here is that local economic actors will optimise the flow of materials, energy and water by implementing joint actions and pooling these resources. In CIRSET, we have gathered a large panel of laboratories that will allow us to explore all the needs and requirements for initiating industrial ecology in this specific context.

<u>At the consumer level:</u>

Studies have been carried out in the packaging and textile industries to determine what actions would enable consumers to take greater responsibility. Studies have yet to be carried out on electrical and electronic equipment to determine how to influence this player positively. Comparative studies in other European countries will be performed before proposing a research direction linked to WP4.

<u>By Service providers:</u>

One of the most effective ways of action in the circular economy is to leave the ownership of an item of equipment to the manufacturer, who then charges for its use and no longer sells the item. Indeed, this solution will largely increase the lifespan thanks to a more robust, modular and better thought-out design because it is suitable for repair. In CIRSET, this solution, which implies the whole product and not only the plastic part, will be studied in the former WP.

<u>Complexity of waste</u>

An important point is the complexity of the plastic waste that needs to be recycled. As mentioned above, plastics come in different forms (thermoplastics, thermosets, elastomers) and are used for other purposes. In addition, they are usually combined with various fillers (glass or carbon fibres, carbon fillers such as carbon black or graphene, and flame retardant additives) to improve their performance.

<u>Collection and sorting</u>

The management of waste electrical and electronic equipment, or WEEE, has been regulated by the European Union since 2003 and is regulated, among other things, by decree no. 2014-928 of 19 August 2014 in France. WEEE can be divided into seven categories and is subject to an Extended Producer Responsibility channel.

Sorting is an operation that can be made difficult by the presence of fillers that will prevent identification of the plastics used as a matrix ("dark plastics", for example). Analysis techniques need to be developed specifically for their identification. In this project, we propose, among other things, the development of a more efficient methodology using artificial intelligence (machine learning), which may be applied to robotics and separation.

Recycling

Depending on the nature of the plastic, the type of recycling to be considered will differ (mechanical, chemical, energy recovery).

- As elastomers are challenging to melt under conventional conditions, they cannot be recycled traditionally, known as "mechanical recycling".

- Thermoplastics are often mixed. A study of their compatibility is essential, as is an analysis of the impact of fillers (including trace metallic fillers from primary separation).

Finally, another more disruptive approach will be proposed for the CIRSET project. In fact, for several years, the LRGP and ERPI laboratories have been working on directly recycling plastic mixtures by 3D printing. This method, validated in the case of a slightly contaminated mixture, would make it possible to remove the previously presented obstacles, namely fine separation and sorting.

3.4. WP 4: Meeting the challenges of the circular economy with innovative approaches to training and knowledge transfer

The challenges we face are paramount in the circular economy and sustainability realm. They necessitate the development of a unique blend of technological, organizational, and societal innovations within and across stakeholder-value networks (Mendoza et al., 2019). One of the most profound ways to promote this transformation is to involve all people through education. The transition to a circular mindset should be as fluid and intuitive as modern science allows. Education plays a central role here. However, it requires the synergy of multiple actors to succeed, and approaches must be differentiated according to the audience (e.g., students, the public, decision-makers, entrepreneurs), their cultures and singularities, and the targeted goals. Such complexity calls for research and innovative implementation. Introducing organizational, behavioral, and mindset change into society is a complex task that requires precision and the latest tools. In the CIRSET program, innovation isn't confined to industrial processes and technologies but extends far beyond them to address these anthropocentric issues.

Given the environmental and ethical stakes involved, it is crucial to avoid generalizing unproven educational approaches that could prove unsatisfactory or even negative later. For instance, the once popular ‘shockvertising’ technique, which aimed to create strong negative emotional responses in consumers to provoke specific behaviors, is now being questioned from an ethics standpoint. In this context, it is imperative to conduct translational educational research that identifies valuable approaches and ensures their ethical implications are thoroughly considered.

Moreover, engaging in more forward-looking work is crucial, particularly regarding emerging theories and technologies in education and, more largely, in human sciences (psychology, ergonomics, economy, management, etc.). This proactive approach allows us to explore capability-based approaches, eudemonic learning experiences, strategies to support cognitive dissonance, and technologies such as persuasive and immersive ones, those offering extended and more tangible reality or AI. Doing so ensures that our educational practices remain relevant and effective in evolving societal and technological landscapes.

In other words, CIRSET seeks to explore what an education promoting a more sustainable and circular mindset could and should look like in the future.

Therefore, in addition to deploying training, communication, and mediation programs, WP4 aims to innovate by building on human sciences research and Work Packages 1 to 3 results, see Figure 9.

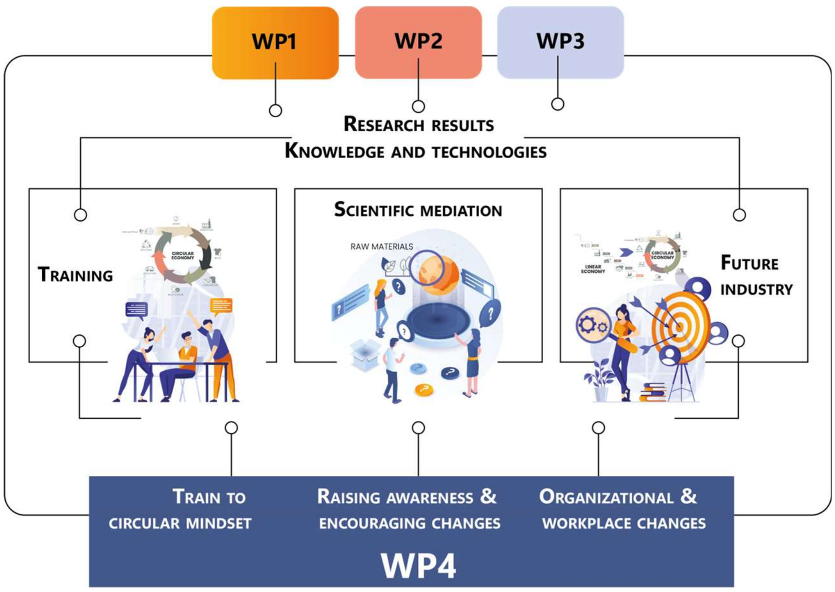

Figure 9 Schematic representation of WP4 structure.

In this sense, CIRSET WP4 is divided into three sub-WPs, each linked to a specific area.

- WP4.1 Innovate within higher education and in-training programs to develop the competencies of tomorrow that are favorable for implementation within society.
- WP4.2 Innovate in mediation and technology transfer approaches to create the right conditions for raising awareness, a collective shared vision, and encouraging the changes needed to cope with transitions.
- WP4.3 Supporting changes in organizations and workspaces and the transition to a circular economy.

These three work modules include the same research directions: 1) exploring/understanding what already exists, 2) designing innovative approaches, including computer-supported ones, and 3) being able to evaluate the impact of dedicated programs through participatory approaches, including different stakeholders from policymakers, industrial, scientist and citizens. Design-based research methodologies in education, human-computer interaction, action, or translational research are favored here. CIRSET will also benefit from the contribution of masters students instructional designers (Inspé de Lorraine MEEF-ingénierie pédagogique) via internships or tutored projects.

WP 4.1 - Innovate within higher education and in training programs

Due to the important role of higher education institutions in the sustainable transition, circular economy education (CEE) has become a recent area of research (Renfors, 2024). Knowledge about learning content is becoming abundant (Keramitsoglou et al., 2023; Kirchherr et al., 2017). It is also well known that knowledge-based pedagogical approaches are important for transferring recent insights on issues related to the exploitation, recycling or reuse of primary and secondary resources. However, they find their limits in the face of developing skills linked to problem-solving, critical, global, and systemic thinking, which underpin the circular mindset. Moreover, to enable students to engage, collaborate, and contribute with various stakeholders, they must build this expertise through situated learning approaches. In addition, they need to be able to take intercultural aspects into account; for example, the circular economy requires a different roadmap depending on the cultures and activities of a particular country (Salas et al., 2021). However, the very emergent nature of this subject, which is about developing these transversal and cross-cultural skills in university training programs, means that previous experiences are lacking. To innovate in this direction, clearer frameworks and evidence are needed to advise educational leaders on which approaches to promote.

Consequently, CIRSET will develop further research on teaching/learning approaches related to change management, circular thinking skills, interculturality, and inclusive attitudes.

The WP4.1 addresses research and innovation in learning and training. First, it will identify initial training needs and potential levers for innovation. Ideally, interdisciplinary work will identify barriers to learning and teaching by studying the students' and teachers' beliefs, practices, and norms that stand in the way of learning or hinder change. It will also define the cultural and ethical dimensions to be considered in training as content. At the same time, we will monitor and assess the state of knowledge derived from recent research and "work in progress" that should be included in training courses and from proven practices, theories, and models conducive in higher education to circular thinking, behavioral change, etc.

Second, based on the previous results, CIRSET will support the design or renovation of training programs required to develop circular thinking competencies. To that aim, innovative digital or hybrid learning environments will be explored for student empowerment (e.g., immersive and collaborative environments, hybrid practical work benches, dilemma-based serious games, or design studios). CIRSET will also develop a training program to support teachers in changing their teaching practices and, more broadly, the school form in higher education.

Finally, we will identify and develop metrics, evaluation methods, and algorithms to measure the impact of theoretical methods, pedagogical tools, and programs. Evaluation of the impact of training programs and tools targeting learning objectives on students' circular mindset, empowerment, and employability will also be implemented during the final third of the project. This item is strongly related to WP4.3

This WP4.1 will build on various master's programs currently offered at UL and directly related to the themes addressed in CIRSET (e.g., Master STPE with M2 SMGE -exploration-, EDRM -sustainable exploitation of mineral resources-, SEE -soil, water, environment-, etc.). It will address issues ranging from "in-the-field" aspects to international deployment and benefit from "in-the-field" training. For example, SMGE has a course in the Massif Central on mineral deposits, including the Li at Beauvoir, while SEE is working on soil decontamination in Lorraine. Moreover, different ERASMUS + programs (ERASMUS+ KA220 ARTeMIS and HERawS), as well as the Erasmus Mundus Master program GREENANO or SPICE-MP, are supported by project members. The project will also build on existing UL facilities, such as the ORION programs (e.g., RECOLTE, TP d'excellence).

WP 4.2 - Innovative mediation for raising awareness and encouraging changes

Knowledge of what needs to be done to meet the global change goals is well-spread within the scientific research community but has limited spread among the large public. This is partly due to limited publicity and popularization. It is important to combat the myths that were inherited by younger citizens from older generations (e.g., "mining is always very dirty," "everything can just be recycled," etc.). At the same time, we need to provide decision-makers and the large public with the tools to help them make changes and decisions.

Unfortunately, changing social attitudes and behavior can be one of the most difficult aspects of the transition to a circular economy and raise research questions (Voukkali et al., 2023). Indeed, an individual's actions are influenced by (i) perception, linked to subjective impression; the more positive one's beliefs, expectations and emotions are about an action, the more inclined one is to engage in it; (ii) awareness degree, dependent on the level of education but also on the influence of socially valued behaviors; (iii) and the natural tendency to act, influenced by the personal conviction that an action will lead to a specific result. People's positive opinions about a phenomenon reinforce their willingness to participate in a particular action. The public disparity in these three major dimensions within the general population limits the effectiveness of programs based simply on awareness-raising. A more inclusive, differentiated, and participatory approach seems advisable.

First, a participative approach based on the "**tiers lieux**" model will explored. ERPI and LRGP have also been working on the concept of Green Fablab to explore disruptive recycling approaches by local communities. Projects such as Green_Local_3D ANR INEDIT (H2020) are part of this initiative.

Third places and innovation spaces are hybrid spaces where people from different backgrounds can meet, collaborate, and commit jointly. The best-known third places are undoubtedly fab labs, but there are many other forms (see, for example, https://francetierslieux.fr). They are based on open, horizontal relationships, with no obligation on either side (e.g., guest/host), facilitating the creation or development of communities. These collaborative environments can foster sustainable experimental learning, provide methodologies and tools for the co-creation of circular solutions, drive the transition toward sustainable smart cities, foster the creation of new sustainable business models, promote sustainable urban entrepreneurship, and facilitate knowledge exchange on circular solutions (Kasmi et al., 2022). These spaces are levers for innovation, thanks to the shared physical and cultural spaces they offer. The challenge of bringing together research players, the large public, and decision-makers for dialogue and co-construction argue in favor of deploying such a space dedicated to CE within the UL. It is essential that the dialogue exists on all levels (including policymakers) and that this dialogue leads to concrete actions and the establishment of necessary regulations. In the dissemination program, CIRSET will promote and support as a part of the SIRIUS («*Stratégie d'Innovation pour le Renforcement des Interactions entre Université et Société*») initiative of the University of Lorraine that has created a Network of open spaces seeking to close the gap between the university and society.

Second, CIRSET will study mediation digital systems that could hybridize traditional approaches. The emerging extended reality, tangible interaction, and data visualization technologies currently open new opportunities for a more immersive approach to science exhibits and to reduce distances (spatial, cognitive, and social) between the public and research results. CIRSET aims to enhance the public experience by stimulating wonder, discovery, and the challenge of preconceptions and encouraging change in everyday life. Reaching audiences with little or no access to culture is a priority here, with the main goal of exploring computer-supported hybridization.

Finally, CIRSET, drawing on the results of ePsyCHI and the ANR thérapeutique involving PErSEUs, proposes to study the behavior and opinion change models adapted to bring civil society to a stronger commitment in favor of CE. The latter will finally be assessed within these techno-educational mediation spaces and devices.

Most of the communication tools mentioned above for the large public will also apply to students outside the training programs specifically dedicated to them. This WP4.2 will also benefit from numerous dissemination experiences implemented by project members (e.g., science en lumière CNRS, Club ORION, Pint of sciences, Sciences and you, actions de la métropole du Grand Nancy, Collecte territoriale de collants usagés (Action réalisée avec le Carnot ICEEL), etc.).

Moreover, the project will benefit from PERSEUS's involvement in the France2030 -ASTERIE project, which is dedicated to innovation in school form for the development of tomorrow's “talents” and piloted by the rectorat de l'académie Nancy-Metz (9M€, 2024-2029).

WP 4.3 - Supports organizational and workplace change as part of the transition to a circular economy

Indeed, while research, technological innovation, and their transfer are necessary conditions for transforming practices, they are not sufficient in their way. Therefore, the systemic approach developed by CIRSET implies supporting these transformations from a managerial point of view, i.e., regarding the skills of stakeholders and their organizations.

This is, first and foremost, the case for human resources management, a field where "green HRM" (Haddock-Millar et al., 2016) has developed to demonstrate how HRM practices can evolve to align with the environmental objectives pursued by organizations. This means recruiting differently, training differently, offering different career paths, and making management decisions based on the search for environmental performance. Such a paradigm implies rethinking HRM and the skills expected of employees. In this respect, CIRSET would benefit from a closer relationship with the LUE "Industrie du futur" project (coord. Hind Bril El Haouzi), which is currently working on a diagnostic project as part of France 2030's national "Compétences et métiers d'avenir" (CMA) call: it will focus on the Twin Transition notion, in conjunction with the Impact program. Given the potential links with CIRSET, this CMA diagnostic project could also benefit CIRSET right from the diagnostic phase to develop a training offer (interdisciplinary, in particular) to complement existing initial and continuing training. To do so, it will then be necessary to:

- take an overview of current training provision dedicated to green transition linked with management within the industry from an interdisciplinary perspective,
- and question its effectiveness: How can we improve visibility, readability, and effectiveness with in-training learners (what skills are developed and applied in the field? Are they integrated, valued, and recognized by organizations in accordance with the green HRM framework?)?
- in light of CIRSET's ambitions, as well as the prospective needs of the socio-economic world, question new needs and opportunities.

Last but not least, and beyond HRM issues alone, other organizational factors could be questioned as levers likely to slow down or accelerate the transformation of companies in the sector, such as tools and methods to support change, the construction of indicators, and the mobilization of different BTB or BTC marketing approaches. This is also the case for the economic valuation of companies covered by CIRSET, which are increasingly exposed to extrafinancial rating criteria (ESG) and thus constitute a powerful potential vector for transformation (Jarjir et al., 2022).

In addition to the work that could be carried out on such issues, their findings could provide original economic value through tools and sector-specific methodologies developed with their organizations.

There is a direct link with WP 2.3 aimed at developing Decision Support Systems (DDS). These innovative tools seek to understand better and ease the exploration of the complex multidimensional trade-offs required by the circular economy shift. The validation of the developed tools will require an iterative interaction process with stakeholders at different levels of the decision-making chain, from policymakers industrialists, workers, and citizens. So, this action will be capital to support the organizational and mindset change process.

CIRSET aims to disseminate scientific knowledge to its partners through industrial collaborations. CIRSET aims to pass on the latest scientific knowledge to its partners as part of its industrial collaborations. Workshops organized by CIRSET scientists aim to address recent questions (e.g., "Which equipment or procedures are available to solve my specific problem? How reliable are my results? What are the material-specific limitations or particularities to look out for?"). They aim to accelerate knowledge transfer, strengthen research-industry partnerships, and establish trusting and mutually enriching exchanges with our industrial collaborators.

References:

Haddock-Millar, J., Sanyal, C., & Müller-Camen, M. (2016). Green human resource management: a comparative qualitative case study of a United States multinational corporation. *The International Journal of Human Resource Management*, *27*(2), 192-211.

Jarjir, S. L., Nasreddine, A., & Desban, M. (2022). Corporate social responsibility is a common risk factor. *Global Finance Journal*, *52*, 100577.

Kasmi, F., Osorio, F., Dupont, L., Marche, B., & Camargo, M. (2022). Innovation Spaces as Drivers of Eco-innovations Supporting the Circular Economy: A Systematic Literature Review. *Journal of Innovation Economics & Management*, *39*(3), 173-214.

Keramitsoglou, K., Litseselidis, T., & Kardimaki, A. (2023). Raising effective awareness for circular economy and sustainability concepts through students' involvement in a virtual enterprise. *Frontiers in Sustainability*, *4*, 1060860.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221-232.

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019). A methodological framework for the implementation of circular economy thinking in higher education institutions: Towards sustainable campus management. *Journal of Cleaner Production*, *226*, 831-844.

Renfors, S.-M. (2024). Education for the circular economy in higher education: an overview of the current state. *International Journal of Sustainability in Higher Education*, *25*(9), 111-127.

Salas, D. A., Criollo, P., & Ramirez, A. D. (2021). The Role of Higher Education Institutions in the Implementation of Circular Economy in Latin America. *Sustainability*, *13*(17), 9805.

Voukkali, I., Papamichael, I., Economou, F., Loizia, P., Klontza, E., Lekkas, D. F., Naddeo, V., & Zorpas, A. A. (2023). Factors affecting social attitude and behavior for the transition towards a circular economy. *Sustainable Chemistry and Pharmacy*, *36*, 101276.