Leverhulme Doctoral Scholarships Programme for Interdisciplinary Resilience Studies (PIRS)

University of Southampton

RECRUITMENT CYCLE for studentships starting: October 2025 (Cohort 2)

SUPERVISORY TEAM

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STUDENTSHIP PROJECT TITLE

Sustainable Development for Critical Minerals: A Game Theoretical Approach

OVERVIEW

This project explores sustainable development strategies for critical minerals (such as lithium, cobalt, and rare earth elements) using game theory. By modelling the strategic interactions between governments, mining companies, and supply chain actors, the research aims to balance economic gains, environmental sustainability, and resource availability. The study focuses on how cooperation and competition influence decision-making in resource extraction, addressing challenges like environmental impacts, geopolitical tensions, and market volatility. This interdisciplinary research integrates game theory, sustainability, and supply chain management, offering insights into resilient, sustainable critical mineral supply chains.

SUMMARY

This project aims to develop sustainable strategies for managing critical minerals such as lithium, cobalt, and rare earth elements, which are essential for technologies like electric vehicles, renewable energy, and electronics. These resources are finite and increasingly contested, raising urgent concerns about environmental degradation, geopolitical risks, and supply chain volatility.

Using **game theory**, this research models the strategic decisions made by key stakeholders, including governments, mining companies, and manufacturers. The focus is on how different actors cooperate or compete over resource extraction, environmental regulations, and profit-sharing. The project will explore scenarios where sustainable practices can emerge through collaboration, despite competing interests, while minimizing environmental impacts and ensuring long-term resource availability. Applicants will benefit from interdisciplinary training, blending **game theory**, **supply chain management**, and **sustainability studies**, gaining expertise in high-demand areas like resource economics and policy-making. The research will directly contribute to the growing field of sustainable supply chains, particularly in critical sectors that rely on rare materials.
The project's impact lies in providing actionable insights for policy-makers and industries to navigate the complexities of critical mineral management, enabling sustainable resource use while maintaining economic competitiveness. It aligns with ongoing research in **resilience studies**, contributing to the global dialogue on resource scarcity and sustainable development.

PROJECT CONCEPT

1. Introduction

The sustainable development of critical minerals—such as lithium, cobalt, and rare earth elements—has emerged as a key challenge in the global transition toward renewable energy and technological advancement. These minerals are essential for the production of batteries, electric vehicles, and other clean technologies. However, their extraction and distribution are fraught with issues related to environmental sustainability, geopolitical tensions, and market volatility. Managing the long-term availability of critical minerals while minimizing environmental and social impacts is a central issue for policymakers, industries, and resource-dependent economies.
This research proposal aims to explore the sustainable development of critical minerals using a game theoretical approach. By examining the strategic interactions among governments, mining corporations, and supply chain actors, this study seeks to develop models that encourage cooperation and fair distribution of resources while promoting long-term sustainability. The study will contribute to sustainable development goals by providing decision-making frameworks that balance economic, environmental, and social objectives.

2. Research Aims and Objectives

The primary aim of this research is to apply game theory to the sustainable development of critical minerals, addressing the tensions between resource extraction, environmental sustainability, and global demand.

Key Objectives:

- To model the strategic interactions between nations, corporations, and communities involved in the extraction and distribution of critical minerals.
- To analyze the role of competition and cooperation in achieving sustainable practices for critical mineral supply chains.

- To provide actionable strategies for policymakers and industry leaders to promote sustainable extraction and equitable resource allocation.

3. Research Questions

- How can game theory be used to model the interactions between stakeholders involved in critical mineral extraction and distribution?
- What are the optimal strategies for balancing the economic, environmental, and social impacts of critical mineral extraction?
- How can cooperative game theory be applied to encourage collaboration between countries and corporations to ensure a stable and sustainable supply of critical minerals?

4. Methodology

This research will apply a game theoretical approach to develop models for the sustainable management of critical minerals. The methodology will include both theoretical and empirical components, focusing on modeling interactions between key stakeholders and examining real-world case studies.

(1) Game Theory Model Development:

- **Non-Cooperative Games**: The study will model non-cooperative games to analyze competition between countries and corporations for control over critical mineral reserves. These models will explore how different stakeholders optimize resource extraction strategies while managing environmental and social risks.
- **Cooperative Games**: Cooperative game theory will be applied to study how alliances can form between nations and corporations to enhance sustainability. Models will explore cost-sharing agreements, resource-sharing arrangements, and joint ventures for responsible mineral extraction and recycling.
- **Dynamic Games**: The study will use dynamic game models to address the long-term sustainability of critical minerals, focusing on how decisions made today impact future availability, environmental costs, and social outcomes.

(2) Case Study Analysis:

- Real-world case studies of critical mineral extraction and distribution (e.g., lithium in South America, cobalt in the Democratic Republic of Congo) will be examined to validate the game theory models. These case studies will highlight key sustainability challenges, governance issues, and cooperative strategies that have been used or could be applied.

(3) Empirical Data Collection:

- Interviews with stakeholders in the critical minerals supply chain (e.g., mining companies, policymakers, environmental groups) will provide empirical data on how game-theoretical decisions manifest in real-world practices. This data will also shed light on the willingness of stakeholders to engage in cooperative strategies for sustainability.

5. Expected Contributions

(1) **Theoretical Contribution**: This study will contribute to both game theory and sustainable development literature by providing novel models for managing the

complex interactions between stakeholders in the critical minerals sector. The research will also extend the application of dynamic and cooperative games to the context of resource sustainability.

(2) **Practical Contribution**: The results of this research will provide policymakers and industry leaders with strategic frameworks for managing critical minerals sustainably. These frameworks will guide decision-making on resource allocation, environmental protection, and international cooperation, with practical applications in industries such as energy, manufacturing, and technology.

Please explain how this project represents a contribution to interdisciplinary resilience studies.

This research is highly relevant to interdisciplinary resilience studies, as it addresses the resilience of global supply chains and natural resource systems in the face of increasing demand and environmental degradation. By integrating game theory with sustainability and supply chain management principles, the study offers a holistic approach to building resilient systems for critical minerals, ensuring that these resources are available for future generations without compromising ecological integrity.

Please list and describe any specific/additional technical training or support to undertake and successfully deliver this project. *Note that students recruited into this programme will undertake a bespoke training curriculum. Students and their supervisory teams will also identify generic skills gaps to address through training courses offered by the University's Doctoral College.*

N.A.
