

ABSTRACT

Solar power is expanding faster than any other energy source, and with it comes a problem few have prepared for: an estimated 78 million tonnes of end-of-life (EoL) solar panel waste worldwide by 2050. Choosing the right recycling method is critical, yet conventional environmental assessments share a structural “blind spot” they overlook the hidden emissions buried in the upstream supply chain.

This study quantifies the climate change impact (GWP100) of recycling crystalline-silicon solar panels in Taiwan across three routes: mechanical shredding (S1), thermal-chemical treatment (S2), and advanced high-purity recovery (S3). An Integrated Hybrid LCA (IH-LCA) is applied to capture both the recycling burden (Module C) and the avoided burden from recovered materials (Module D) in accordance with EN 15804+A2. In doing so, it addresses a gap in the literature by applying the framework to all three recycling routes under a coal-heavy Asian grid.

The hybrid model identified a truncation gap of 44.6 to 56.3 percent, corresponding to indirect emissions omitted by conventional process-based assessments. All three routes nonetheless yield net-negative GWP. S3 achieved the lowest net GWP (-3,268 kgCO_{2e}/t), followed by S2 (-1,810) and S1 (-1,442). However, S3's performance depends critically on recovering solar-grade silicon; when silicon is credited at metallurgical grade, S3 becomes the highest-emitting route (-456 kgCO_{2e}/t). Aluminium frame recovery, by contrast, functions as a universal "carbon anchor," ensuring net-negative results across all three routes.

The study further demonstrates that input-output models, while appropriate for estimating recycling burdens, are structurally unsuited to avoided-burden crediting (Module D). The results point to two priorities for Taiwan: aluminium recovery as a minimum recycling standard, and renewable-powered advanced recycling facilities.

Keywords: end-of-life photovoltaics; integrated hybrid LCA; Module D; avoided burden; crystalline silicon; input-output analysis; Taiwan; carbon intensity