An Overview of the **C**ircular **E**conomy **L**ifecycle **A**ssessment and **VI**sualization (**CELAVI**; pron: *c'est la vie*) Framework

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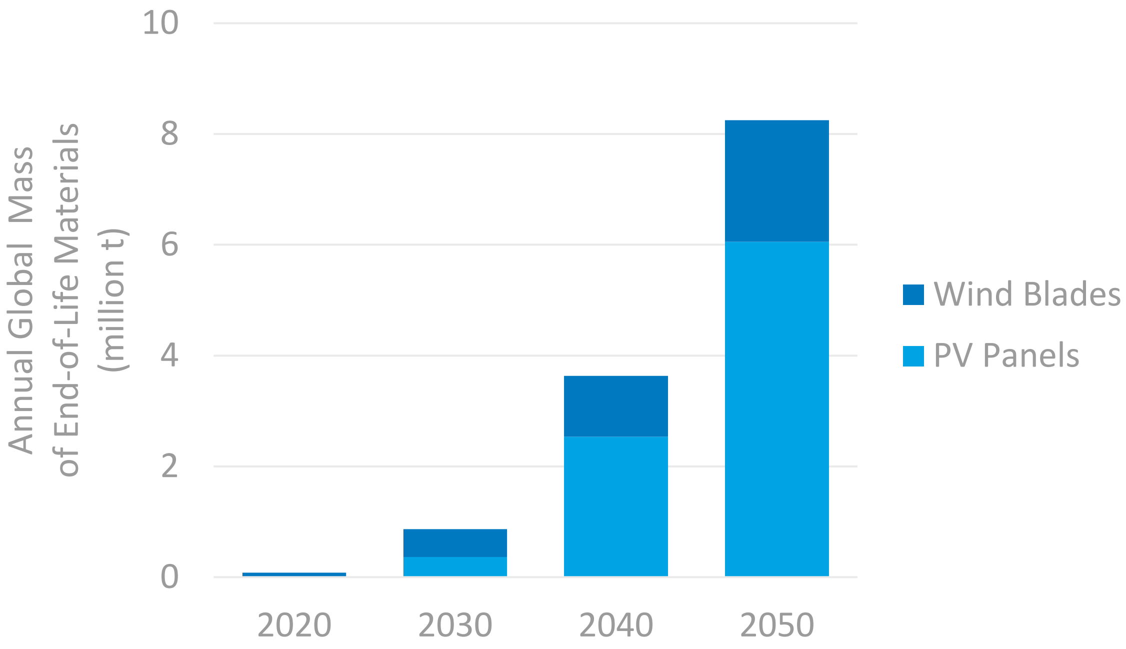
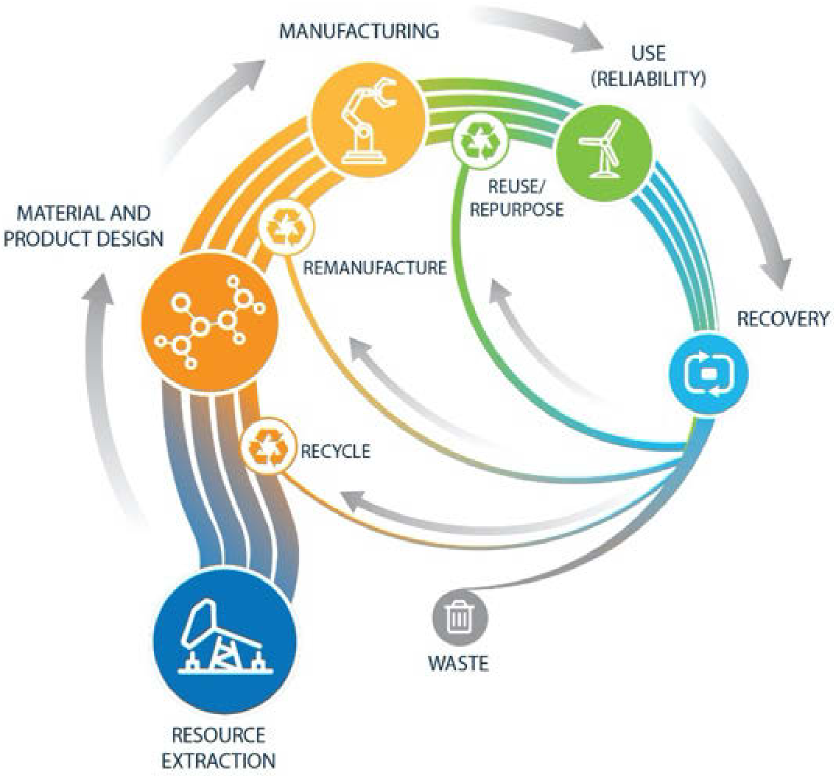
Motivation:

Waste from renewable energy technologies, such as wind and solar photovoltaics (PV), is projected to increase in the coming decades.



Data compiled from: IRENA PVPS Report 2016 and Liu and Barlow 2017



Potential Solution?

The circular economy spurs material efficiency (e.g., through redesigning, reusing, and recycling products).

Primary Research Question:

What are the environmental and economic impacts of transitioning to a circular economy for energy materials?

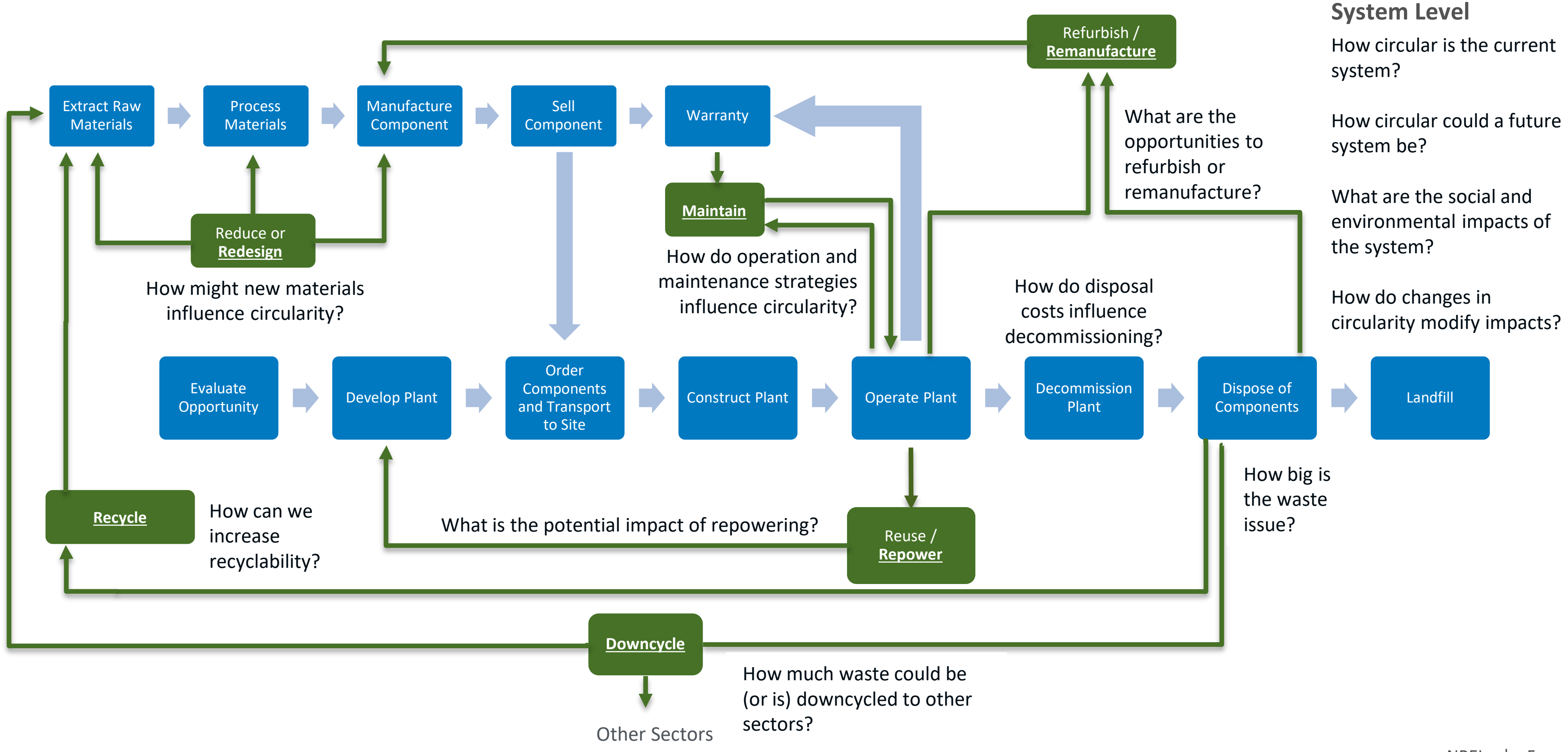
- How will this transition influence the externalities of energy systems?
- How will these impacts vary regionally?
- What are the uncertainties associated with these results and how can this information be used to inform decision making?

Example Renewable Energy System Diagram:

Type of Pathway

Linear Pathway

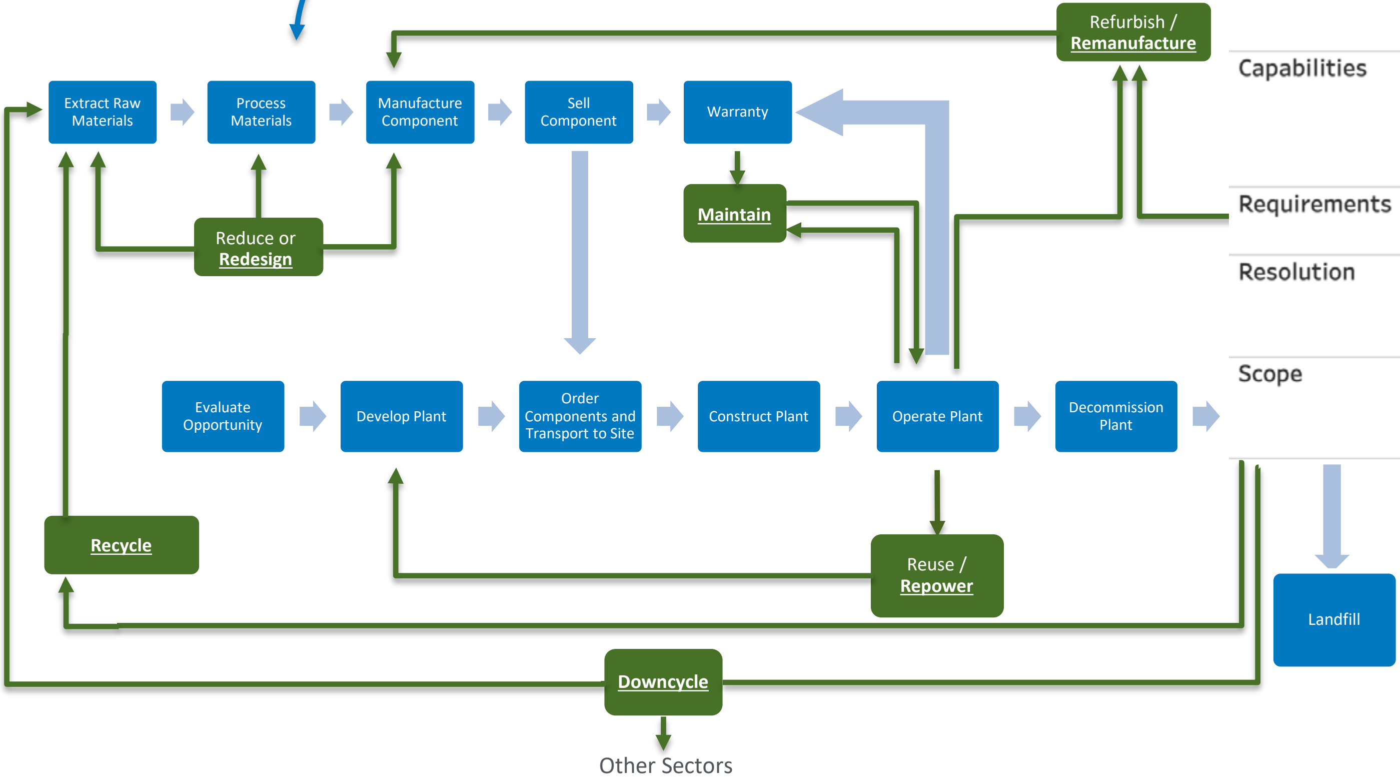
Circular Pathway



How does circularity affect our choice of methods?

Complex, interdependent system with temporal and spatial variation

To model this system, we need to satisfy a variety of requirements



Capabilities	Able to incorporate uncertainty
	Able to represent social dynamics
	Able to represent system non-linearities
	Easy to expand
Requirements	Low computational needs
	Reasonable data needs
Resolution	Spatial: at least state-level
	Technological: at least single technology
	Temporal: dynamic
Scope	Economic: at least national
	Spatial: at least national
	Temporal: at least multi-year

A variety of methods already exist. Why not use those?

Method	Research question
Industrial ecology	
Process-based life cycle assessment (LCA)	What are the environmental impacts related to a product or system?
Environmentally extended input-output (EEIO)	What are the environmental impacts related to an economic system?
Material flow analysis (MFA) (static and dynamic; emergy/exergy)	What are the material (or energy) flows and stocks related to a system?
Complex systems science	
System dynamics (SD)	How do underlying system structures influence the behavior of complex dynamic systems (e.g., systems with interdependence and circular causality)?
Discrete event simulation (DEM)	What is the sequence of (eventually stochastic) events that trigger the dynamics of a system?
Agent-based modeling (ABM)	What are the interactions among a system’s individual parts and how do they drive its overall behavior?
Operations research (OR)	What is the best solution for a decision-making problem?
Other fields	
Transition frameworks	What are the social and technical factors which facilitate the transition of a system towards sustainability?
Eco-design and guidelines	What are the designs or processes that minimize the environmental impacts of a system?

Do any existing method satisfy our requirements?

No Somewhat Yes

Method

		Industrial ecology			Complex systems science				Other fields	
	Project Requirement	Process-based life cycle assessment	Environmentally extended input-output	Dynamic material flow analysis	System dynamics	Discrete event simulation	Agent based model	Operations research	Transition frameworks	Eco-design, guidelines
Capabilities	Able to incorporate uncertainty	Somewhat	No	Somewhat	Somewhat	Yes	Somewhat	Yes	Somewhat	No
	Able to represent social dynamics	No	No	No	Yes	No	Yes	Somewhat	Yes	No
	Able to represent system non-linearities	No	No	Somewhat	Yes	No	Yes	Somewhat	Somewhat	No
	Easy to expand	Somewhat	No	Yes	Yes	Yes	Somewhat	Yes	Somewhat	No
Requirements	Low computational needs	Yes	Somewhat	Somewhat	Somewhat	Somewhat	Somewhat	Somewhat	Yes	Yes
	Reasonable data needs	No	Somewhat	Somewhat	Somewhat	Somewhat	No	Somewhat	Yes	Yes
Resolution	Spatial: at least state-level	Somewhat	Somewhat	Yes	Yes	Somewhat	No	Somewhat	No	Somewhat
	Technological: at least single technology	Yes	Somewhat	Somewhat	Somewhat	Yes	Yes	Yes	No	Yes
	Temporal: dynamic	No	No	Yes	Yes	Yes	Yes	No	No	No
Scope	Economic: at least national	Somewhat	Yes	Yes	Yes	Yes	No	Somewhat	Yes	No
	Spatial: at least national	Yes	Yes	Yes	Yes	Somewhat	No	Somewhat	Yes	No
	Temporal: at least multi-year	Somewhat	No	Yes	Yes	Yes	Yes	No	No	No

CELAVI hybridizes existing methods to meet the demands of modeling circularity transitions and associated impacts.

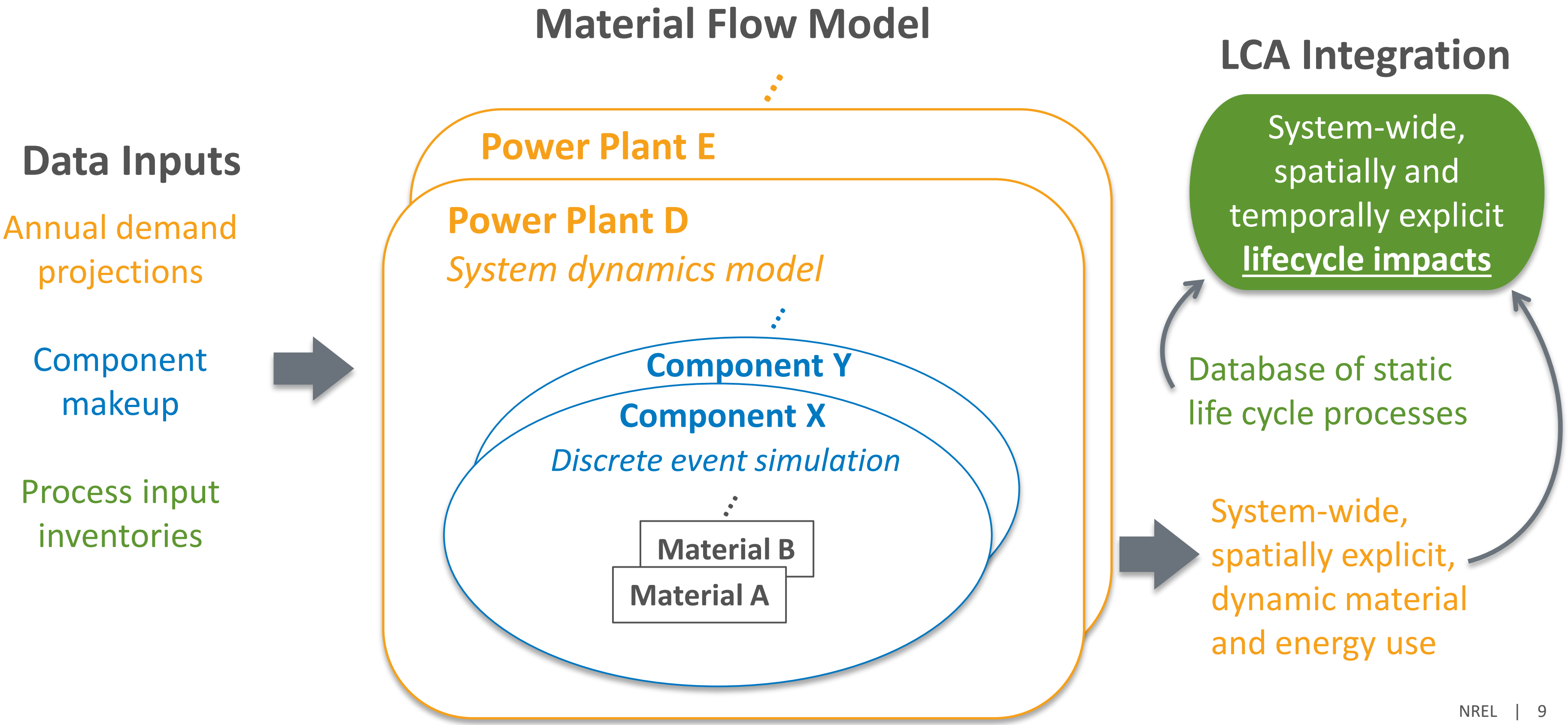
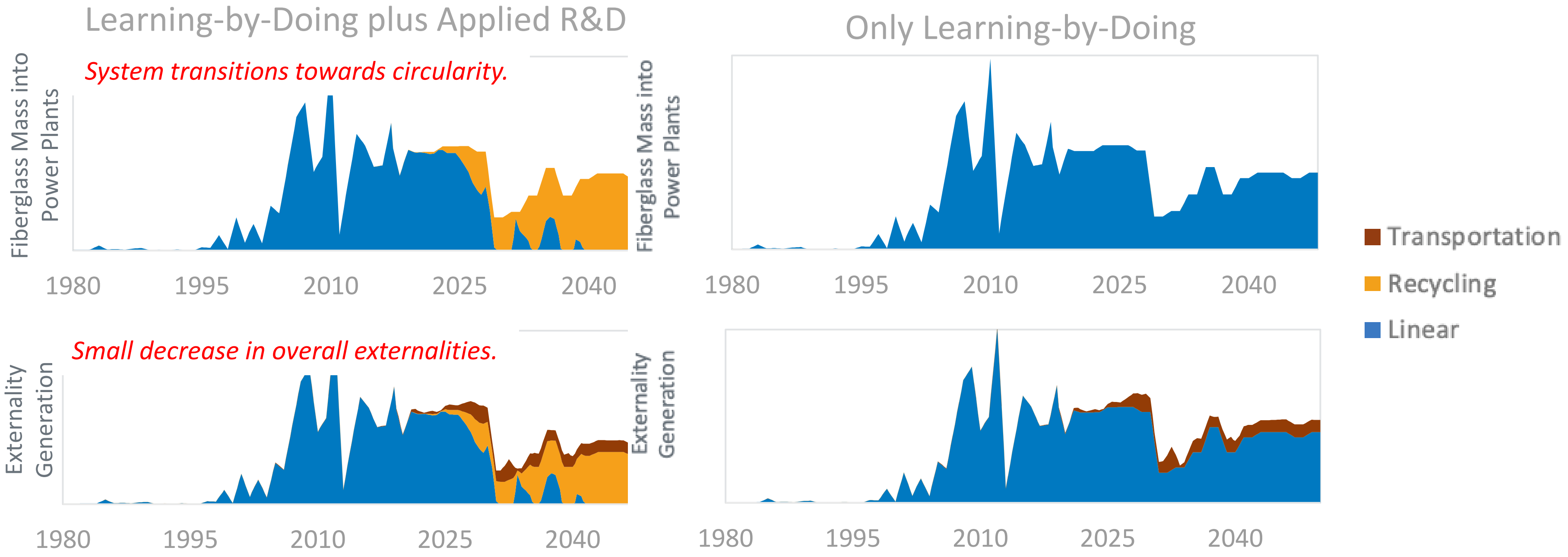


Illustration of a potential case study:
Can we rely on learning-by-doing to increase wind turbine blade recycling and decrease related externalities?

Assumptions

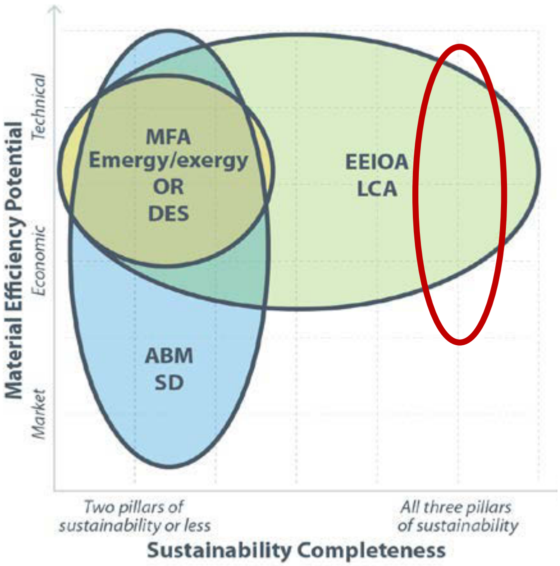
- Wind blade fiberglass recycling processes currently exist but are not widely implemented
- Recycling cost reductions can come from industrial learning-by-doing and/or from applied R&D

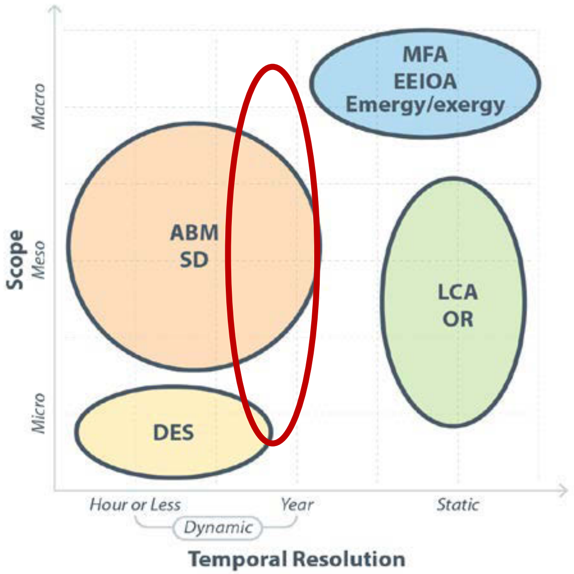


Please note: these figures illustrate the types of behavior that we see and the trends over time

- They are intended for illustrative purposes only
- They are not intended to be used to obtain absolute magnitudes (model is still being developed and vetted)

How does CELAVI compare to other methods? CELAVI combines LCA, MFA, SD, and DES





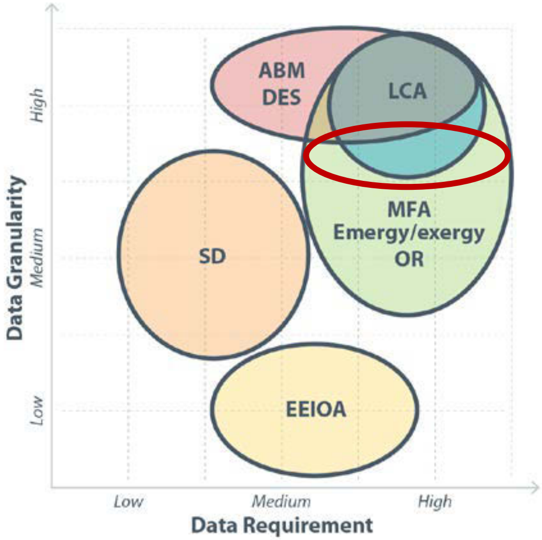


Image credits: J. Walzberg, G. Lonca, R. Hanes, A. Eberle, A. Carpenter, and G. Heath. (in prep). *Do we need a new circularity assessment methodology? A critical literature review.*

ABM=agent-based modeling; SD=system dynamics; MFA=material flow analysis; EEIOA=environmentally extended input output analysis; LCA=life cycle assessment; OR=operations research; DES=discrete event simulation.

Future Work

CELAVI Overview

- Project is intended to develop a prototype circular economy modeling approach that is relevant to multiple energy technologies
- Outcomes will include:
  - a modeling framework
  - demonstration for one energy system use case (current focus: wind blades)
  - at least one regional case study
  - incorporation of uncertainty and visualization

Potential Future Expansion of CELAVI

- More technologies
- More regions
- Open-source release
- Published case studies
- Integration with other models and tools

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Thank you

www.nrel.gov

Further questions about CELAVI?
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