Beyond Carbon Accounting:

How sustainable are the technologies of the energy transition?

ICPSE 2019

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www.re-wind.info

Science Foundation Ireland sfi For what's next

Overview

- The underacknowledged successes of the energy transition
- Tales from the fringes of the transition: social acceptability, resource depletion and environmental impacts
- Renewable energy technologies and the Circular Economy paradigm
- Case Study: Composite Wind Turbine Blades
- The way forward

The Energy Transition

SUCCESS STORIES

Success Story: Deployments

Growth of installed wind power capacity worldwide

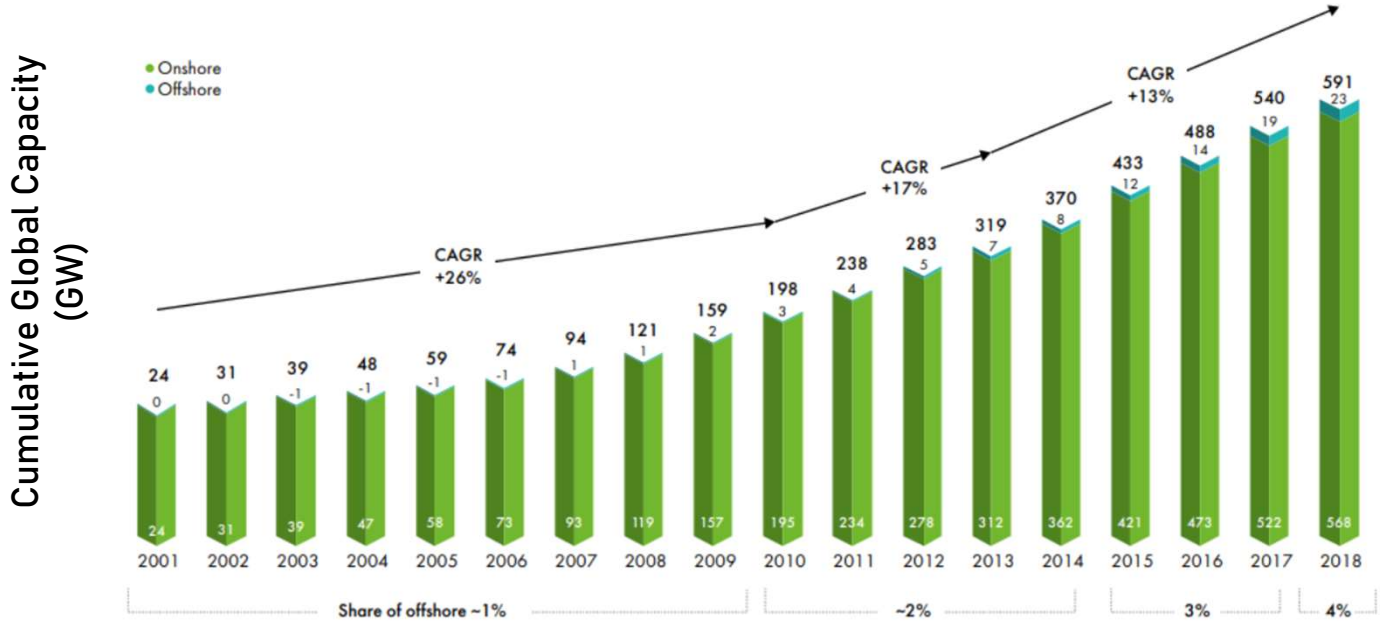
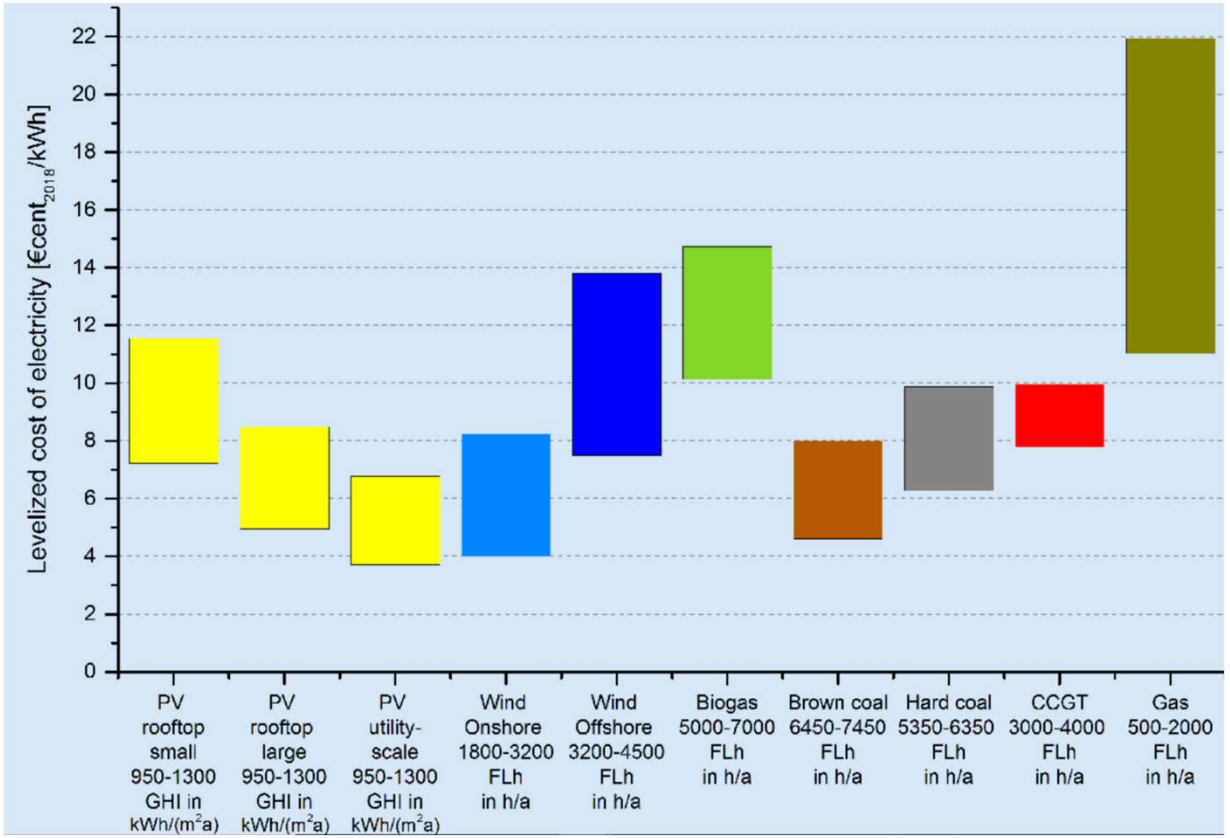


Image: GWEC

- Global installed wind power capacity grew from c. 14 GW to 159 GW in the decade 1999-2009 (3).
- In the following decade total capacity increased to c. 600 GW
- 30% of Irish electricity from wind in 2018 (Denmark: 40%)

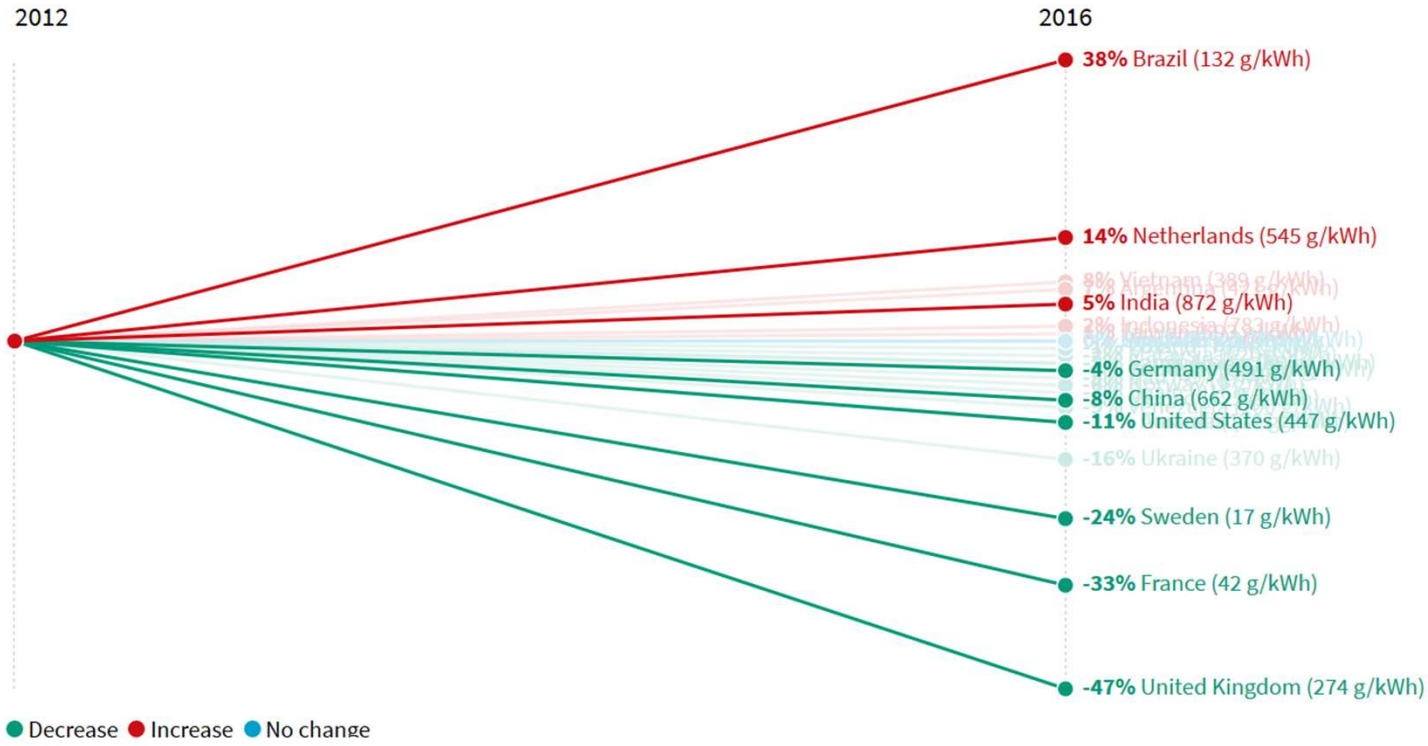
Success Story: Cost Competitiveness



Graphic: Fraunhofer ISE

- Solar PV and Wind have achieved cost competitiveness with CCGT

Success Story: Decarbonisation



Graphic:
World Resources Institute

- Reductions achieved by transitions from coal to gas, fossils to renewables/nuclear

Tales from the edge

SOCIAL, ENVIRONMENTAL AND RESOURCE ISSUES

Energy Densities

Renewables vs Conventional Sources

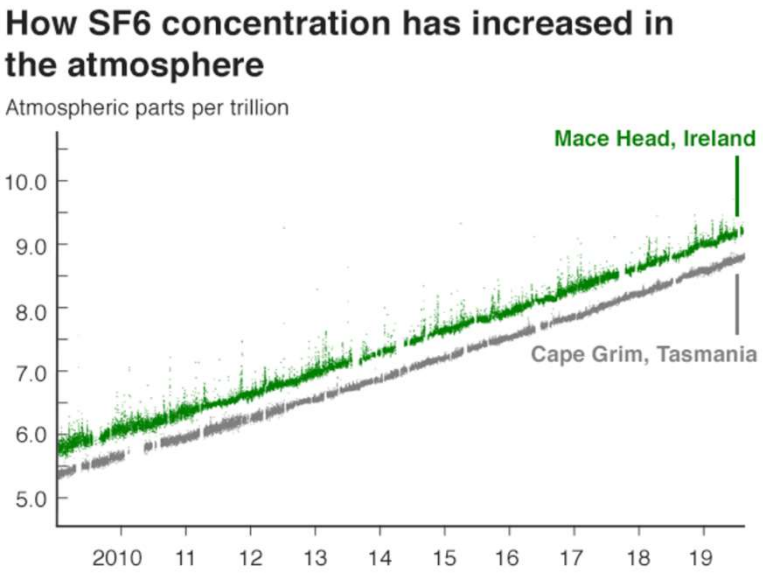
Resource	Description	Energy J
Wind	1 m^3 of air moving at 8 m s^{-1}	38.4
Tidal/hydrokinetic	1 m^3 of water moving at 3 m s^{-1}	4,612
Tidal: impoundment	1 m^3 of water, 5 m head	50,374
Fossil	1 m^3 of bituminous coal	29,155,000,000
Nuclear fission	1 m^3 of enriched Uranium	5.3×10^{16}

Notes on Table 1: Density of air: 1.2 kg m^{-3}; density of seawater 1027 kg m^{-3}; assumed density of coal 833 kg m^{-3}; assumed energy density of coal 35 MJ kg $^{-1}$;

- The Energy Transition is associated with a shift towards **lower energy density** and **more distributed** resources

Environmental Impacts

- SF_6 leaks from switchgear
- SF_6 : 23900 x warming effect of CO2



Graphic:
University of Bristol

Social Acceptability

Sabotaged anemometry mast, Scotland

Image: Mike Lee https://creativecommons.org/licenses/by-sa/2.0/

Social Acceptability

CNN World Africa Americas Asia Australia China Europe India Middle East United Kingdom Edition

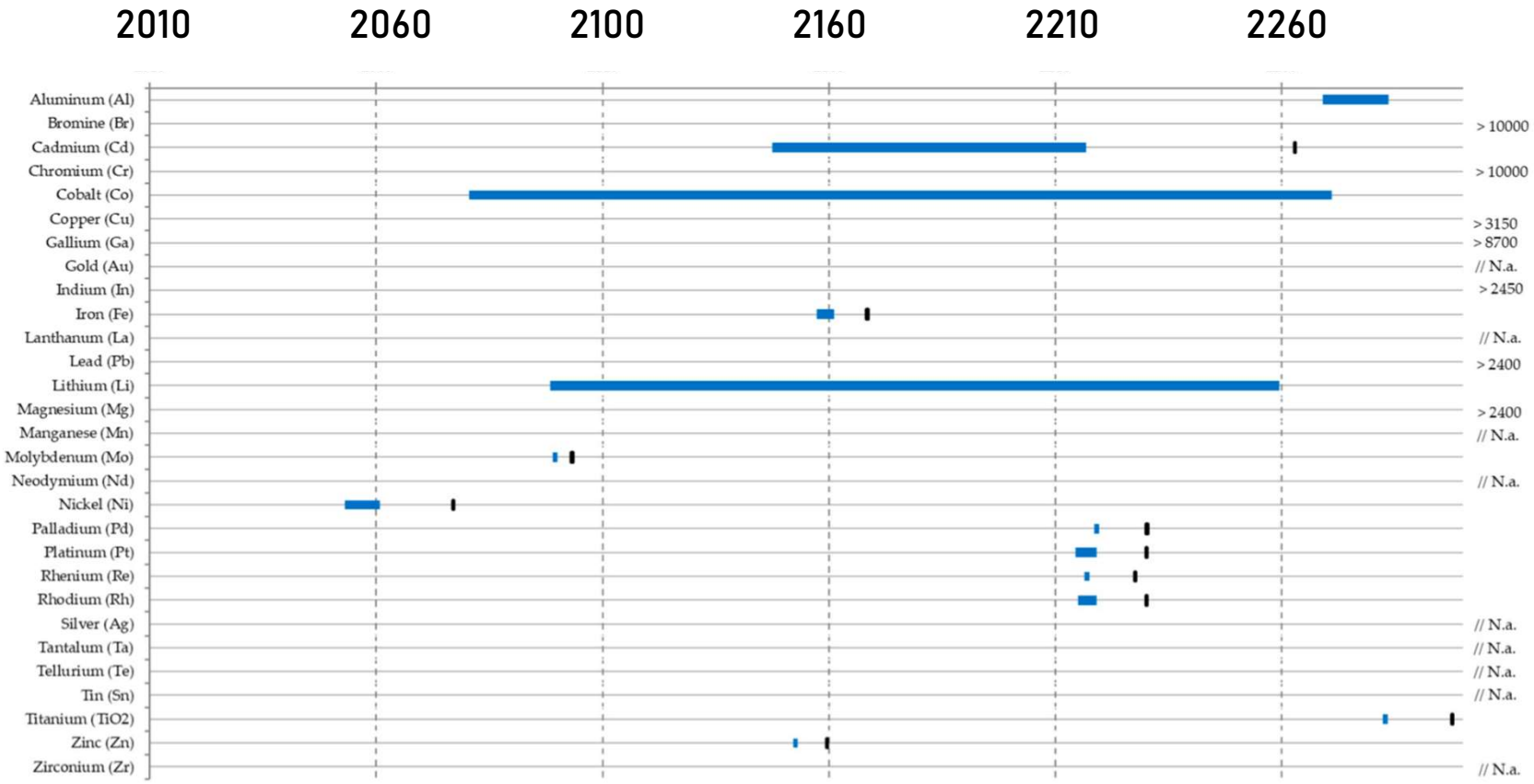
As Ireland goes green, rural workers feel punished

By Kara Fox, CNN

Updated 1012 GMT (1812 HKT) February 8, 2019

Bord na Móna workers fear the bog closures will be a major blow to the local economy.

Resource Depletion



Ni, Co required for the energy transition will near depletion by mid-century

Moreau et al. *Resources* 2019, 8, 29; doi:10.3390/resources8010029

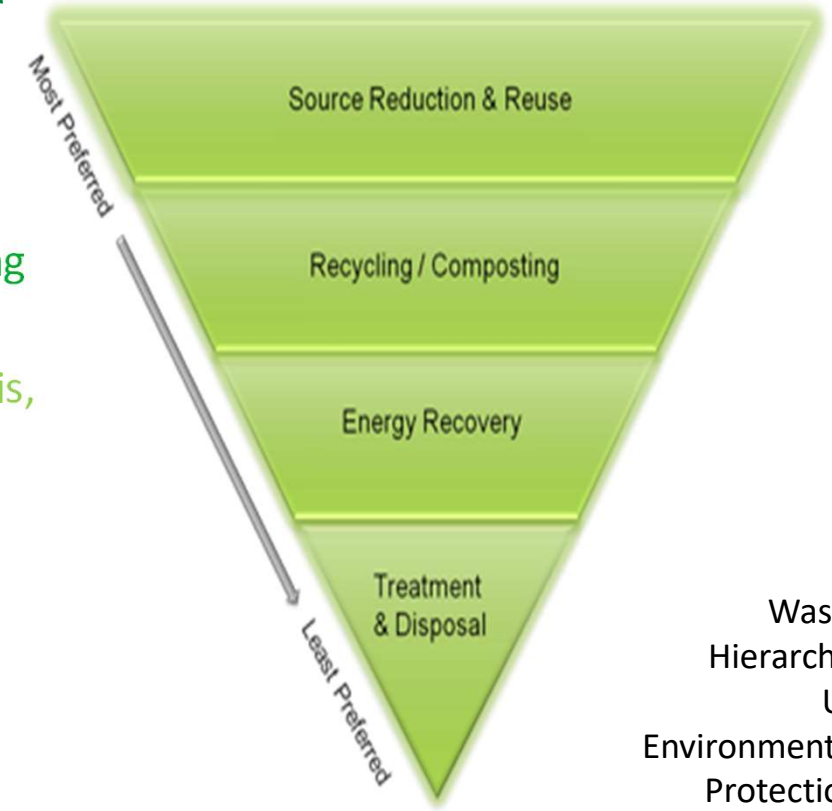
Renewable Energy Technologies:

THE CIRCULAR ECONOMY

The Waste Hierarchy

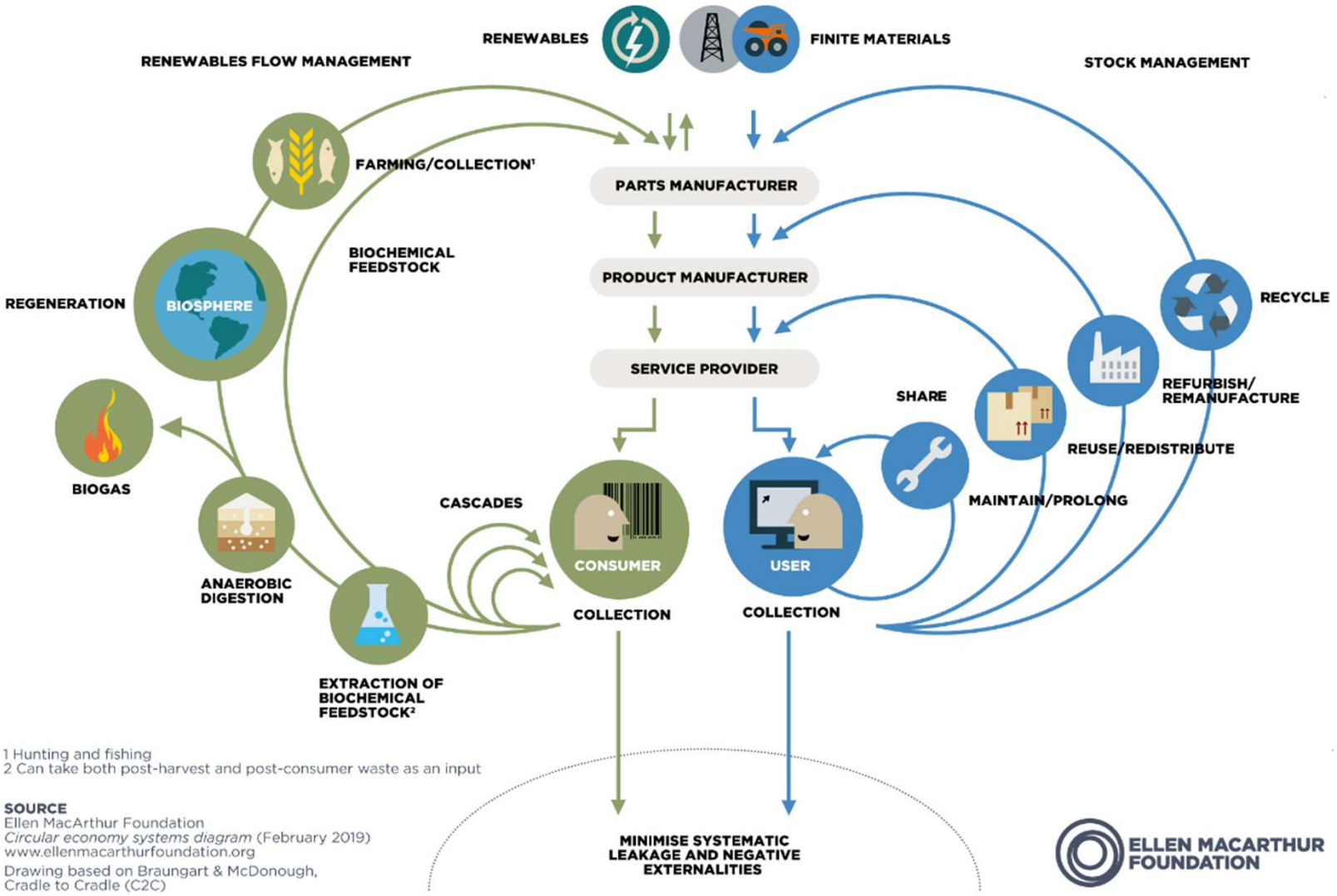
Repurposing **lies near the top of the Waste Hierarchy**

- **Prevent:** either extend project lifetime or sell blades on secondhand market
- **Repurposing**: Remanufacturing for use in new products
- **Recycling**: Shredding, grinding and milling for filler for FRP or concrete
- **Materials Recovery**: Pyrolysis, thermolysis, solvolysis to recover polymer resins or fibers or gasses for energy
- **Co-processing in cement kilns: raw material substitution**
- **Incineration** – with or without energy recovery, then landfill ash
- **Landfilling**



Waste Hierarchy: US Environmental Protection Agency

The Circular Economy



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

Case Study

END-OF-LIFE COMPOSITE WIND TURBINE BLADES

End of life blades: waste or resource?

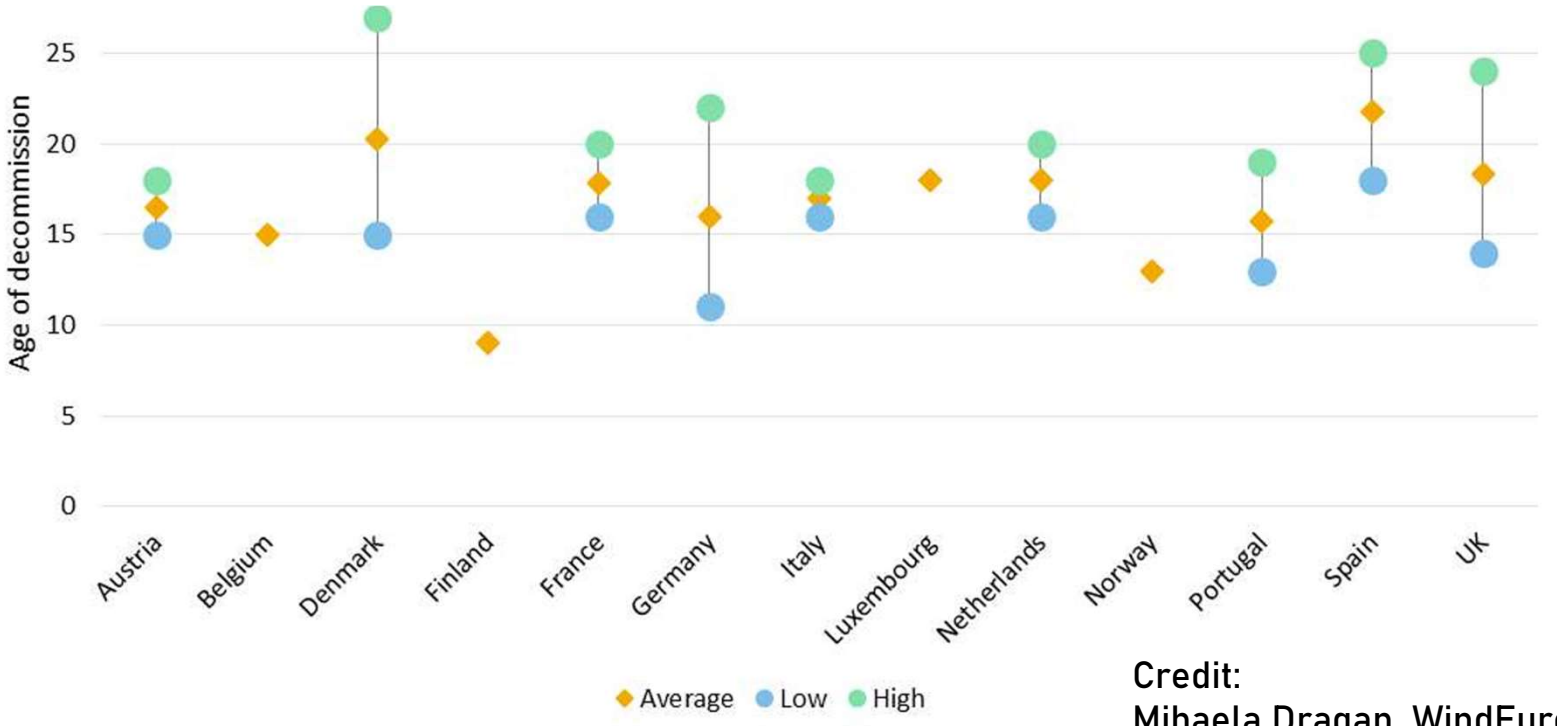
- Wind turbine blades primarily composed of non-biodegradable GFRP composites
- Annual global blade waste is expected to reach 40 million tonnes by 2050
- Current solutions: incinerate, stockpile, landfill, grind for aggregates
- Can feasible repurposing options be found?

Cut GFRP composite waste
Image: BRIO project
Credit: Elhuyar Fundazioa

Wind farm lifetimes

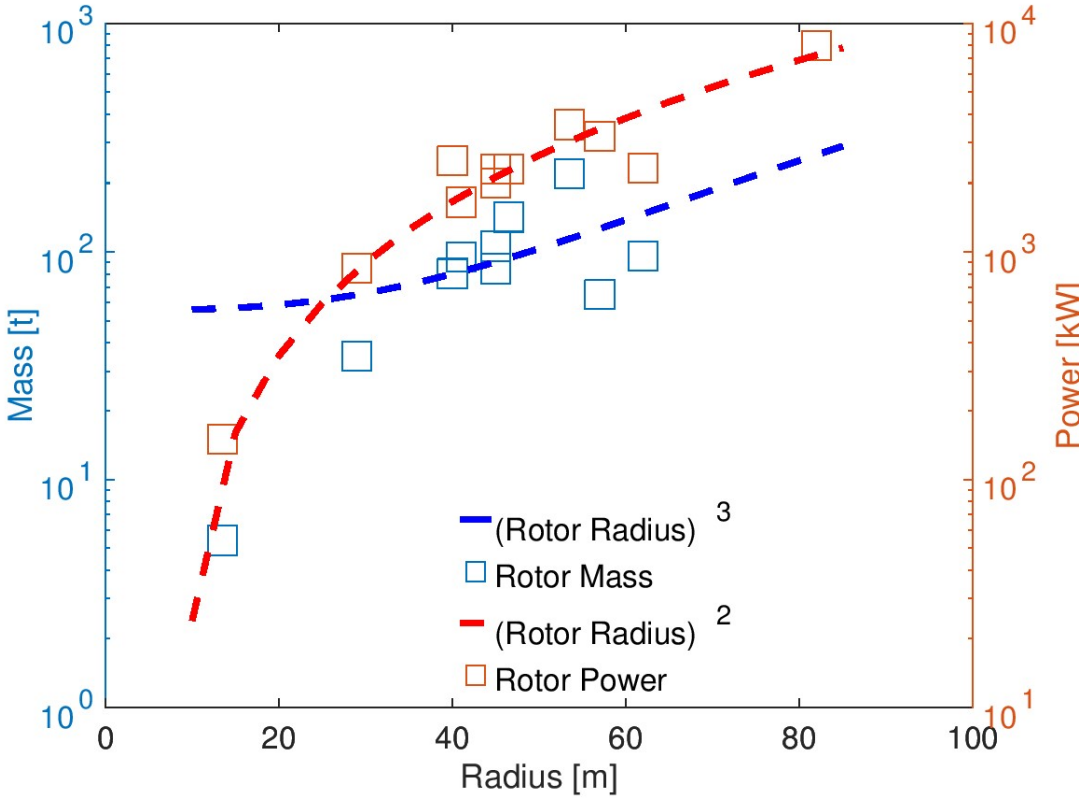
Average years to decommissioning in repowering projects

- Varies widely by project (9-27 years)
- … and by country (Spain average 22 years; Germany 16 years)



Credit:
Mihaela Dragan, WindEurope

Increase in blade mass: the square-cube 'law'



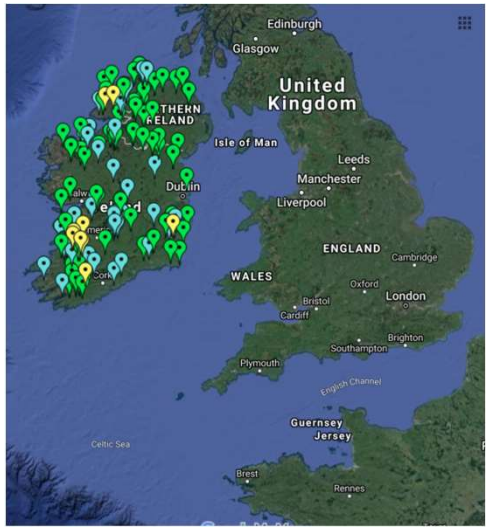
Rotor power increases with **square** of blade length

Rotor mass increases with **cube** of blade length

=> Blade mass has grown faster than the rated power as turbine rotor sizes have increased

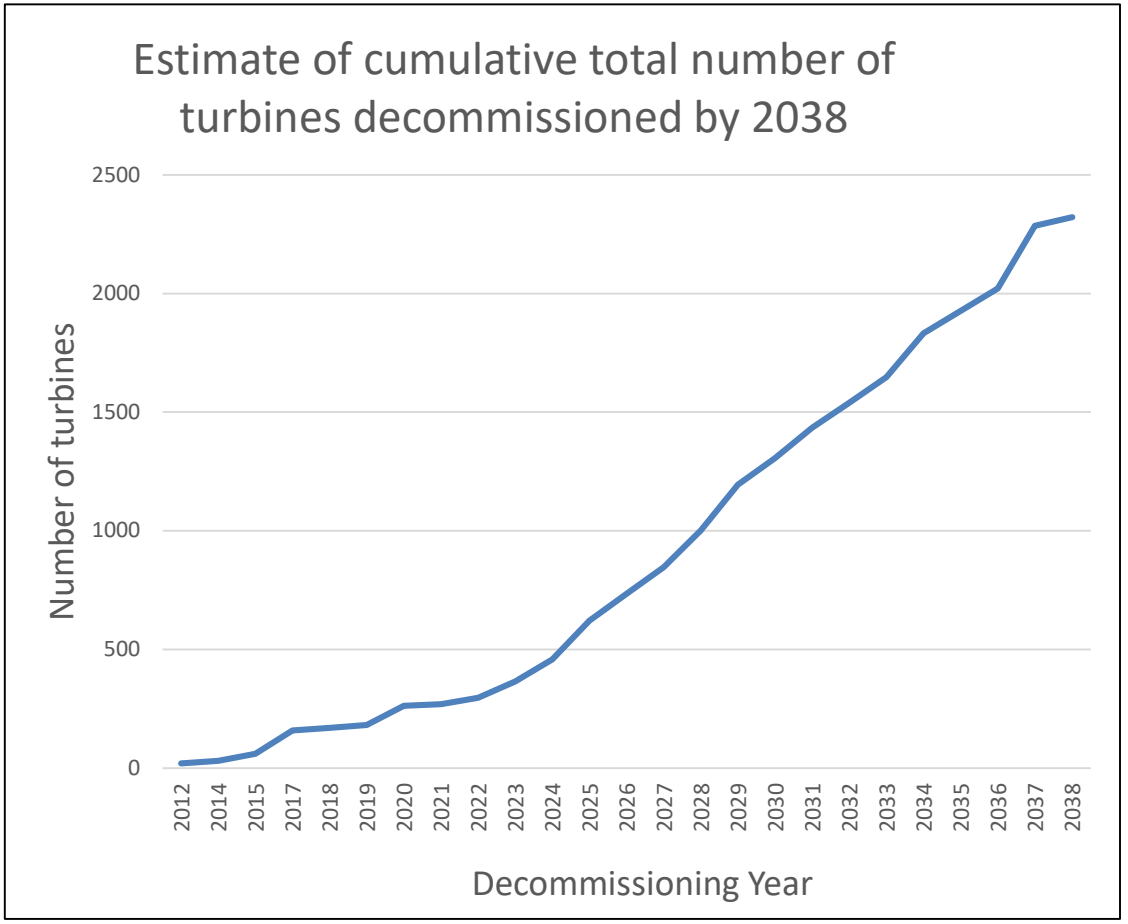
Supporting data: thewindpower.net & Schubel et al. http://www.mdpi.com/1996-1073/5/9/342

Turbine end-of-life & the GFRP blade 'waste' issue



Approximate total number of turbines to be decommissioned in Ireland by 2038:

2323



Emma Delaney, QUB

Wind farm end of life decision factors

When does a wind plant reach end of life?

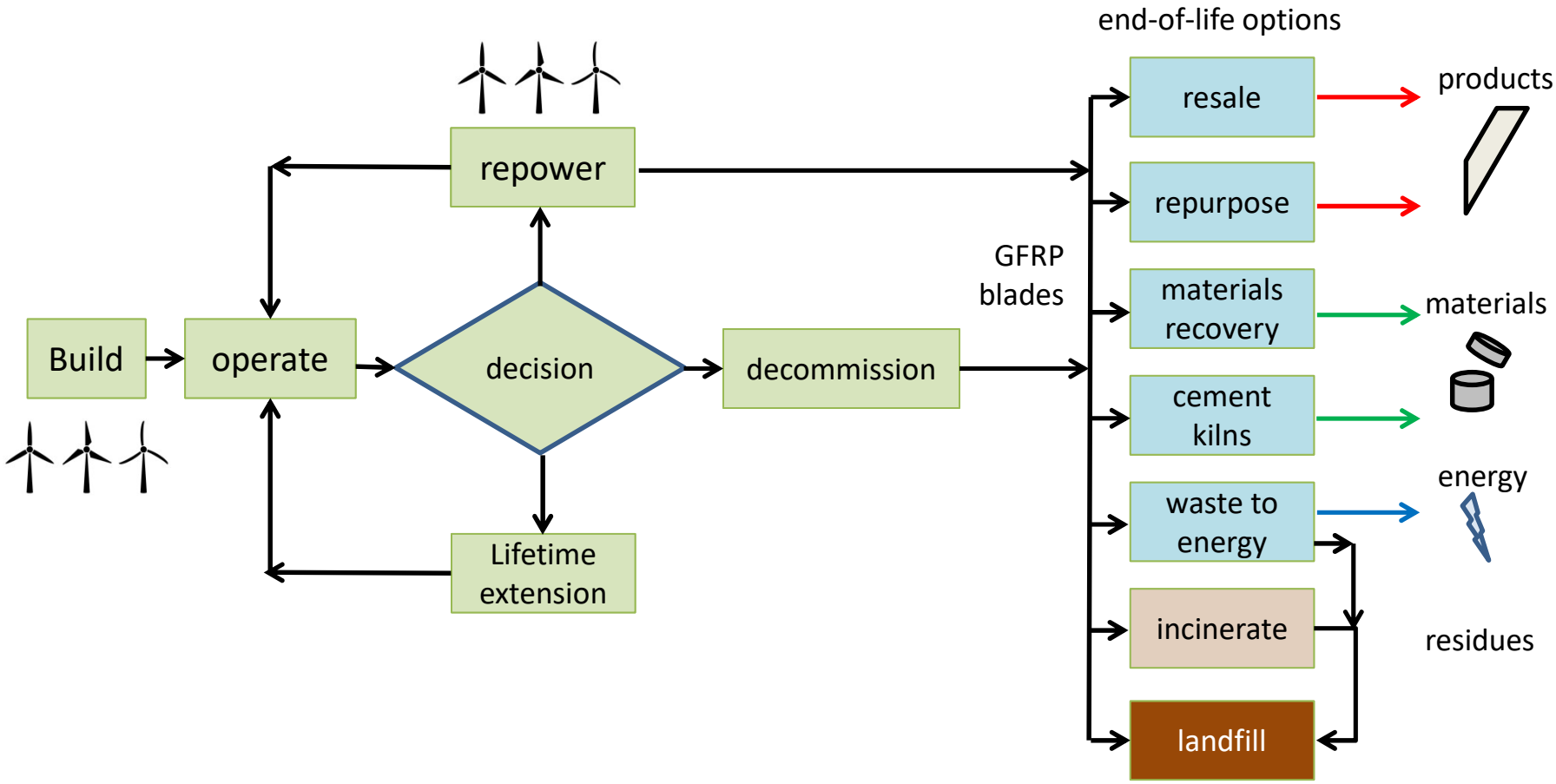
- End of design life
- Expiration of planning permission
- Market reforms
- Expiration of subsidies
- Operating costs: wear, fatigue, failures, outages, repairs
- Obsolescence

What happens next?

- Decommission
- Repower
- (continue operation)

Altamont Pass, USA.
Image: Noah Berger, National Geographic

Wind farm lifecycle



Blade Repurposing: Methodology

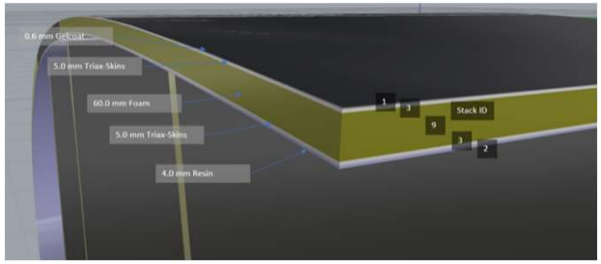
More than **50 blade repurposing concepts** identified initially

Design Office exercise (Winter 2019, Belfast) will develop and refine three concepts

The success of reuse cases depends on **technical feasibility**, **location** & **social**, **environmental** and **economic** sustainability

A transdisciplinary approach has developed tools to assess all of these:

- All-Ireland blade geodatabase
- 3-D LiDAR scanning
- Blade geometry reconstruction software
- Structural analysis & testing methods
- Community engagement methodology
- Lifecycle analysis (LCA)
- Robust set of internationally-deployable success indicators : environmental, social and economic



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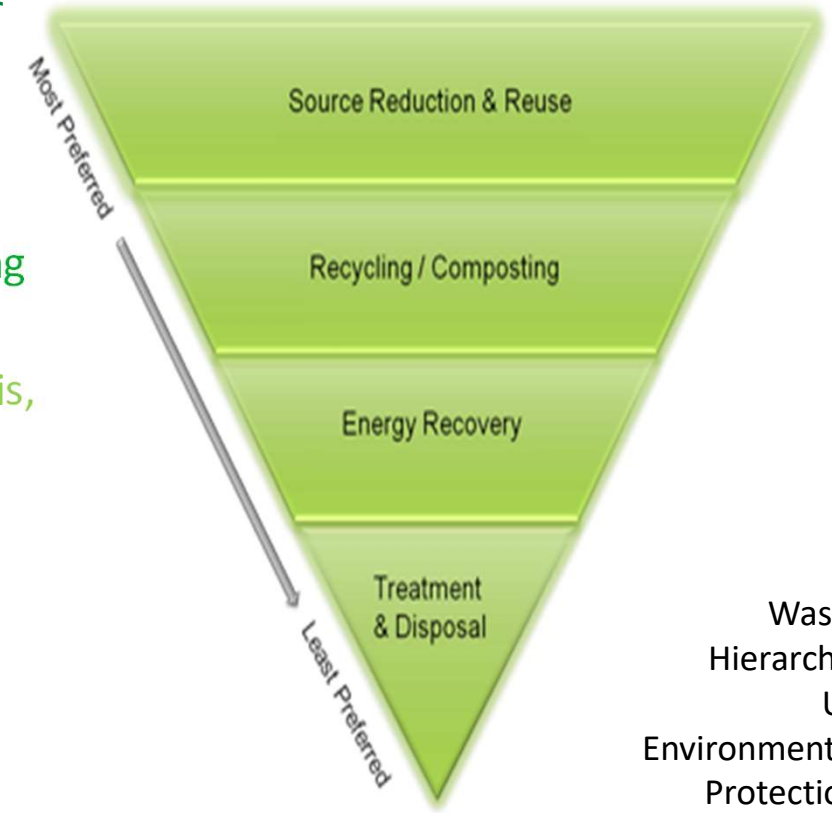
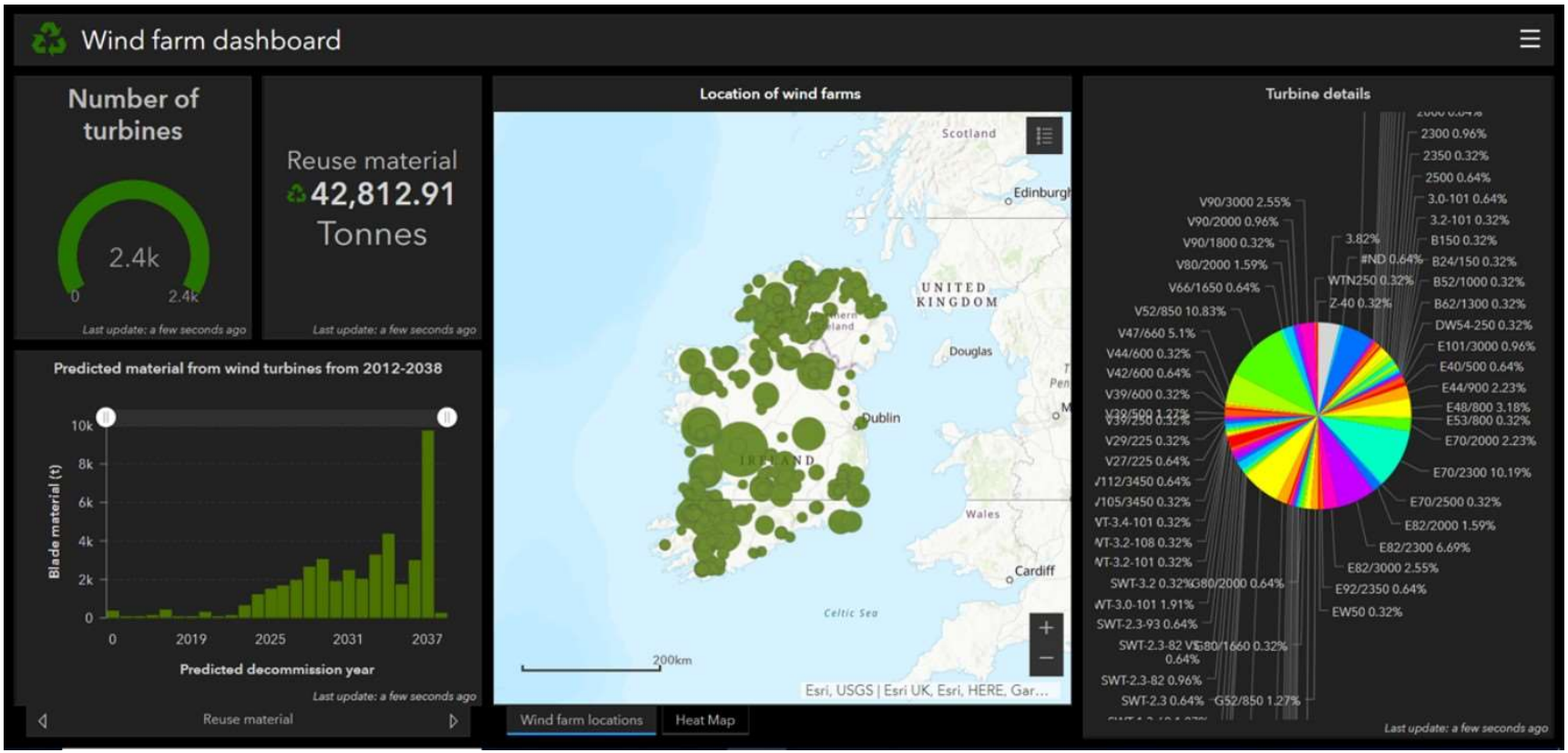


Waste Hierarchy: US Environmental Protection Agency

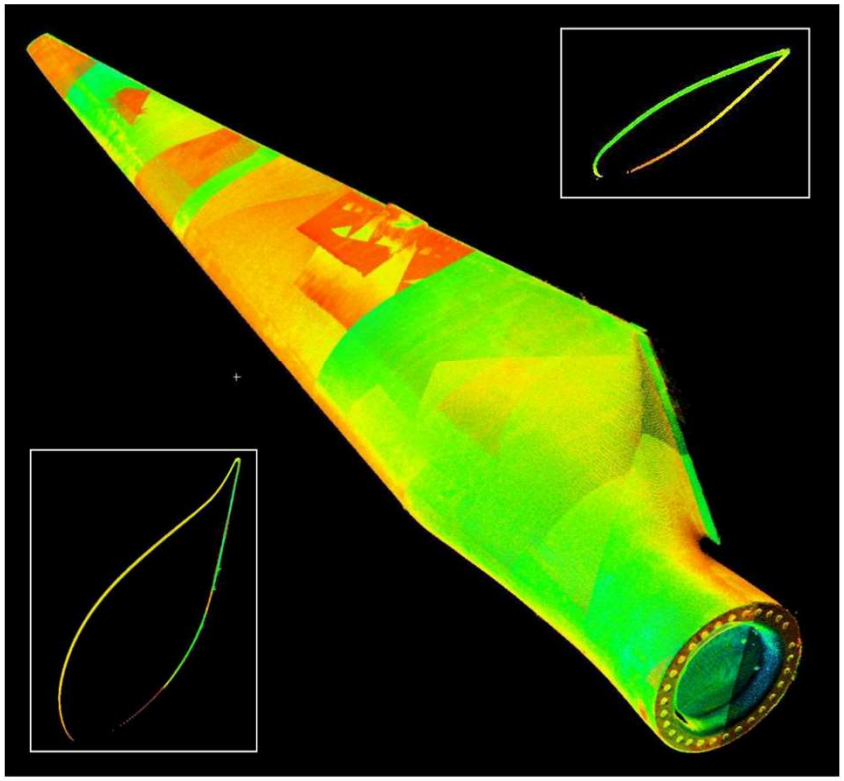
GIS Dashboard & Database

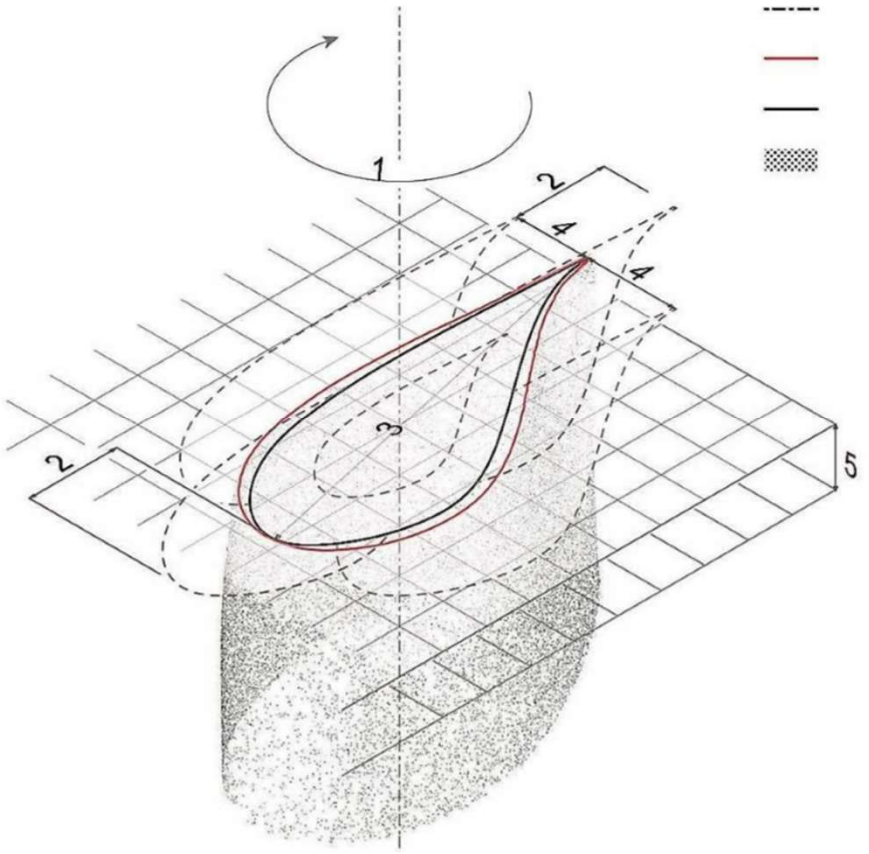


Tool allows database to be queried by:

location, turbine type, blade dimensions, projected decommissioning date

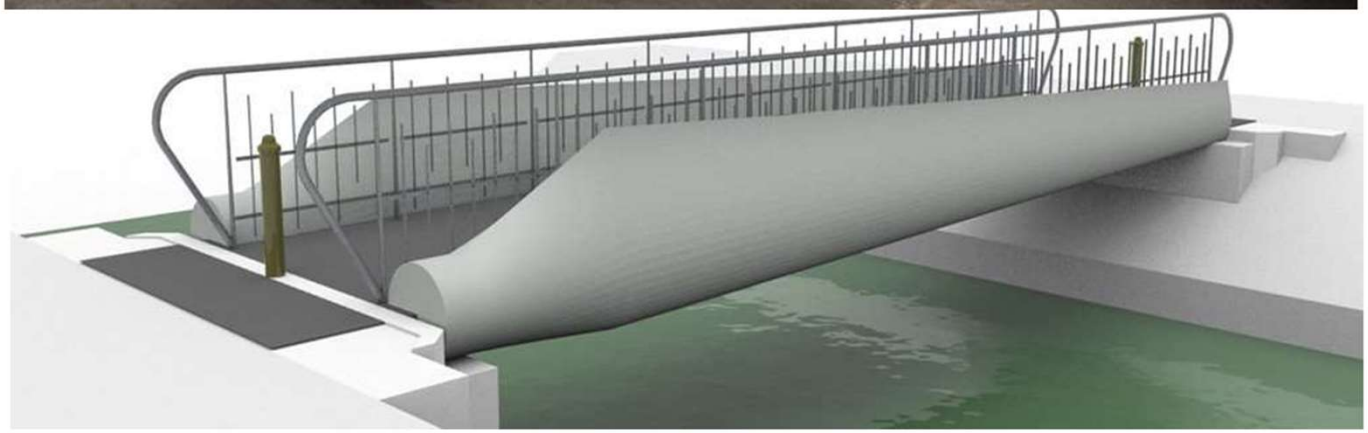
3-D LiDAR scans of decommissioned blades
Rebuilding blade models from point clouds





Reuse case: pedestrian bridge

Aftermarket V29 blades (14.3 m) in Northern Ireland

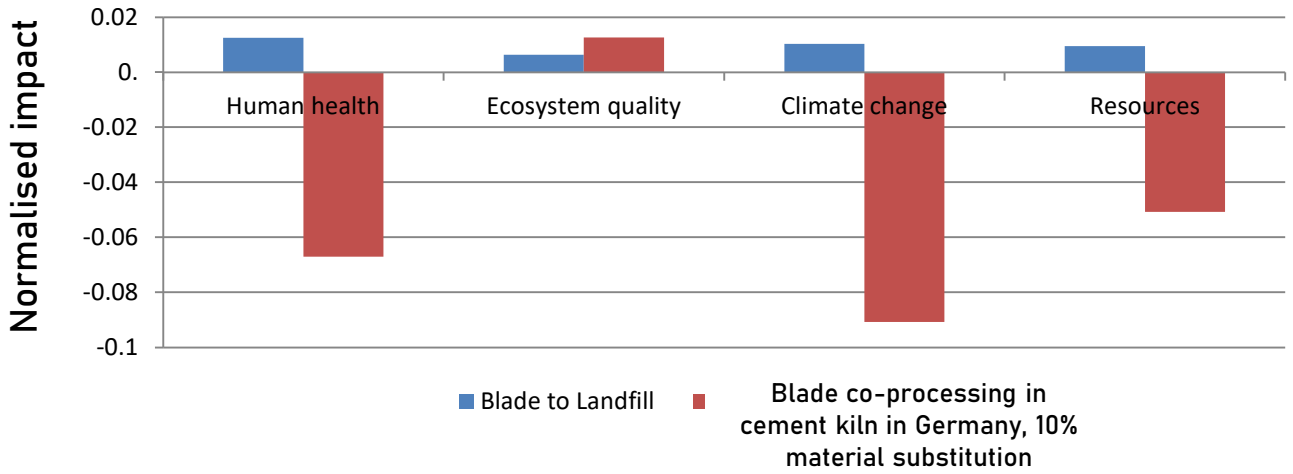


8 m footbridge for greenways in Ireland

Reuse case : emergency housing

Environmental impacts of end-of-life options

- Life cycle assessment carried out on two 'conventional' end-of-life options



- Cement kiln co-processing has far lower environmental impacts than landfill

The Way Forward

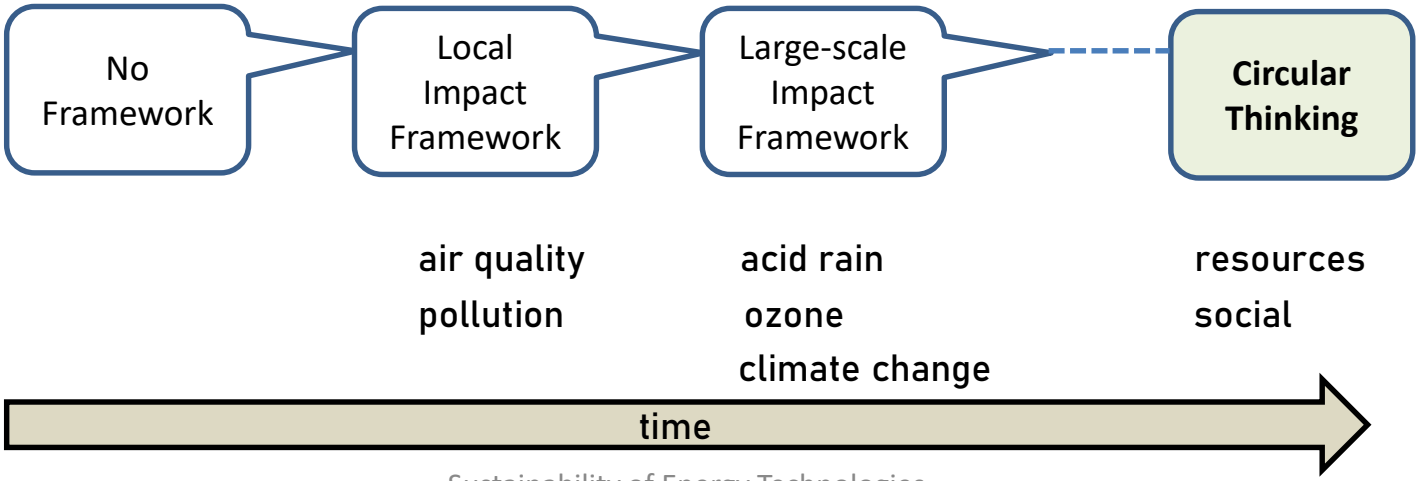
SYSTEMS-LEVEL CIRCULAR THINKING

Challenges for the coming decades

- Renewables are cost-competitive with fossil fuels
- There is huge further potential for decarbonisation with renewables and associated technologies
- However…
  - Carbon accounting alone does not capture the impacts of these technologies
  - Challenges associated with low energy density and distributed resources have led to social, environmental and economic impacts

Systems-level circular thinking

- First step is resource conservation and recovery
- Need to develop **robust**, **integrated** impact assessment frameworks



New impact assessments

- Life cycle analysis augmented with social aspects: S-LCA?
- UN's Sustainable Development Goals may provide basis for new methods
- These have to feed back into design
- We are developing methods to measure the 'social licence' for wind turbine blade deployment business models

Thank you

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