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May the availability of critical raw materials affect the security of energy systems? An analysis for risk-aware energy planning with TEMOA-Italy

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Under review for publication on Materials Today Energy

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Partenariato Esteso Finanziato dal PNRR - Missione 4, Componente 2, Investimento 1.3

Outline

- Introduction
- Aim of the work
- Case study, Italian energy system
- Metric definition
- Scenarios analysis
- Technology mix, materials consumption and energy security
- Conclusion and perspectives

Introduction: energy security and the role of materials

Energy security

- **Uninterrupted energy supply**
- **Affordable price**
- **To everyone**

- **Equitable access**
- **Economy growth**
- **Climate change**

What is missing in literature?
Supply risk of **Critical Raw Materials (CRMs)**

May **CRMs affect** the **energy security?**

- Renewable energy technologies
- Low-emitting vehicles

Material intensive

- Geographical concentration
- Political instability

Material supply bottlenecks

Reference: IEA, "Energy Security", https://www.iea.org/topics/energy-security

Aim of the work

Analyze the **energy security** of future **energy systems** in different **material supply disruption scenarios**

How?

Material Supply Risk (MSR)

- Technology composition
- Energy transition

Energy security metric

- Quantification
- ESOM outcomes

ESOM: TEMOA-Italy

- Italian energy system
- Material supply process
- Material intensity

Material supply disruption scenarios

- Geopolitical restriction
- Energy system
- Energy security

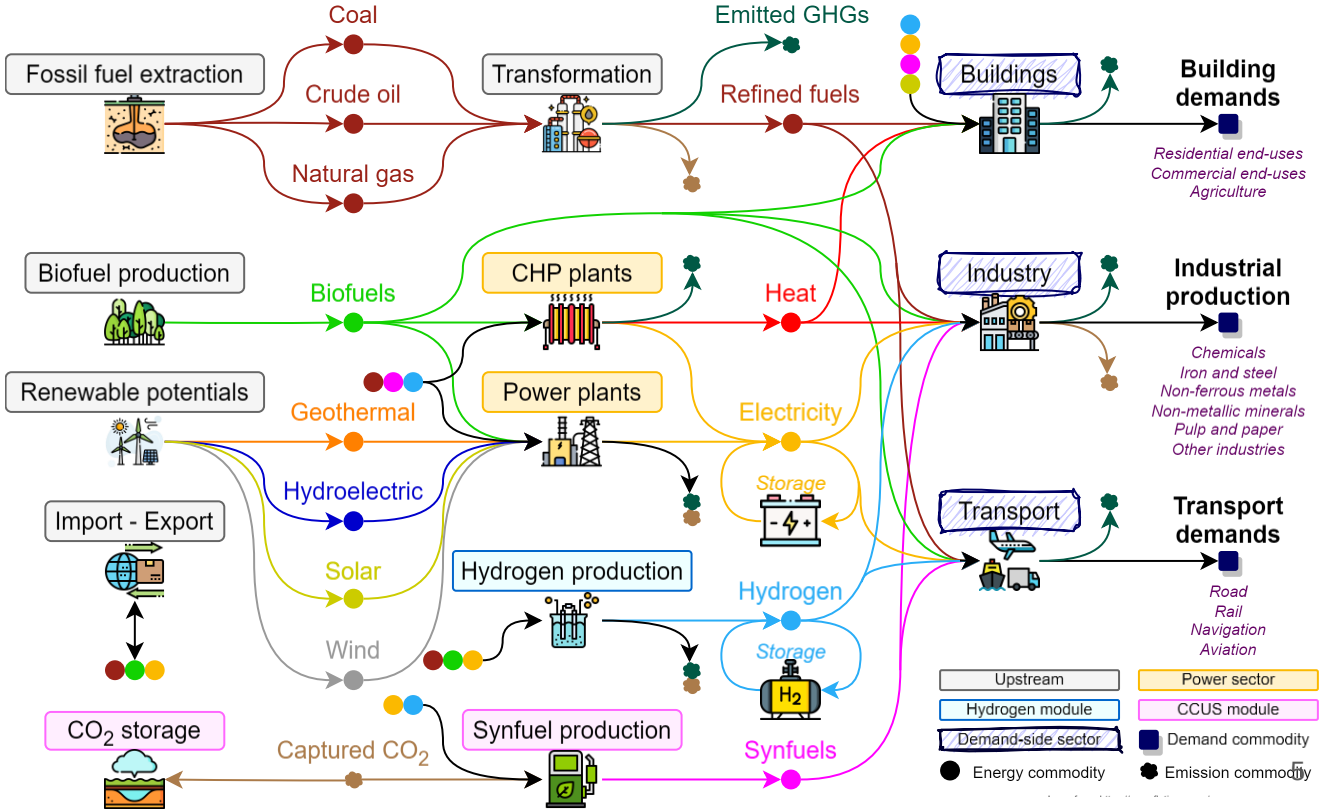
TEMOA-Italy GitHub Repository

The TEMOA-Italy model

Energy System Optimization Model for the **Italian** energy system, developed with the **TEMOA modelling** framework.

Main features:

- **Modelling all the energy sectors**
- **Single region**
- **Medium-to-long term analysis** (up to 2050)
- **Outcomes**
  - Activity
  - Capacity



Energy security metric

Energy security level

Comprehensive Energy Security Metric

Metric structure

Dimensions

Material Supply Risk	Energy Supply Risk	Internal Reliability

Indicators

Material Supply Risk (MSR)	Renewable Energy Supply (RES)	Energy Intensity (EI)
Material **shortages**	**Emission** reduction	**Consumption** efficiency
	Diversification Energy Supply (DES)	**Capacity Factor (CF)**
	Resource dependence	**Continuity** of supply
	Self Sufficiency (SS)	**Capacity Credit (CC)**
	Country dependence	Resource **adequacy**

Aggregation

$$\mathbf{ESI} = \frac{1}{3} \cdot (1 - \mathrm{MSR}) + \frac{1}{9} \cdot (\mathrm{RES} + \mathrm{DES} + \mathrm{SS}) + \frac{1}{9} \cdot ((1 - \mathrm{EI}) + \mathrm{CF} + \mathrm{CC})$$

Material Supply Risk (MSR)

SR_{tech_j} for different **power technologies** expressed in a logarithmic scale

Evaluating the **supply risk of a technology** (SR_{tech_j}):

Material intensity $\left(\frac{kg}{Cap}\right)$ of the technology (j): Amount of **material consumed by the technology**

Supply risk (-) of the consumed material (i): **Risk of inadequate supply**

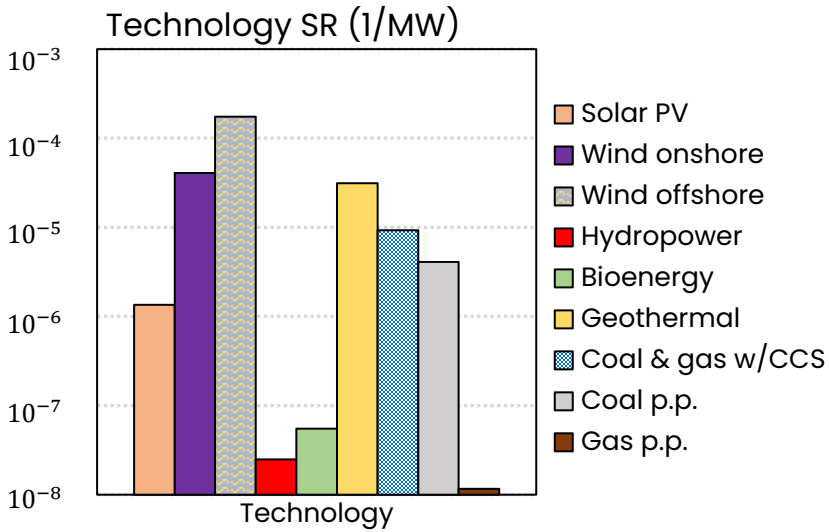
$$SR_{tech_j} = \sum_{i}^{n} m_i \cdot \frac{SR_i}{c_i} \left(\frac{1}{Cap}\right)$$

MSR of the system

Material global consumption $\left(\frac{kg}{year}\right)$
Higher consumption, less volatile market.

$$MSR = \sum_{j}^{k} SR_{tech_j} \cdot Cap_j$$

Installed capacity (Cap) of the technology (j)



Material intensity applied to:

- **Power generation and storage**
- **Hydrogen generation through electrolysis**
- **Cars**

Reference: N. Martin et al., "New Techniques for Assessing Critical Raw Material Aspects in Energy and Other Technologies", Environmental Science and Technology, 2022.

Scenario analysis

Reference scenarios:

Business As Usual (BAU): Free from constraints.

Net Zero Emission (NZE): Reach carbon neutrality in 2050.

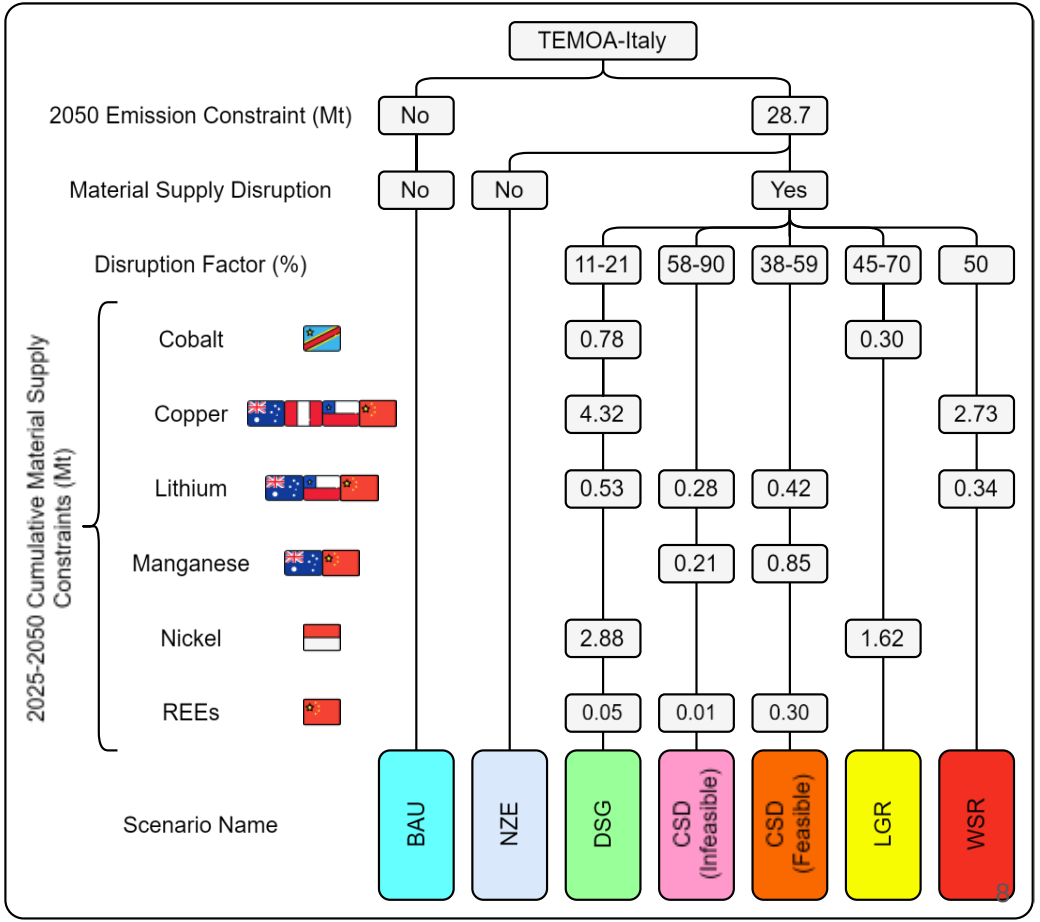
Material supply disruption scenarios:

Demand-Supply Gap (DSG): Inadequate material supply, demand not satisfied.

Chinese Supply Disruption (CSD): Reduced material supply from China.

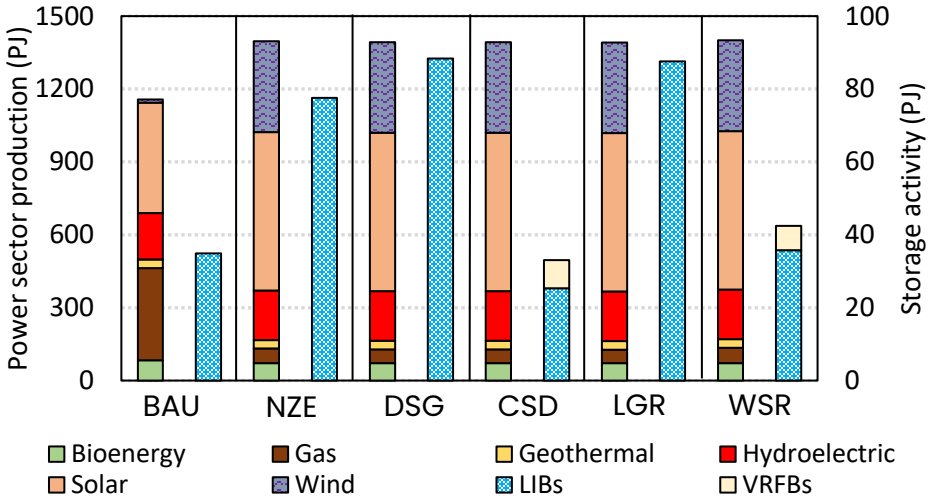
Low Governance Region (LGR): Supply disruption from political unstable regions.

Water Stress Region (WSR): Effects of climate changes on global material supply.



Technology mix

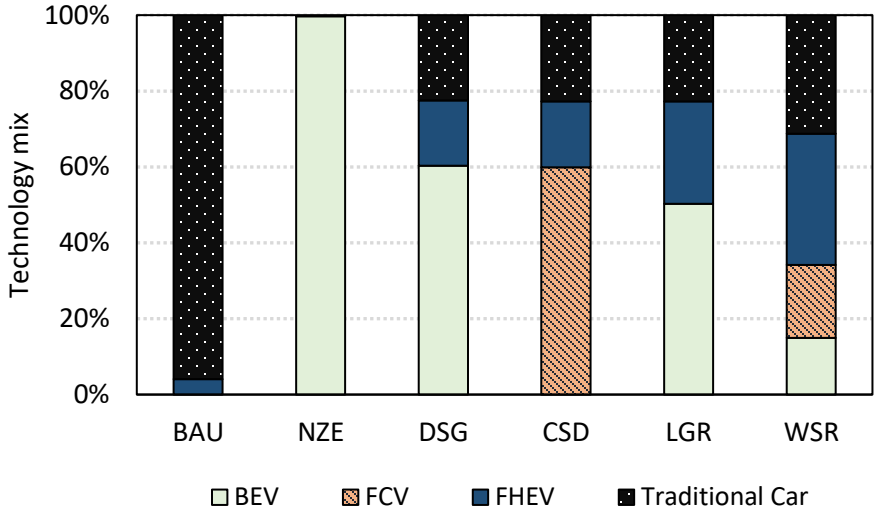
Power sector production and **storage** activity **in 2050** for the different scenarios.



In low emission scenarios:

- **Similar power generation mix**, with prevalence of **solar and wind** production.
- Lithium-ion batteries (**LIBs**) lead the **storage sector**.
- **CSD and WSR** scenarios concern the penetration of vanadium-redox-flow batteries (**VRFBs**).

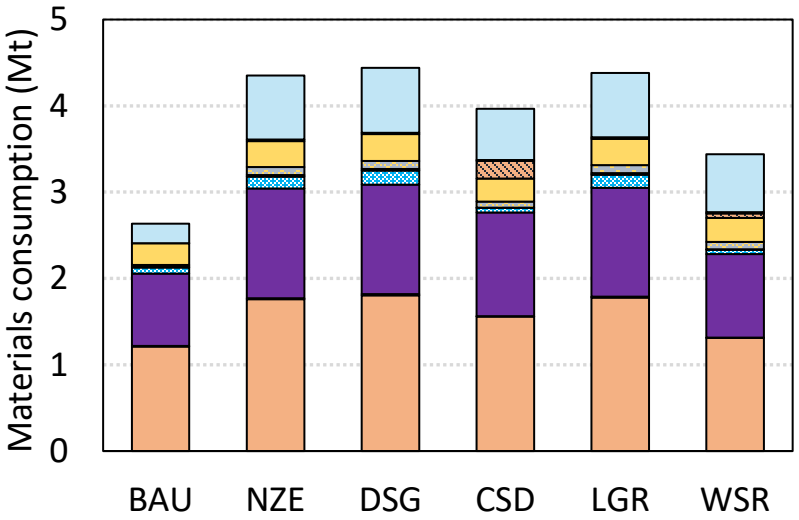
Cars technology mix in 2050 for the different scenarios**.**



- In the **material supply disruption scenarios,** the technology mix is **more diversified** than the BAU and NZE scenarios.
- Higher consumption of **bio-diesel** due to the **constraints on the emissions**.

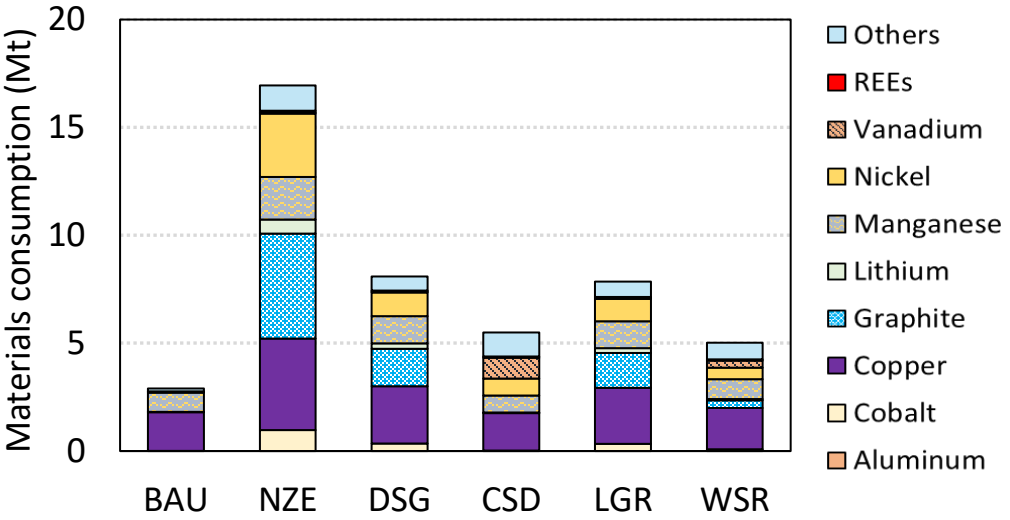
Materials consumption

Cumulative materials consumption (2025 ÷ 2050) for **power and storage** technologies



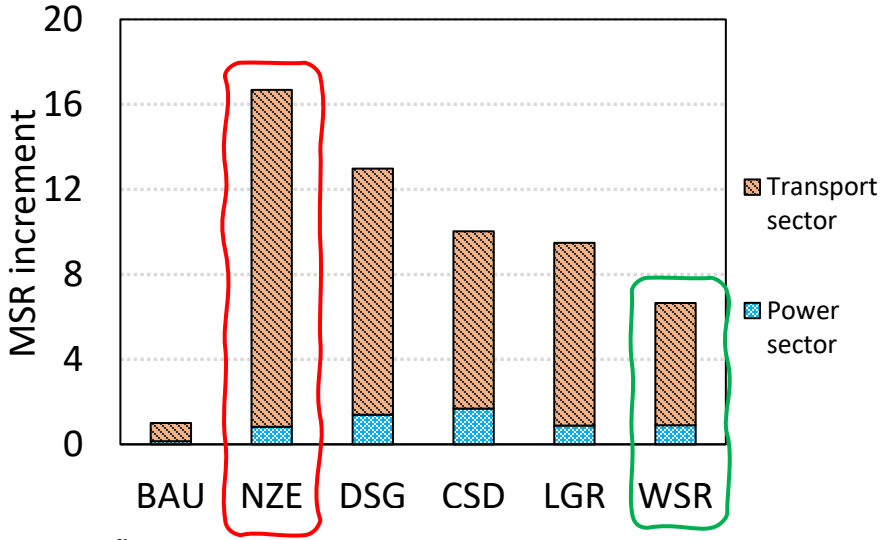
- **Similar consumption** in all the low emission scenarios.
- **Aluminum and copper** are the most consumed materials.

Cumulative materials consumption (2025 ÷ 2050) for the **transport** sector (cars)



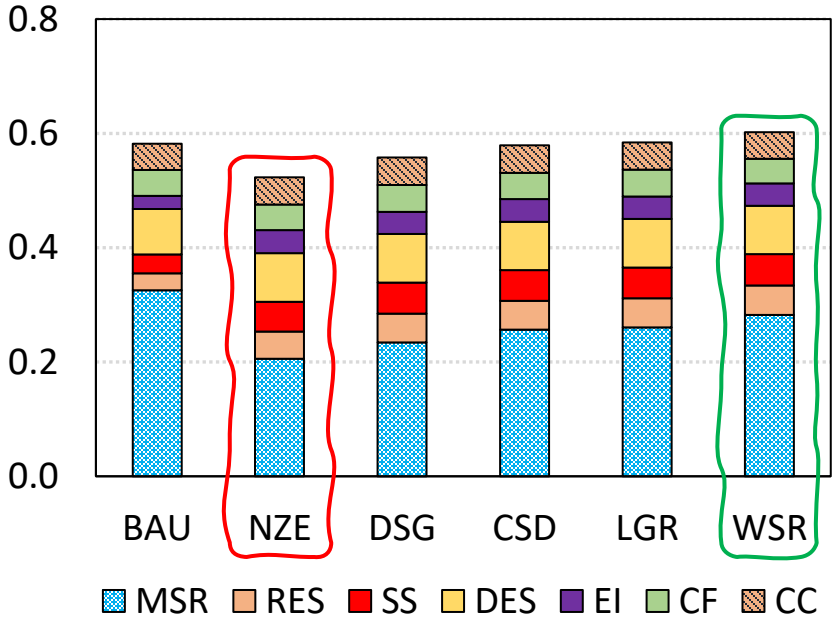
- **Peak for NZE** due to battery electric vehicles (BEVs) monopoly.
- A more **diversified technology mix** leads to a **lower consumption.**

MSR and energy security



Transport sector influences more the MSR

- **NZE** provides the **highest value of risk**.
- The scenarios that consider a **possible disruption** in the material supply present **lower value of risk**.



MSR affects energy security

NZE: lowest energy security

WSR: highest energy security

Conclusions and perspective

Conclusions

A **novel energy security metric** that includes the **risk of material supply.**

To **support policymakers** in making more **aware decisions** on future **energy policies and investments**.

Leading to a **safer energy transition.**

Perspective

- Endogenously evaluation of energy security through **multi-objective optimization process**.
- Inclusion of **new sectors** in the **material supply risk analysis.**
- **Exploring near-optimal system configurations with MGA.**

Many thanks for the attention

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