# Recycling as a Means of Reducing Material Related Supply Risks

Steffen J. Schlosser[0009–0008–6081–7721], * and Tobias Naegler[0000–0003–2390–1672]
German Aerospace Center (DLR), Institute of Networked Energy Systems (VE)
* Corresponding author
*e-Mail address*: steffen.schlosser@dlr.de

## Introduction

The energy and transport (E&T) transition requires a large-scale adoption of:

- Renewable energy sources (RES)
- Storage technologies
- Electric vehicles (EV)

For certain key materials, incl. neodymium, dysprosium, and lithium, the increase in demand will lead to stronger geopolitical dependencies.

Recycling can be a means of mitigating geopolitical dependencies [1,2]:

- Domestically recycled materials can reduce imports of primary materials
- Flexibility to choose supplier countries in order to minimize risk

## Research Questions

Investigation of E&T scenario [3] compatible with a well-below 2°C target until 2050:

1. What is the theoretical recycling potential, at a 100 % recycling rate (RR), of E&T technologies and how does it evolve over time?
2. Which raw material demand share can be covered by domestic recycling?
3. How can recycling ambitiousness mitigate geopolitical dependencies?

**European perspective:**

- E&T technologies located in the EU are recycled in the EU after End-of-Life (EoL)
- Materials from EU-based recycling non-problematic in terms of geopolitical risk

## Methods

- Material flow analysis [4,5] to determine raw material demand
- Political situation assessed via $WGI$ [6]
- EU supplier country distribution $c_{i,r}$ acc. to current global production distribution
- Recycling scenarios:
  1. "Ambitious": 80 % RR by 2050, with linear increase of current RR
  2. "Theoretical": 100 % RR
- Geopolitical risk of materials $r$ assessed via: $HHI\text{–}WGI_r = \sum_i WGI_i \cdot (c_{i,r})^2$ [7]
- Geopolitical risk (GR) associated with total material demand via aggregation with absolute mass $m_{sys,r}$ as weight [8]: $GR_{sys,r} = m_{sys,r} \cdot HHI\text{–}WGI_r$

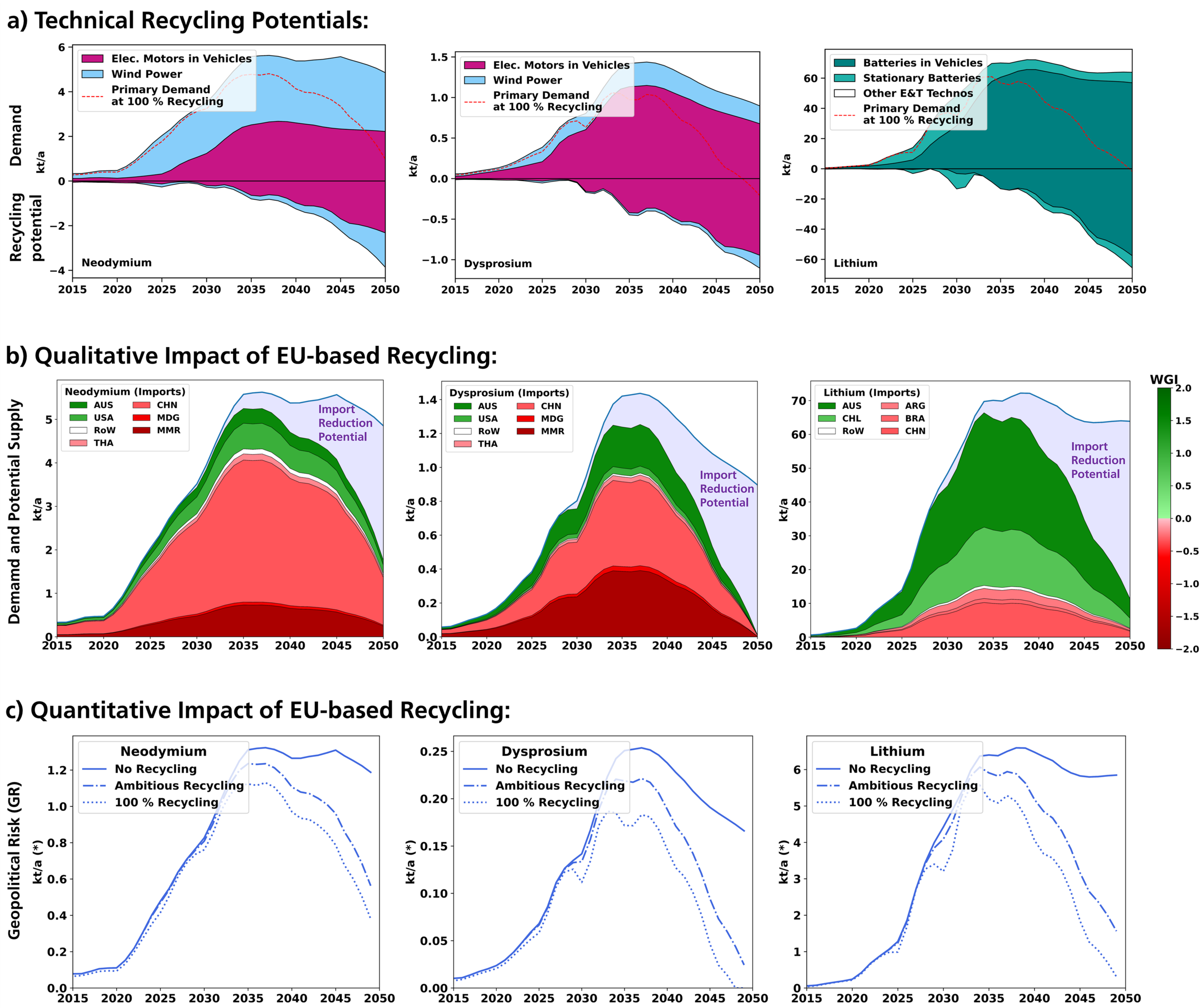


**Figure 1:** Illustration of a) the theoretical recycling potential with 100 % recycling of End-of-Life (EoL) for E&T technologies, b) the potential of EU-based recycling to replace foreign imports in an ambitious recycling scenario, and c) the geopolitical risk on the scenario level with a sensitivity test.

## Results

**Fig. 1a) Demand and recycling potential:**

- Theoretical recycling potential could drastically reduce neodymium primary material demand
- Zero dysprosium and lithium primary material demand before 2050 theoretically possible

**Fig. 1b) Imports with ambitious recycling:**

- Ambitious recycling could drastically decrease non-EU imports
- Ambitious recycling could enable exclusion of politically unstable supplier countries to optimize geopolitical risk

**Fig. 1c) Geopolitical risk:**

- Risk exclusively for non-EU imports
- High potential of EU-based recycling to mitigate geopolitical dependence

## Conclusions

Demonstrated geopolitical risk mitigation by recycling. Further refinements are required:

- Specific & prospective analysis of EU import dependence
- Import dependence on whole E&T technologies [9]
- Combined assessment for all materials

**References:**

[1] Santillán-Saldivar et al. "How recycling mitigates supply risks of critical raw materials: Extension of the geopolitical supply risk methodology applied to information and communication technologies in the European Union." *Resources, Conservation and Recycling* 164 (2021): 105108.
[2] Yamamoto et al. "The role of recycling in alleviating supply chain risk–Insights from a stock-flow perspective using a hybrid input-output database." *Resources, Conservation and Recycling* 185 (2022): 106474.
[3] Luderer et al. "Impact of declining renewable energy costs on electrification in low-emission scenarios." *Nature Energy* 7.1 (2022): 32-42.
[4] Schlichenmaier and Naegler. "May material bottlenecks hamper the global energy transition towards the 1.5° C target?" *Energy Reports* 8 (2022): 14875-14887.
[5] Gervais et al. "Material requirements for the energy transition - Energy technology profiles and environmental impacts." FhG Working Paper (2022).
[6] Kaufmann and Kraay: "The Worldwide Governance Indicators, 2024 update: Aggregate governance indicators 1996-2024." (2024), http://www.govindicators.org/
[7] Blengini et al. "EU methodology for critical raw materials assessment: Policy needs and proposed solutions for incremental improvements." Resources Policy 53 (2017): 12-19.
[8] Schlosser and Naegler. "Supply Disruption Probabilities of Renewable Energy Sources and Storage Technologies: Assessment from an Energy System Perspective." *Presentation at IRTC conference 2024* (2024).
[9] Lekavičius et al. "The diversification of energy resources and equipment imports in the European Union." *Energy* 307 (2024): 132595.

Funded by the:
Federal Ministry of Education and Research
in the project *ARIADNE II*
Funding code: 03SFK5B0-2

DLR