Integration of Circular Economy Initiatives within Western Macedonia's Renewable Energy System

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Who We Are

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Energy and Materials for Recycling

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Opportunities & Challenges

Circular Economy, *what it is & why it matters*

50% of global greenhouse gas emissions come from resource extraction and processing.

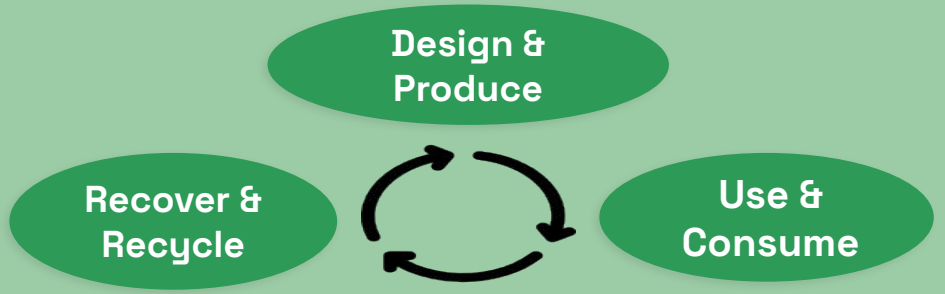
Why Does It Matter?

Protect the Environment

Improve Economics

Elevate Communities

What Is a Circular Economy?



The Traditional Model (Linear)

Extract → Make → Use → Discard

The Circular Model

Materials stay in circulation through redesign and recover.

Separation of recyclable and non-recyclable components remains a challenge.

Solar Panels: Material Management

Most solar panels are silicon photovoltaic panels (PVP). Each PVP consists of:

Recyclables

- **Glass:** front protective layer
- **Aluminium:** frame
- **Silicon:** solar cells
- **Copper:** electrical connections
- **Silver:** conductive paste

Non-Recyclable

- **Plastic/Polymers (EVA):** encapsulation
- **Backsheet Materials:** protection layer

Vasileiada PV Plant, Western Macedonia

Solar Panel Recycling Methods

Mechanical Recycling

Chemical Recycling

Thermal Recycling

Solar Panel Recycling Technologies

Laser Separation

Electrochemical Recovery

Why is recycling difficult?

- Complex Multi-Layer Structure
- Low Economic Value
- Separation Difficulty
- Transportation Costs

The main challenge is that recovering valuable materials requires complex processing, while landfilling remains cheaper in the short term.

Wind Turbines

Material	Method	Secondary Use	Difficulty in recycling
Fiberglass	• Pyrolysis & Chemical Solvolysis • Milling to powder	Cement additive (silica, calcium)	Loss of fiber length/strengt hHigh chemical cost
Carbon Fiber	• Thermal treatment • Li-Cycle technology	Automotive, sports equipment	Extremely difficult separation from resins
Resins & Adhesives	• Incineration (energy) • Chemical solvents	Energy recovery via combustion	Thermosets: do not remelt due to strong bonds.
Gelcoat	• Milling • Thermal melting	Concrete additive	Low value. Bonded to composites

Lithium-Ion Batteries

Recycling Pathways

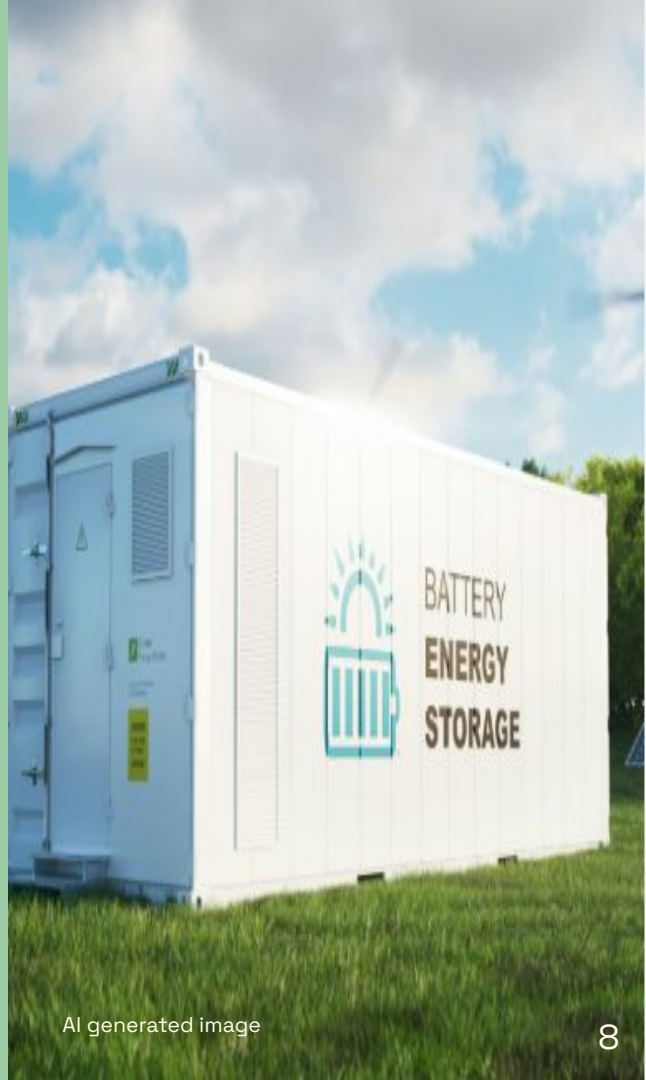
- **Mechanical:** Shredding & material separation
- **Pyrometallurgy:** High-heat metal smelting
- **Hydrometallurgy:** Chemical acid dissolution
- **Direct:** Cathode restoration & relithiation

Second-Life Applications

- **Renewable Storage:** Solar & wind smoothing
- **Grid Stability:** Supply/demand balancing
- **Backup Systems:** Emergency power units
- **EV Charging:** High-demand peak support

Leading Recycling Technology

Mechanical + Hydro process	Industrial Pyro + Hydro process	Hydro-to-Cathode Synthesis	Direct Cathode Relithiation



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Environmental Risks of Non-Recycling

Solar Panels

Leaching of lead and cadmium lead to soil and groundwater contamination.

Massive increase in landfill demand for solar panel disposal poses land management issues.

Wind Turbines

Blades occupy vast landfill space.

Resin/fiberglass separation is nearly impossible.

BESS (Li-Ion)

Fire hazards and chemical sensitivity of electrolytes/separators are significant challenges.

Rising metal demand increases mining pressure.

Global Consequences:

Failure to implement circularity leads to massive waste build-up, increased toxic exposure in local communities, and intense pressure on natural resources through non-stop mining of virgin materials.

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Secondary Market

01

Specialized E-Waste Processors

Umicore, Li-Cycle, Redwood Materials

The industrial backbone

02

OEM Takeback Programs

Vestas, Siemens Gamesa, Tesla, and First Solar

Manufacturer-led

03

Recycling Marketplaces

London Metal Exchange, Circulor

Emerging infrastructure

Old Device → **Collected & Processed** → **Minerals Certified** → **Sold to Producer** → **New Product**

⚠️ *Key barrier: The market is still small, fragmented, and inconsistent in quality.*

First Solar Recycling Brochure

Connections to Site Visits in Kozani

The Vasileiada PV Plant

DIADYMA & Integrated Waste Management

CERTH Innovation Hub Green

"We need to reduce the quantity of natural resources we take from the Earth. Resources are limited compared to the population."

Financing Circular Economy Solutions

Why

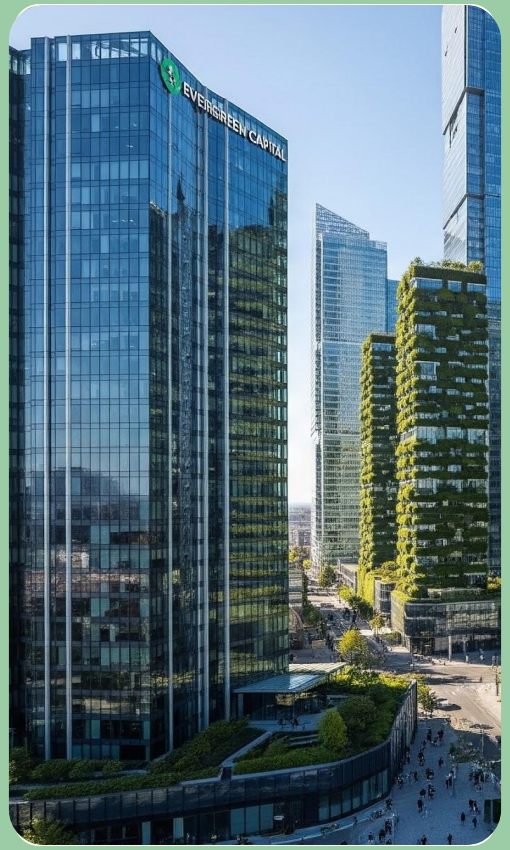
- CE is an economic and environmental lever.
- EU's renewables buildout creates future waste stream and needs financing now.

Opportunity

- Cost savings with recycling outweigh mining raw materials.
- Rising critical mineral prices make recycling economically viable.
- EU Just Transition Fund can support pilot projects (€1.6B for WM).

Challenges

- Misaligned timelines, high CapEx, delayed material flows need to be addressed.



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Circular Economy Policy

Why

- EU leads globally CE-renewables policy and Greece implements as Member State.
- EU-designated Coal Region in Transition creates policy instruments.
- Gaps exist for PV End-of-Life solutions.

Opportunity

- EU Battery Regulation mandates recycled content minimums.
- EU Critical Raw Materials Act reduce EU's reliance on foreign suppliers.
- EPR schemes make manufacturers accountable for life cycle of products.

Challenges

- No global harmonized standards affect purity.
- Lack of end-of-life mandates for solar panels in most markets disincentivizes CE solutions.

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Technology for the Circular Economy

Why

- Recycling tech maturity differs, with batteries leading, followed by PV, then wind blades.
- EU R&D is funded heavily via Horizon Europe; in Greece via CERTH and UOWM.

Opportunity

- Direct recycling and solvolysis are maturing rapidly.
- AI-assisted sorting improves efficiency.
- CERTH-type R&D hubs accelerate tech transfer.

Challenges

- No consistent purity standards for recovered materials, limits reusability.
- PV and blade recycling still scaling from lab to commercial deployment.

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Thank you!

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