Product-Level Critical Raw Material Assessment: Application to Light-Emitting Diodes

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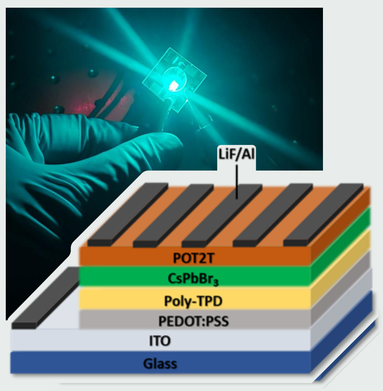
INTRODUCTION

Critical Raw Materials (CRMs), characterized by their simultaneous economic importance and supply risk, have become a subject of urgent relevance due to ongoing geopolitical tensions. Between 2011 and 2023, the European Union published five distinct CRM lists, with materials being added or removed in each iteration. This volatility creates significant uncertainty within the scientific community regarding objectives aimed at reducing critical material consumption. Consequently, relying exclusively on raw material's inclusion in the most recent list is an insufficient criterion for comprehensive criticality assessment.

Concurrently, environmental impact reduction is traditionally addressed through Life Cycle Assessment (LCA) methodologies, which compare impacts based on a standardized functional unit. Various methodological frameworks, have proposed approaches aligned with LCA to estimate product criticality.

These methods use risk and socioeconomic criteria to link criticality to the functional unit, calculating it as the product sum of material mass, supply risk, and vulnerability or economic importance.

This study proposes a methodological adaptation to analyze product criticality, which has been applied to evaluate the criticality reduction of a perovskite LED (PeLED) compared to a conventional LED, both normalized to a functional unit of 1 m^2.



METHODOLOGY

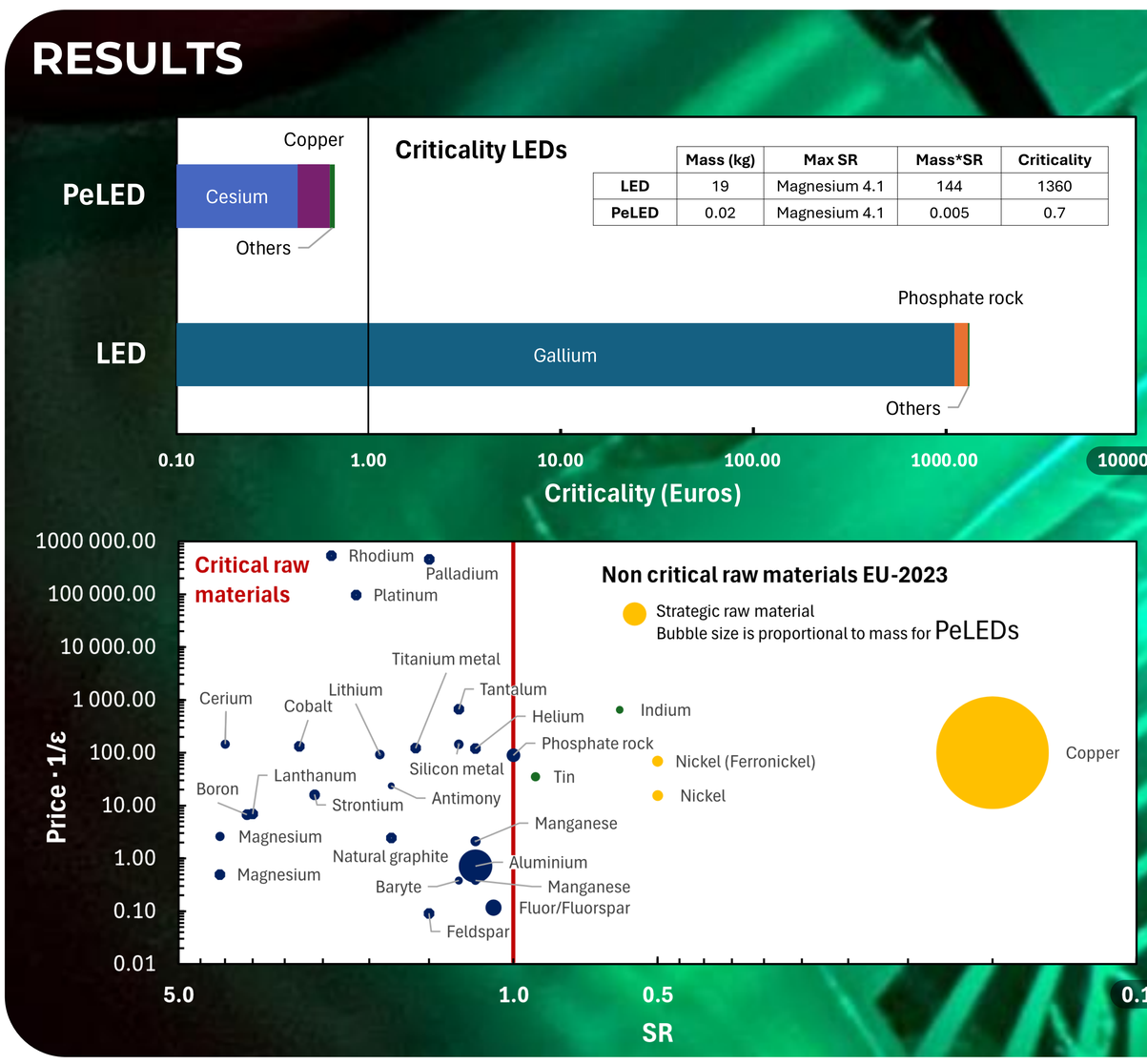
The most widely accepted formula for risk calculation, Risk score=Likelihood x Severity, has been adapted here to evaluate product criticality. To define the likelihood component, the European Union's supply risk (SR) index[1,2] was selected over alternative metrics such as GeoPolRisk[3]. For the severity component, we modeled how material prices are affected by production fluctuations, which depends on the material mass (m), its market price (P), and the inverse of the short-term price elasticity of supply (1/ε)[4]. Criticality encompasses all constituent materials (i) within a product and is expressed in economic units according to the following expression:

$$\text{Criticality} = \sum_i \text{SR}_i \cdot \text{m}_i \cdot \text{P}_i \cdot {}^{1}/_{\varepsilon_i}$$

In addition, our research reveals the serious errors caused by using "in-ground" raw material masses available in databases like Ecoinvent as inventory data. We demonstrate how this issue can be overcome through the strategic selection of a minimal set of final unit materials to which an average price can be easily assigned. The comparative analysis includes all critical and strategic raw materials (characterized by very low SR) listed by the EU, alongside other potentially critical materials including indium, tin, and cesium.

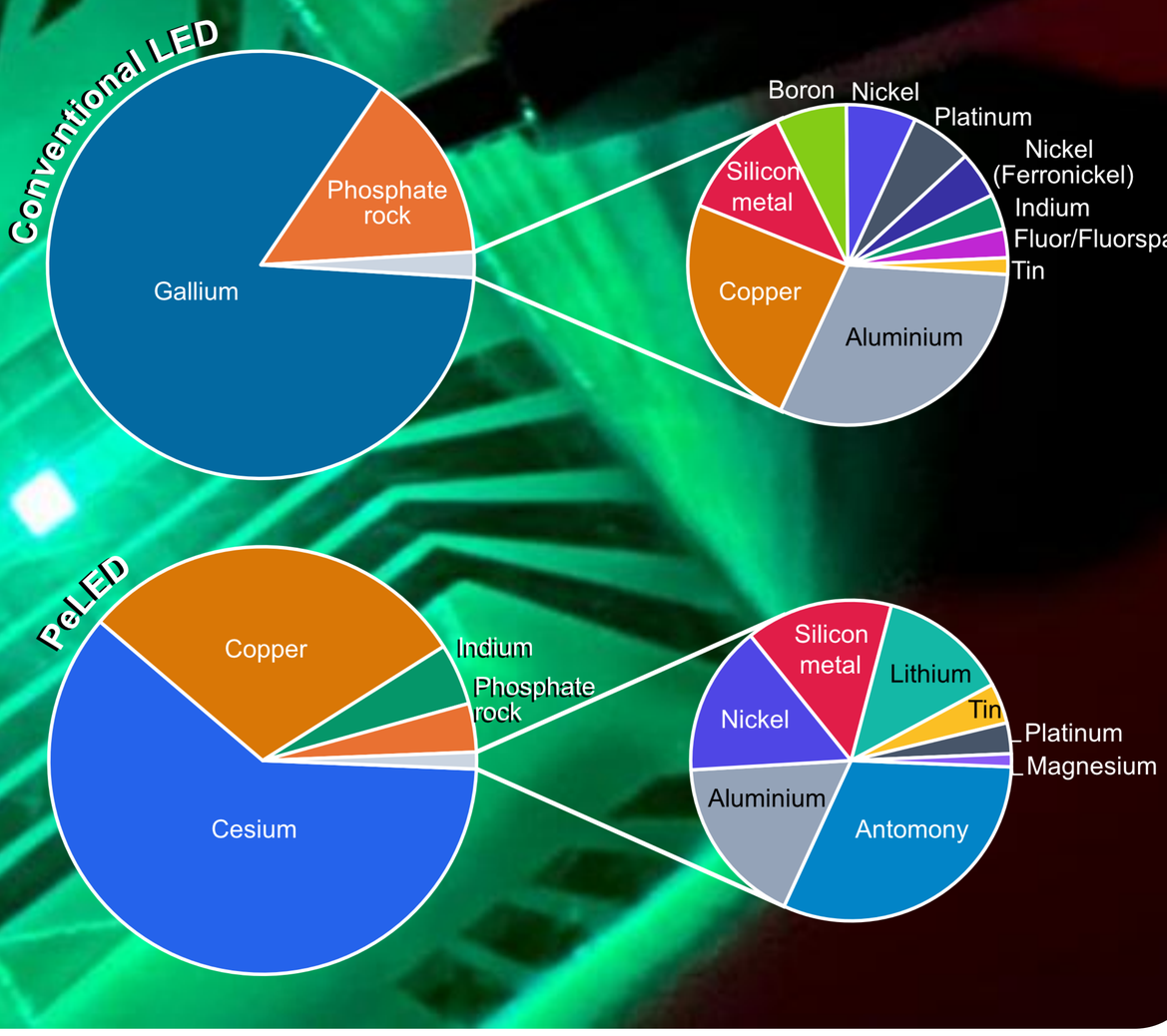
The PeLED inventory data, incorporating a $CsPbBr_3$ nanocrystal emissive layer, were derived and up-scaled from research conducted at INAM[5] and compared to a conventional LED die[6] of equivalent surface area.

RESULTS



Criticality LEDs

	Mass (kg)	Max SR	Mass*SR	Criticality
LED	19	Magnesium 4.1	144	1360
PeLED	0.02	Magnesium 4.1	0.005	0.7



CONCLUSIONS

- Relying exclusively on a raw material's inclusion in the most recent official list is an insufficient criterion for comprehensive criticality assessment.
- At the product level, analyzing price volatility provides a more representative measure of supply disruption severity than evaluating economic importance at a national or regional scale.
- Inventory analysis supported by LCA databases is instrumental in uncovering hidden critical raw materials within the supply chain.
- Critical material masses should not be determined based on "in-ground" values. To ensure methodological consistency and reliability, assessments should utilize the quantities of non-repetitive primary materials from which other database entries are derived, ensuring a direct correspondence with market prices.
- Perovskite LEDs present a viable pathway to mitigate material criticality, provided remaining stability challenges are resolved prior to commercialization.

References

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