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Comparative Life Cycle Assessment of Recycling Processes for Perovskite Solar Cells

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ABSTRACT

Perovskite solar cells (PSCs) have emerged as an attractive option among the new generation solar cells, and research efforts have been focused on commercializing these emerging photovoltaic (PV) technologies. There has been a growing interest in the research community regarding recycling PSCs to recover valuable materials and minimize the environmental impact at their end-of-life. Assessing the environmental impacts of these recycling approaches is crucial for the sustainable development of PSCs. This study evaluates and compares the environmental impacts of five recently developed recycling approaches for PSCs using the life cycle assessment (LCA) tool. The result of this study, based on impact assessment method, which included acidification (kg SO2-eq.), ecotoxicity (CTUe), eutrophication (kg Neq), GWP (kg CO2-eq), human toxicity (CTUh), cancer and non-cancer, human health particular air (kg PM2.5-eq), ozone depletion (kg CFC11eq), and smog (kg O3-eq) reveals that a novel recycling approach utilizing potassium iodide (KI) solution has lower environmental impacts. In contrast, the processes involving hydrogen iodide (HI), dimethylformamide (DMF), and butyl-amine (BA) are found to have significantly higher environmental impacts in the majority of the impact categories analyzed. The findings of this study will help identify environmentally friendly recycling options feasible for industry scale implementation.

BACKGROUND

- **Perovskite solar cells (PSCs)** are a **promising alternative** to traditional solar cells with **rapidly advancing efficiencies**.
- PSC has seen a remarkable increase in power conversion efficiency of ~26%

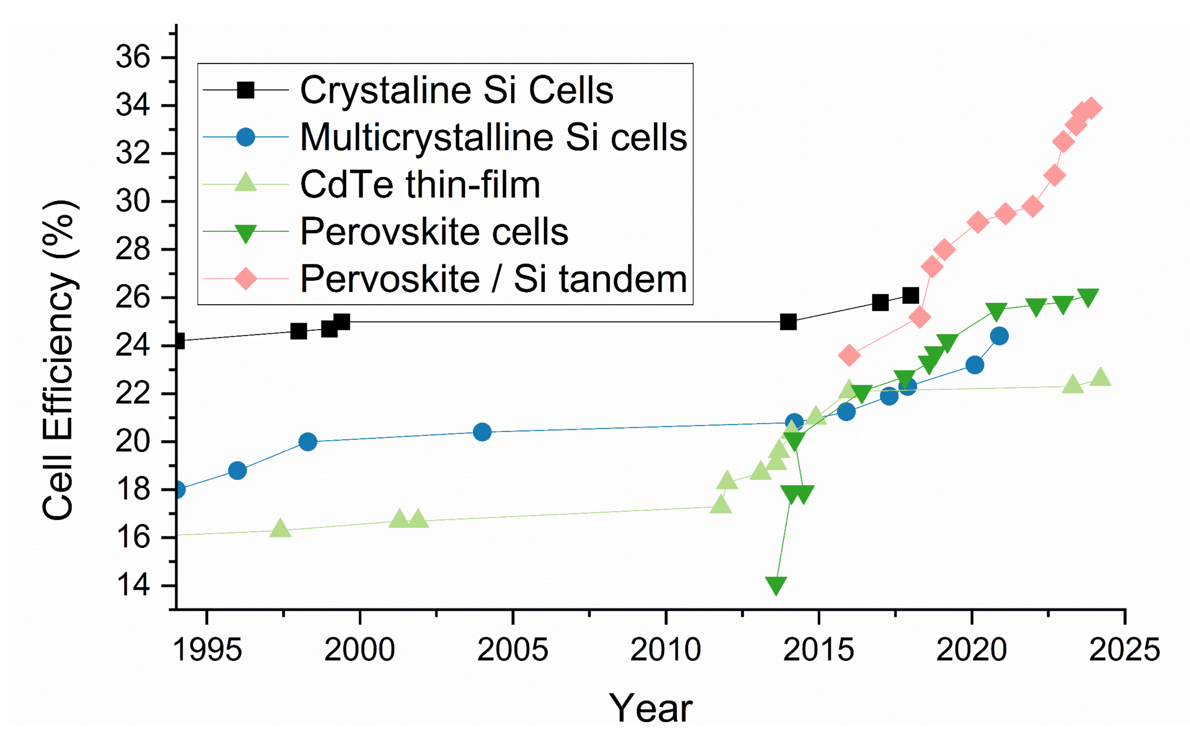

Figure 1. The power conversion efficiency of existing photovoltaic technologies

- The environmental sustainability of **end-of-life** management, specifically recycling methods, is crucial. This is especially relevant in **lead** recycling, which recovers valuable materials and **reduces environmental contamination risk.**

OBJECTIVE

This study aims to leverage the research findings to develop sustainable end-of-life management practices for PSC technology. Our focus is on **industry-scale** implementation of the most **eco-friendly** recycling techniques. By doing so, we aim to **minimize environmental impact**, promote **resource conservation**, and ensure responsible handling of PSC waste materials.

- Environmental Impact:
  - Compare the environmental impact of **recycling processes** against **the disposal of perovskite PV waste**.
- Material Recovery Techniques:
  - **Investigate** various recycling techniques for **recovering lead and glass**

METHODOLOGY

- The **research methodology** involved a **Life Cycle Assessment (LCA),** a tool that helps **identify** the most **impactful** stages and processes in a product's lifecycle, in this case, from gate to grave, which corresponds to the end-of-life stage.

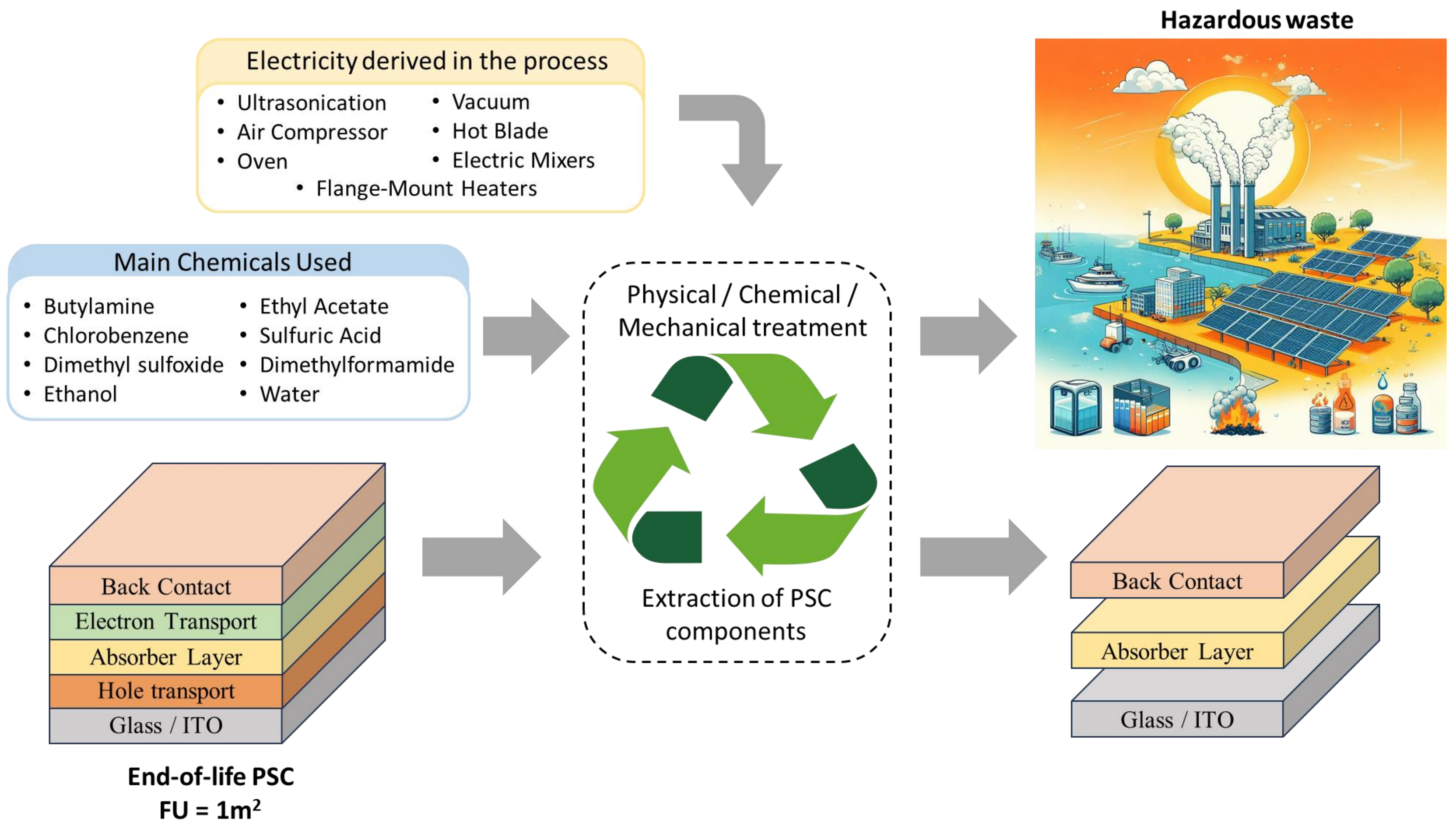

Figure 2. The system boundary for the life cycle assessment involving the six recycling methods selected with their respective inputs and outputs

- Inventories for the LCA were created by gathering data on **chemicals and electricity used as inputs and waste generated from this process with recovered elements of the PSC as output** during the recycling processes of perovskite solar cells.
- Some **assumptions** were made to ensure accurate **projections** for recycling methods on an **industrial scale**:
  - Complete **immersion** of the PSC in the **solvent**
  - We proposed using **large-scale equipment** for some lab-generated processes, such as evaporation, ultrasonication, and drying, based on the **functional unit** of a complete **1m² of PSC**.

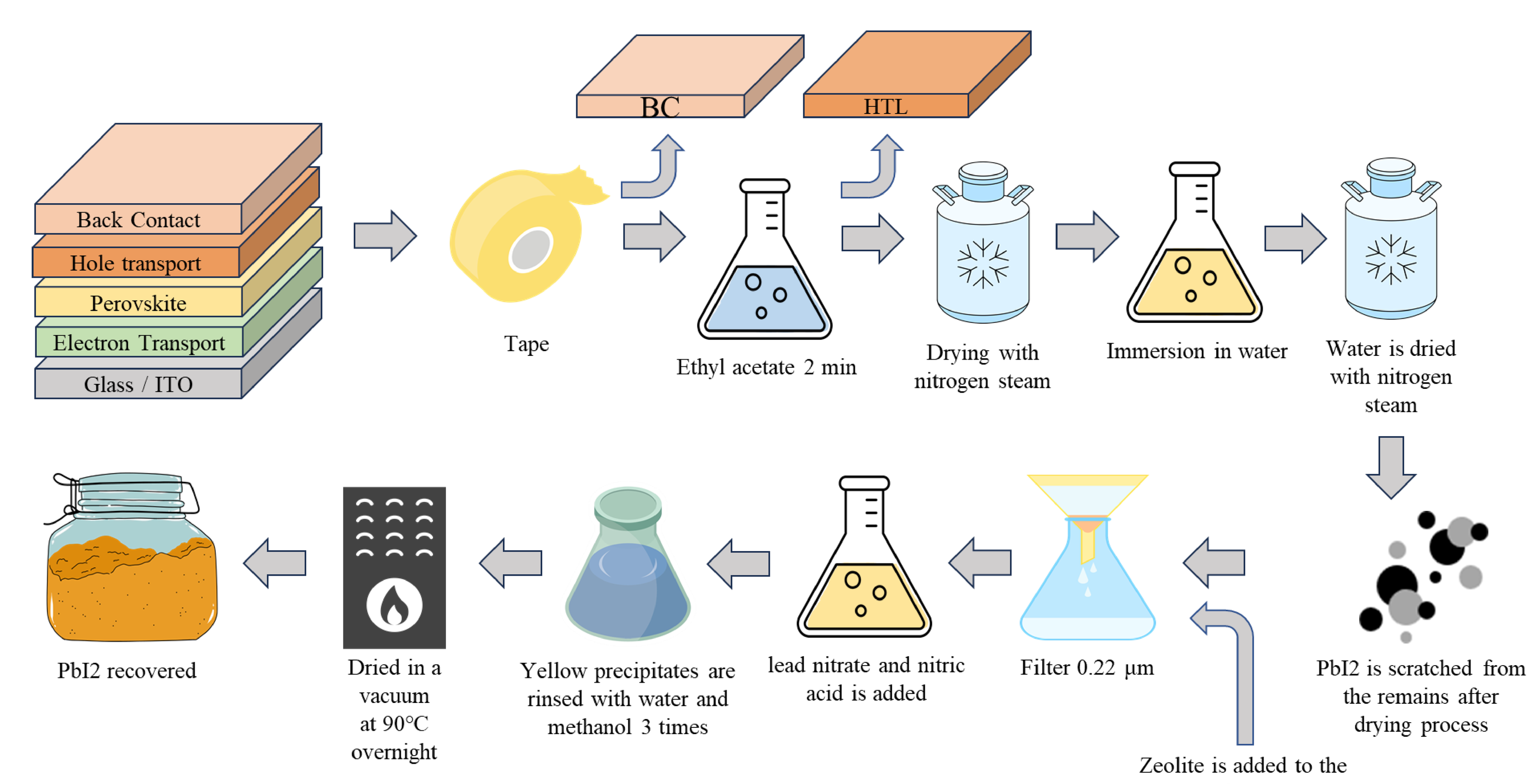

Figure 3. This is an example of a recycling method proposed by Meng Ren et al. 2021. This method recovered back contact, HTL, and PbI_2. The authors proposed using zeolite to absorb the lead, which has a purity of 99.99%; this lead is later used to refabricate a new PSC.

RESULTS

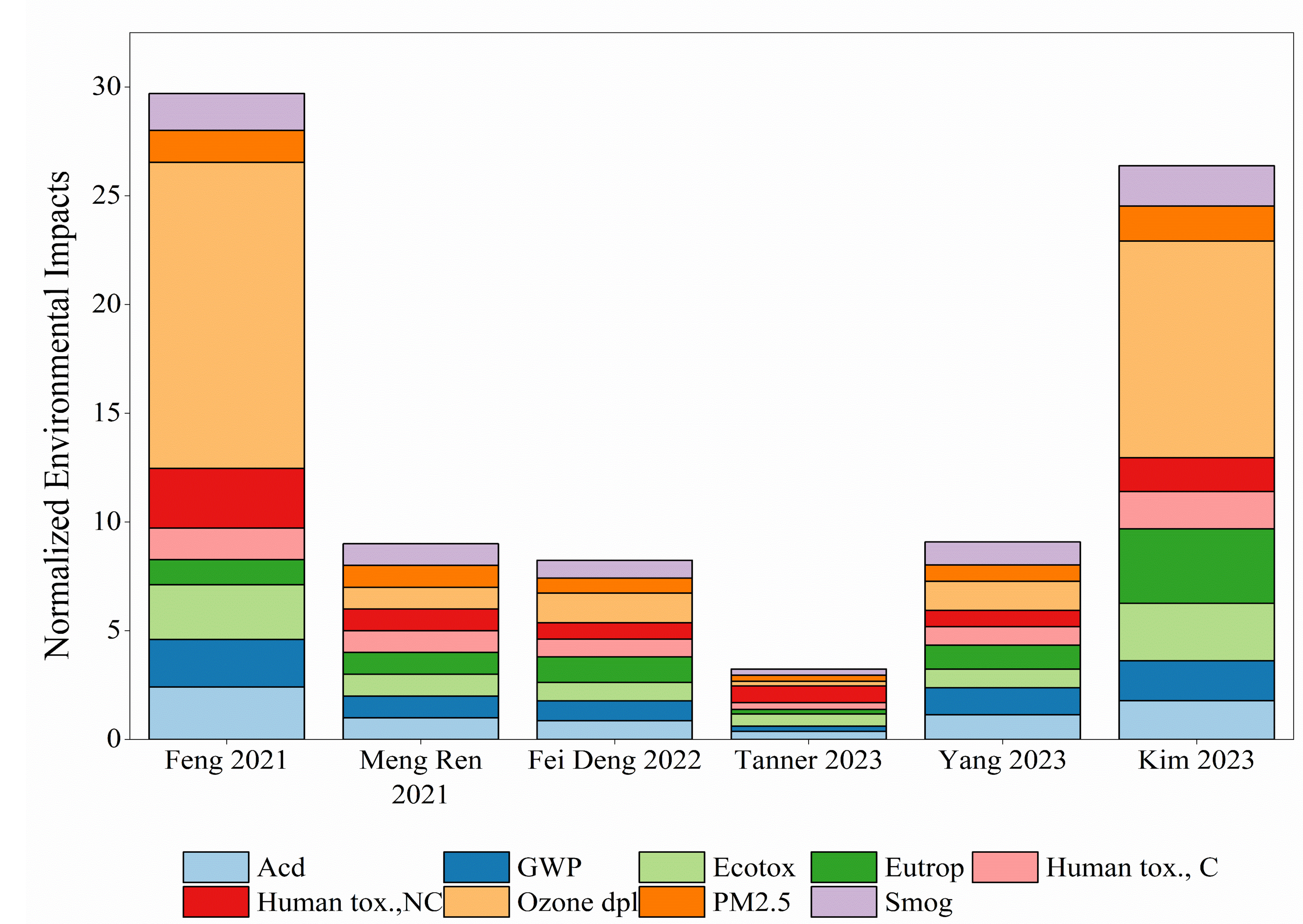

Figure 4. Total impacts comparison of PSC recycling methods when normalized to Fei Deng et al. 2022 impact categories results.

- The LCA revealed that recycling methods using **iodide solutions** had the **lowest environmental impacts.**
- Processes involving **Hydriodic acid (HI), dimethylformamide (DMF), and butyl-amine (BA)** had **significantly higher environmental impacts.**
- **Feng et al. 2021** and **Kim et al. 2023** methods, particularly ozone depletion, had higher impacts.

CONCLUSIONS & FUTURE WORK

- **Tanner et al. 2023 method** was the most eco-friendly, with **58% lower**
- Expanding the scope of the study to compare the **environmental impacts of PSC recycling with those of other photovoltaic technologies**. This would help position PSCs within the broader context of **sustainable** solar energy solutions.
- Conduct a more detailed LCA to identify and **compare** the **environmental impacts** of the **recycling methods** with the **complete creation of a PSC**

ACKNOWLEDGEMENTS

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