Developing & Evaluating Energy Justice Metrics for Early-Stage Materials Research

Nikita Dutta, Bettina Arkhurst, Clara Houghteling, Kate Anderson, & Liz Gill

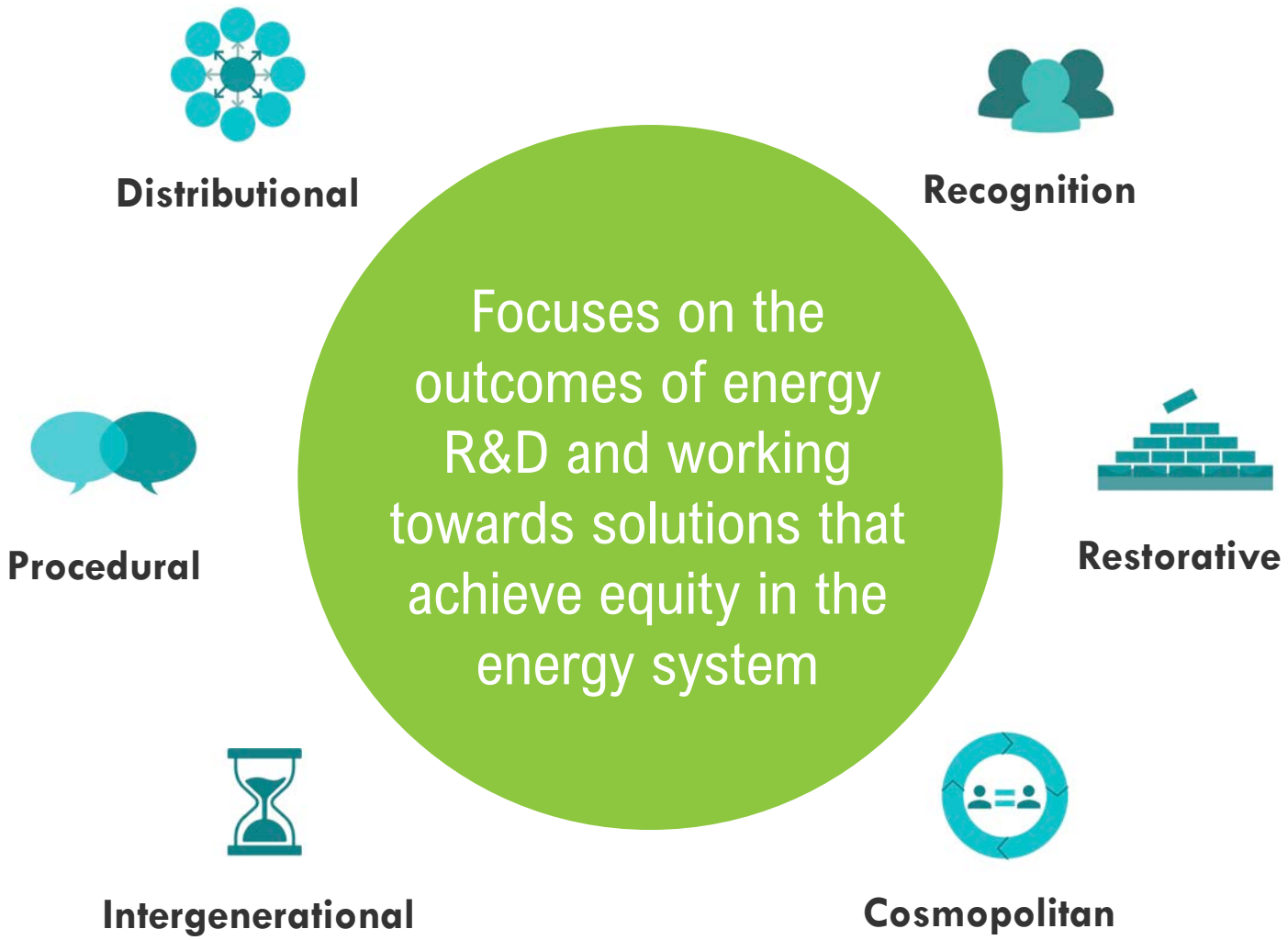
MRS Fall Meeting

November 28, 2023

Outline

1. Intro to Energy Justice
2. Relevance to Early-Stage Research
3. JUST-R Metrics Framework
4. Case Study Evaluation
5. Future Developments

Energy justice places a focus on community impacts



Energy Justice aims to achieve equity in social & economic participation in the energy system, while remediating social, economic, & health burdens on those historically harmed by the energy system ("frontline communities").

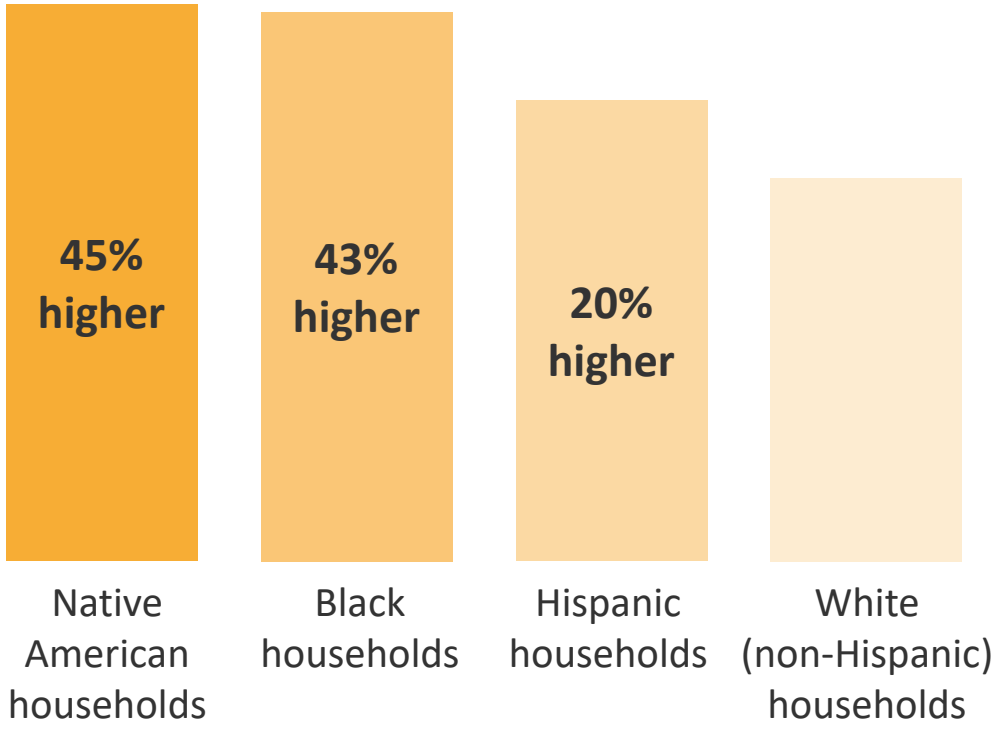
Equity recognizes individual's or group's circumstances & allocates resources/opportunities needed to reach a just outcome.

2020, "Equity vs. Equality: What's the Difference? | Online Public Health," GW-UMT; Cooper, 2019, "Section 1 - Defining Energy Justice: Connections to Environmental Justice, Climate Justice, and the Just Transition," Initiative for Energy Justice. (https://iejusa.org/section-1-defining-energy-justice/)

Example: Communities experience different benefits & burdens from the current energy system

Household energy burdens:

Median household energy burdens vary by demographics:



ACEEE 2022: https://www.aceee.org/energy-burden

Exposure to pollution from fossil fuel peaker plants:

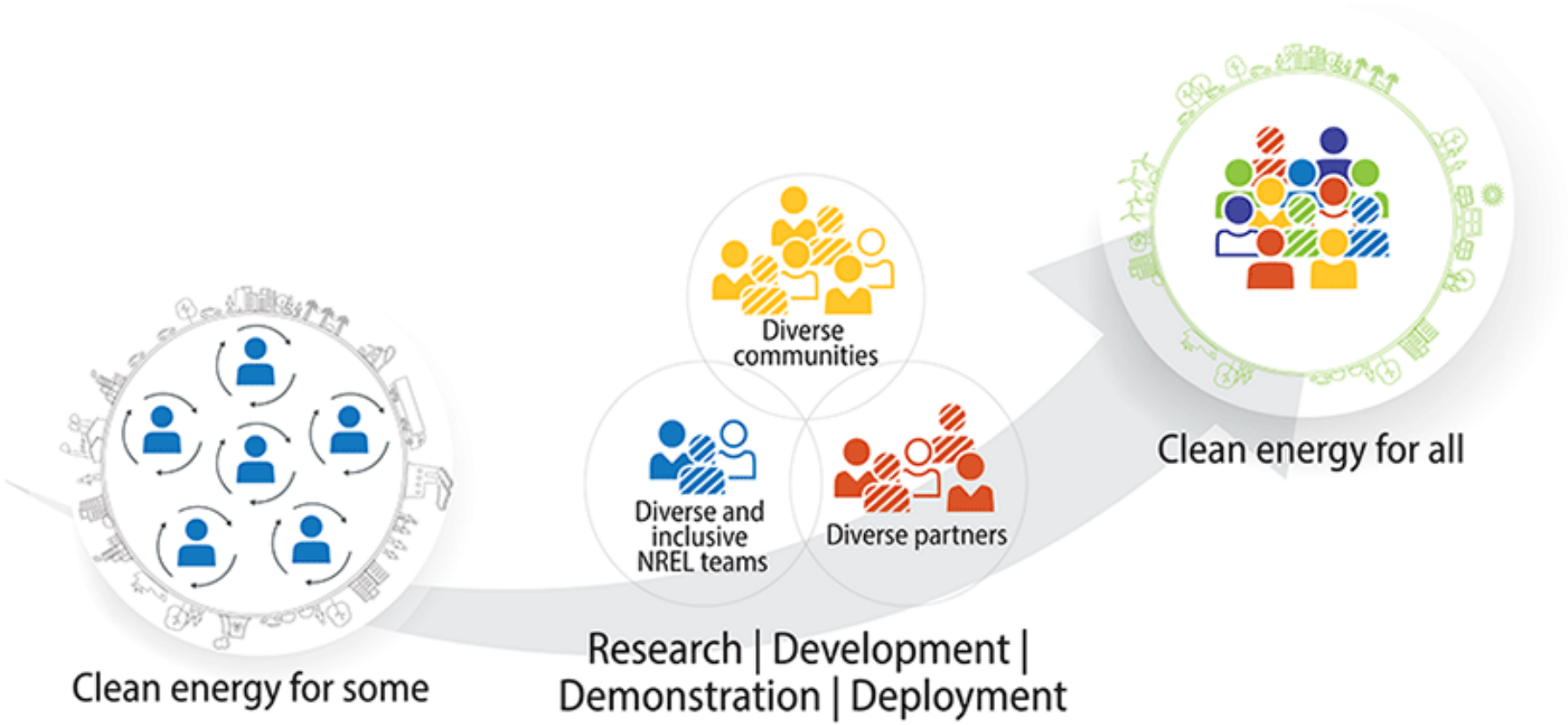
Highly polluting peaker plants neighbor areas with higher populations of people of color:

Number of Peakers	Average nitrogen oxide (NOx) emission rate	People of color percentage of population (within 3-mile radius)
346	14.6 lb/MWh	0 - 13%
304	16.4 lb/MWh	13 - 31%
348	14.2 lb/MWh	31 - 65%
150	**23.8 lb/MWh**	**65 - 100%**

Clean Energy Group, "Mapping the Inequities of Fossil Fuel Peaker Power Plants": https://www.cleanegroup.org/mapping-the-inequities-of-fossil-peaker-power-plants/

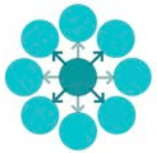
A just transition seeks to address these inequities in a transition to clean energy

Energy justice overlaps climate & environmental justice, which are all relevant to a just transition, but energy justice places a specific focus on development & deployment of energy technologies/systems.



Graphic by Anthony Castellano.

Principles of energy justice

Type of Justice		Definition	Example
Distributional		Equitable distribution of benefits and burdens across a population	Ensuring a technology does not negatively impact the health of one community while lowering the electric bill of another community

McCauley, D. A., Heffron, R. J., Stephan, H., and Jenkins, K., 2013, "Advancing Energy Justice: The Triumvirate of Tenets," International Energy Law Review, **32**(3), pp. 107–110.; Jenkins, K., McCauley, D., Heffron, R., Stephan, H., and Rehner, R., 2016, "Energy Justice: A Conceptual Review," Energy Research & Social Science, **11**, pp. 174–182.

Principles of energy justice

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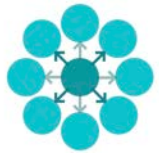
Distributional		Equitable distribution of benefits and burdens across a population	Ensuring a technology does not negatively impact the health of one community while lowering the electric bill of another community
Procedural		Equitable engagement, fairness, and transparency when allocating resources and reconciling disputes	Working with a community when deploying a new technology in that community

McCauley, D. A., Heffron, R. J., Stephan, H., and Jenkins, K., 2013, "Advancing Energy Justice: The Triumvirate of Tenets," International Energy Law Review, **32**(3), pp. 107–110.; Jenkins, K., McCauley, D., Heffron, R., Stephan, H., and Rehner, R., 2016, "Energy Justice: A Conceptual Review," Energy Research & Social Science, **11**, pp. 174–182.

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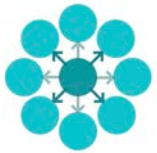
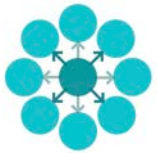
Distributional		Equitable distribution of benefits and burdens across a population	Ensuring a technology does not negatively impact the health of one community while lowering the electric bill of another community
Procedural		Equitable engagement, fairness, and transparency when allocating resources and reconciling disputes	Working with a community when deploying a new technology in that community
Recognition		Respect for the rights, needs, values, understandings, and customs of a population	Including and uplifting underrepresented voices on a research team

McCauley, D. A., Heffron, R. J., Stephan, H., and Jenkins, K., 2013, "Advancing Energy Justice: The Triumvirate of Tenets," International Energy Law Review, **32**(3), pp. 107–110.; Jenkins, K., McCauley, D., Heffron, R., Stephan, H., and Rehner, R., 2016, "Energy Justice: A Conceptual Review," Energy Research & Social Science, **11**, pp. 174–182.

Further principles of justice to consider

Type of Justice		Definition	Example
Distributional		Equitable distribution of benefits and burdens across a population	Ensuring a technology does not negatively impact the health of one community while lowering the electric bill of another community
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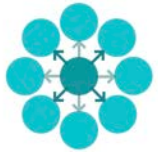
Restorative		Acknowledging, ameliorating, and addressing previous negative impacts that caused inequities	Building renewable energy sources on historically polluted lands in order to benefit the community
Intergenerational		Considering future generations, when evaluating changing effects of energy technologies over time	Ensuring natural materials that may be needed today are available for future generations to use
Cosmopolitan		Ensuring the well-being of persons, rather than communities or nations across the energy life cycle	Considering mining practices and the health implications on mining communities even if they will not be the end-users of a technology

Healy, N., Stephens, J. C., and Malin, S. A., 2019, "Embodied Energy Injustices: Unveiling and Politicizing the Transboundary Harms of Fossil Fuel Extractivism and Fossil Fuel Supply Chains," Energy Research & Social Science, **48**, pp. 219–234.; Sovacool, B. K., Martiskainen, M., Hook, A., and Baker, L., 2019, "Decarbonization and Its Discontents: A Critical Energy Justice Perspective on Four Low-Carbon Transitions," Climatic Change, 155(4), pp. 581–619

Intro to energy justice: Key takeaways

Energy justice seeks to achieve equity in participation in & benefits/burdens from the energy system and encompasses several types of justice:



Distributional

Procedural

Recognition

Restorative

Intergenerational

Cosmopolitan

These ask us to consider:

How did we get here?

Who is **included** & who is not? Burdens? Benefits?

What impacts do we expect our work to have in the **future**?

What **trade-offs** are we making?

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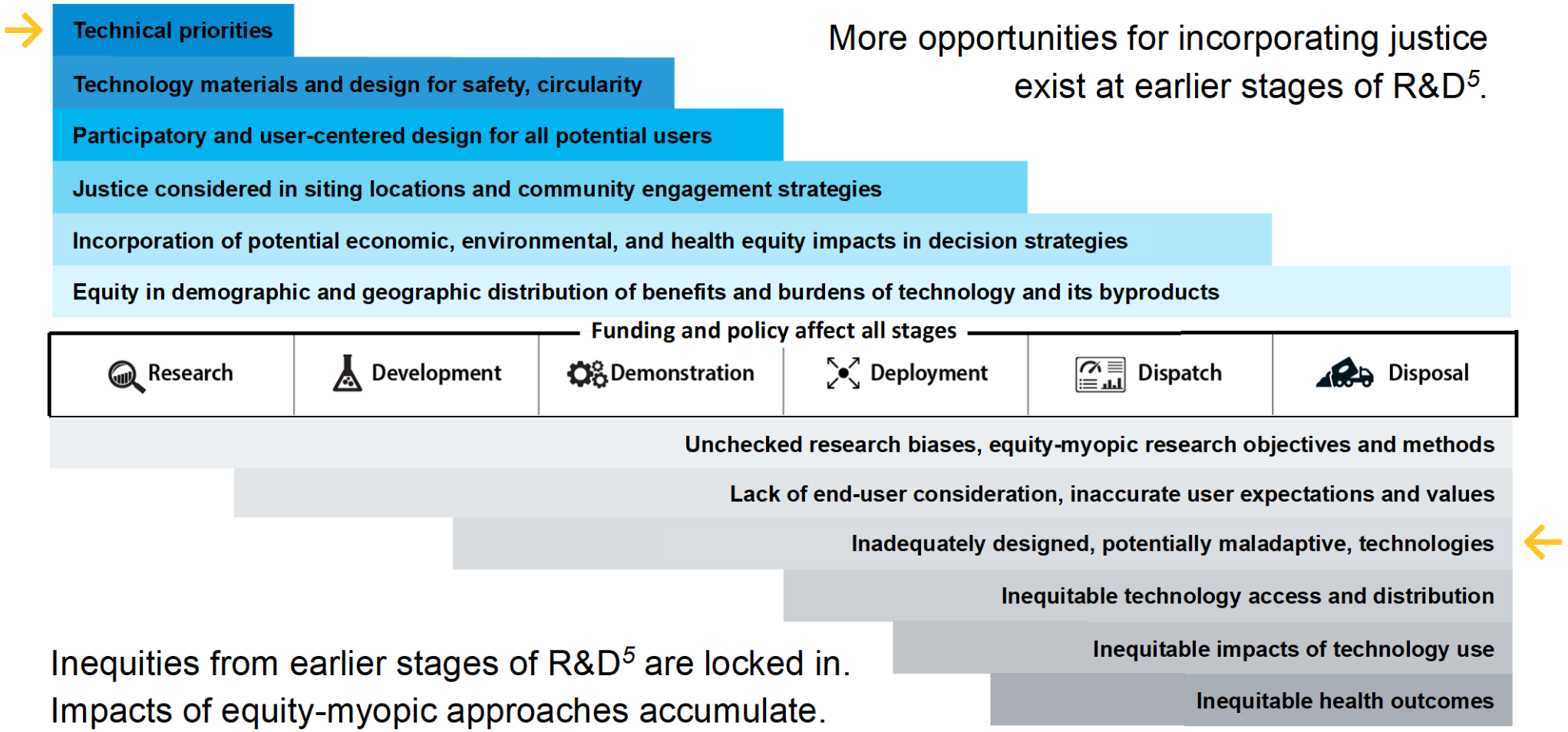
Why consider energy justice in early-stage work?

Negative impacts can be "locked in" by early-stage R&D decisions. More opportunities exist to address these impacts the earlier they are considered:



Arkhurst, B., W. Hawthorne, I. Ferrall, K. Fu, & K. Anderson. 2023. "Incorporating Energy Justice throughout Clean Energy R&D[5]: A Review of Outcomes and Opportunities." (*Under review.*)

Example: Critical material dependence can be locked in by early-stage materials research

Cobalt in lithium-ion batteries poses both energy justice (resource depletion, unethical mining) & economic (expensive, unstable supply chain) challenges.

ARTICLE

https://doi.org/10.1038/s41467-022-29022-z OPEN

Check for updates

Battery technology and recycling alone will not save the electric mobility transition from future cobalt shortages

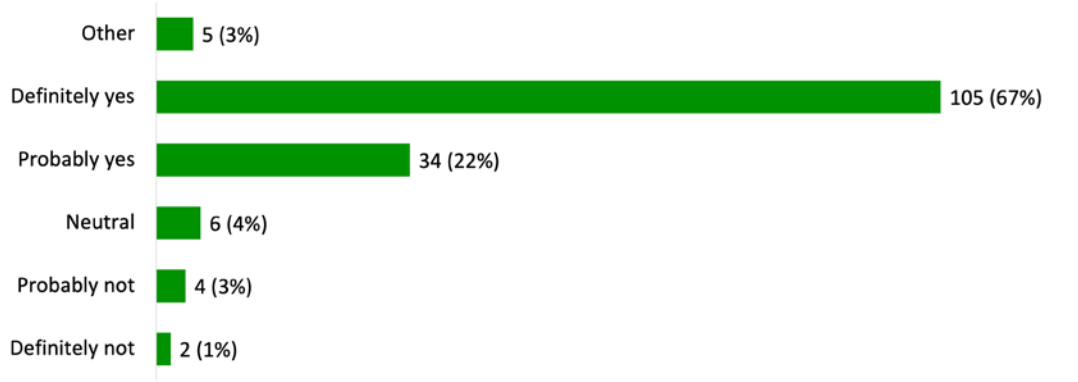
Anqi Zeng[1,2,3,8], Wu Chen[2,8], Kasper Dalgas Rasmussen[2], Xuehong Zhu[1,3]✉, Maren Lundhaug[4], Daniel B. Müller[4], Juan Tan[5], Jakob K. Keiding[5], Litao Liu[6], Tao Dai[7]✉, Anjian Wang[7] & Gang Liu[2]✉

Nature Communications (2022).

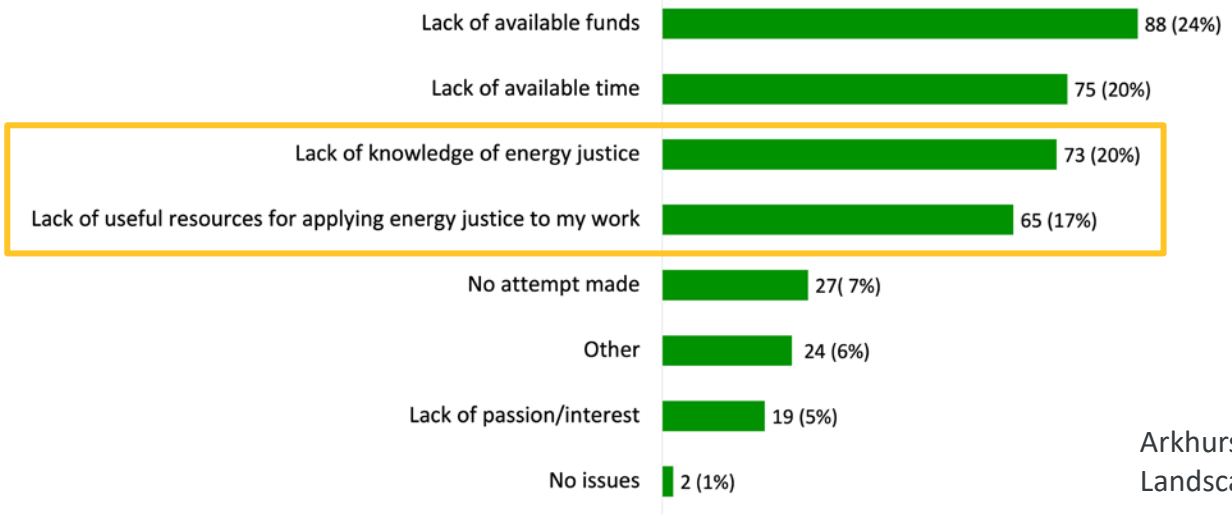
"Low-cobalt battery cathode technology development could alleviate, but not prevent, the supply crisis. The demand-supply gap would still occur around 2028-2033, even though cobalt-free LFP technology already penetrated the market in 2020 and it is predicted that the next-generation cobalt-free battery technologies will become commercialized by 2030."

Challenge: Lack of resources for considering energy justice in early-stage R&D

Do you believe aspects of energy justice should be incorporated into the energy technology design process?



Which of the following have been issues you have faced when attempting to apply energy justice to your work?



Literature reviews, surveys, and interviews showed a substantial gap in knowledge on how to consider energy justice at early stages of R&D.

This research worked to address lack of resources by **developing & assessing metrics to consider energy justice in all phases of technology development**, from early research through deployment.

Arkhurst, B.,K., A. Schauer, K. Fu, & K. Anderson. 2023. "An Investigation of the Energy Justice Landscape in Renewable Energy Technology Research and Design" (*In Preparation*).

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JUST-R Metrics for Early-Stage Energy Research

Justice Underpinning Science & Technology Research

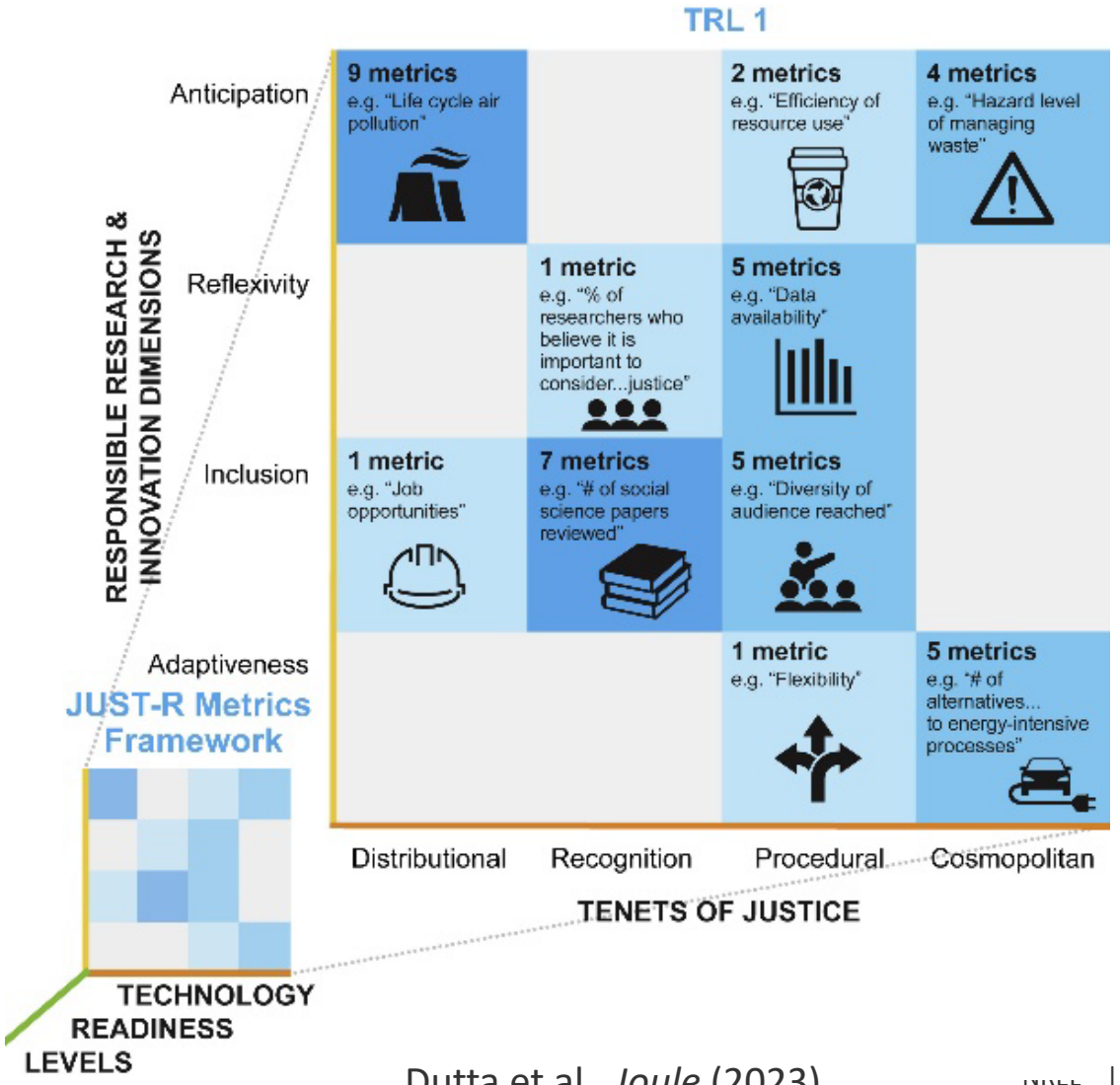
Dutta, Nikita S., Elizabeth Gill, Bettina K. Arkhurst, Mary Hallisey, Katherine Fu, and Kate Anderson. 2023. "JUST-R Metrics for Considering Energy Justice in Early-Stage Energy Research." *Joule* **7** (3), 431-437.

Leveraging energy justice tenets with dimensions of Responsible Research & Innovation

JUST-R framework brings together **50 metrics**—30 from literature, 20 new—oriented around:

- Core tenets of energy justice
- Dimensions of Responsible Research and Innovation (RRI), which considers social impacts of research (Stilgoe, Owen, & Macnaghten, 2013).

Metrics are organized by technology readiness levels, with an emphasis on early stages of research.



Dutta et al., *Joule* (2023).

New metrics seek to…

Consider the whole research life cycle

Distribution of hazard exposure during research life cycle + Hidden process costs

Broaden the knowledge guiding our research

Breadth of pre-existing knowledge review + Distribution of research results

Expanding our solution parameter space

Identification of set vs. flexible parameters

Example 1: Consider the whole research life cycle

Distribution of hazard exposure during research life cycle:

- ↓ Hazard level of extracting or synthesizing material inputs
- ↓ Hazard level of lab processes
- ↓ Hazard level of managing waste
- ↓ Extent to which hazards would increase at industrial scale

Hidden process costs:

- ↓ Estimated cost of managing waste generated by research
- ↓ Estimated cost of energy consumed during research
- ↑ Projected cost savings from operating new tech vs. competing tech

Asks of the researcher: Consider the whole research life cycle, beyond what occurs in lab.

EJ impacts: Evaluating parts of life cycle individually gives insight into how costs, savings, & hazards may be distributed among communities on scale-up.

Example thought process: Cobalt-containing lithium-ion batteries

- Hazard level of laboratory processes
  → *Sufficiently **low** due to small scale & engineering controls.*

- Hazard level of extracting or synthesizing material inputs
  → ***High** health hazards associated with artisanal & small-scale cobalt mining – **hazards distributed among individuals & communities who are not necessarily technology end users**, an example of cosmopolitan justice.*

Example 2: Broadening use of knowledge

Breadth of pre-existing knowledge review:

- ↑ Number of social science papers reviewed
- ↑ Number of non-academic sources reviewed
- ↑ Diversity of authors of scientific papers reviewed

Distribution of research results:

- ↑ Proportion of results published open access
- ↑ Number of non-academic reports of results
- ↑ Number of non-academic oral presentations of results
- ↑ Diversity of audience reached
- ↑ Diversity of team members credited for & publicly presenting work

Asks of the researcher: Reflect on knowledge that goes into or out of a research project – who is represented or benefits?

EJ impacts: Promotes public engagement, cultural compatibility, & earlier identification of social impacts.

Example thought process: Heterogenous catalysis for fuel production

- Number of social science papers reviewed
  → *Learn about **social impacts of precious metal extraction** for catalysts.*

- Number of non-academic sources reviewed
- Diversity of authors of scientific papers reviewed
  → *Learn about **feedstocks appropriate for different communities or geographies** & social perception or impacts of their use.*

Example 3: Expanding parameter spaces

Identification of set vs. flexible parameters:

- ↑ Number of alternatives explored to waste-intensive processes
- ↑ Number of alternatives explored to energy-intensive processes
- ↑ Number of alternatives explored to hazardous or unethically sourced materials
- ↑ Number of environmental parameters tested
- ↑ Number of non-tech solutions explored to solve key problems

Asks of the researcher: Combat the inertia of following what is normally done in the field, ask questions, & think creatively.

EJ impacts: Early insight into whether technology is likely to be deployable at scale in diverse environments without significant negative impacts.

Example thought process: Wind resource modeling

- Number of alternatives explored to energy-intensive processes
  → *Incorporate **energy consumed by turbine/material transport** into analyses.*

- Number of environmental parameters tested
  → *Ensure models take into account **diverse boundary conditions/features relevant to different communities**, e.g. cultural differences in architecture, geographic differences in terrain.*

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Case Study Evaluation

Arkhurst, Bettina K., Clara Houghteling, Nikita S. Dutta, Katherine Fu, Ardelia Clarke, Kate Anderson, and Elizabeth Gill. 2023. “Evaluating energy justice metrics in early-stage research using the JUST-R metrics framework.” *Frontiers in Environmental Science* 11:1206013.

Evaluation aids understanding of how researchers engage with framework & how it can be improved

To assess effectiveness of the framework, conducted case studies with 12 research teams working across energy technologies applying JUST-R metrics to their work:

Evaluation Criteria

Accessibility

Users can understand & apply technique

Impact

Technique enables actionable changes

Appeal

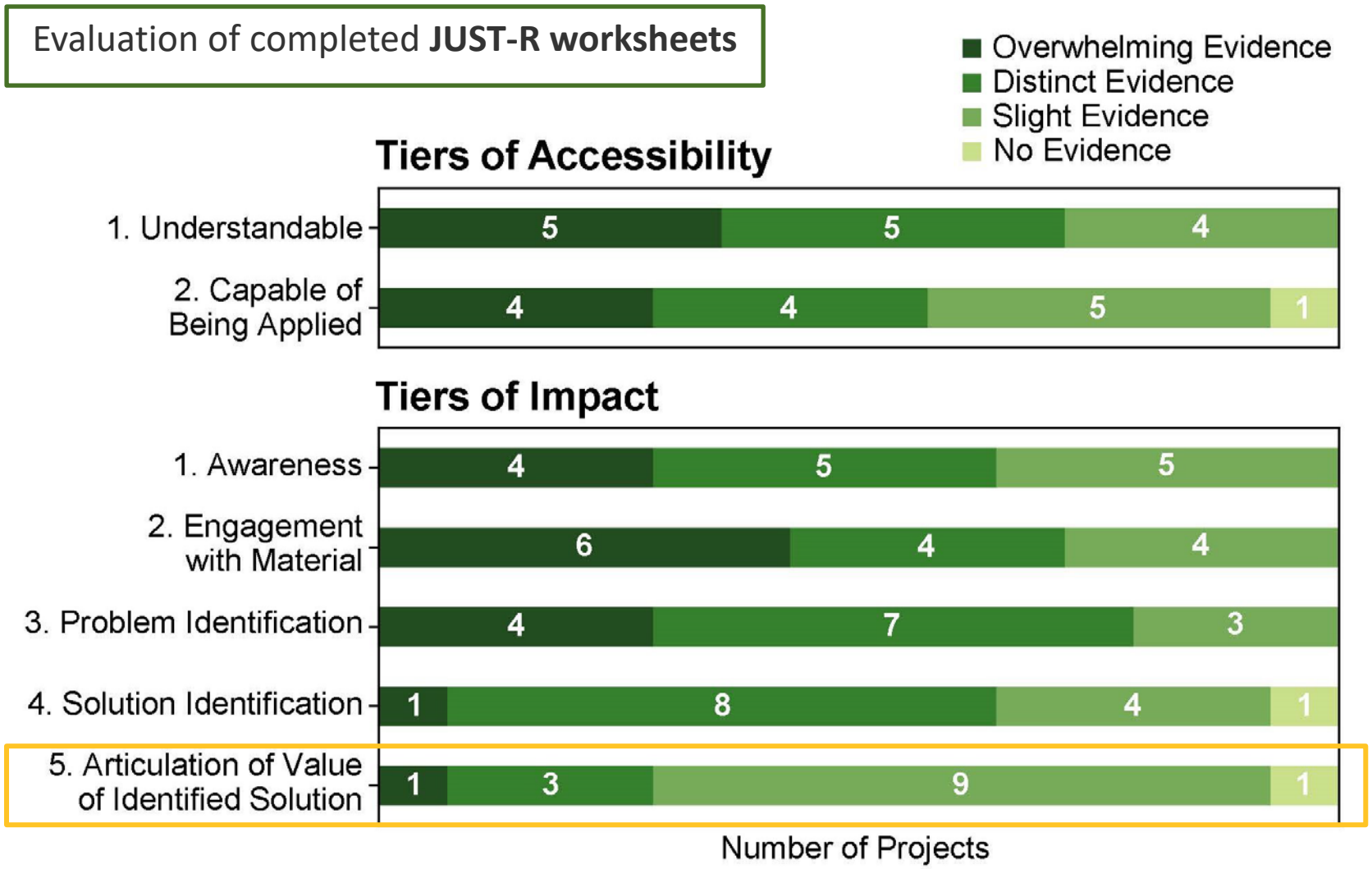
Users find technique valuable

For each metric:

- Assess for your project
- Identify potential energy justice issues
- What could be done differently?

Results: Evidence of accessibility, engagement, & problem/solution identification

Evaluation of completed **JUST-R worksheets**



Evidence of accessibility, engagement, & problem/solution identification observed across most cases.

Cases were less able to articulate the value of applying identified solutions to their research.

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Analysis showed broadened perspectives & understanding, as well as need for further support

Evaluation of completed **JUST-R worksheets, workshop transcripts,** and **debrief session transcripts**

Theme 1: New Perspective or Viewpoint	Theme 2: Institutional Support and Incentives	Theme 3: EJ Understanding and Responsibility	Theme 4: Method Design by TRL and Research Area
Broadening Perspective	Time, Funding, Incentives	Lack of EJ Connection	Examples and Facilitation
Scope Creep	Available Information	EJ Responsibility	Early Implementation
Happy to Participate	Expertise Development	Insufficient Solutions	Conclusive Ending
Teaching Tool			Redundancy/Irrelevancy
			More Specialized Tool
			Shrinking Perspective

Theme Categories with Associated Subthemes

EJ = Energy Justice

TRL = Technology Readiness Level

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Analysis showed broadened perspectives & understanding, as well as need for further support

Theme 1: New Perspective or Viewpoint
Broadening Perspective
Scope Creep
Happy to Participate
Teaching Tool

*"The further we cast our net, the more discussions we would need, **the more people we would need to involve**…"*

*"It kind of forced me to think **outside of my usual box**… I don't normally think that way every day; I feel happy with that."*

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Analysis showed broadened perspectives & understanding, as well as need for further support

"I think even the most energy justice-oriented people or people who could be persuaded to be oriented that way have a hard time with that unless they know that that's ***part of the incentive structure that they're supposed to be reporting to****, because otherwise their priorities need to be somewhere else."*

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Analysis showed broadened perspectives & understanding, as well as need for further support

Theme 3: EJ Understanding and Responsibility

- Lack of EJ Connection
- EJ Responsibility
- Insufficient Solutions

*"[**We] have few options** for where we can source materials due to needing very high purity source materials."*

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Analysis showed broadened perspectives & understanding, as well as need for further support

*Some researchers hoped to see **a simple and explicit connection** between their work and energy justice upon completion of the framework, such as "a score that tells you whether your research is improving energy justice or is harming energy justice."*

Arkhurst & Houghteling et al., *Front. Env. Sci.* (2023).

Key takeaways & opportunities for future work

Which of the following have been issues you have faced when attempting to apply energy justice to your work?

Consider metrics at program level & incorporate energy justice-supportive language into funding calls.

Resources, policies, & dedicated staff to assist researchers with thinking through projects.

Arkhurst, B.,K., A. Schauer, K. Fu, & K. Anderson. 2023. "An Investigation of the Energy Justice Landscape in Renewable Energy Technology Research and Design" (*In Preparation*).

Areas of Future Work

Specializing metrics for individual research areas

Seeking feedback on potential for collaboration with ongoing projects

Facilitate easier assessment & longer term engagement throughout early-stage projects

Developing offline & online tools to provide further resources & promote follow-through

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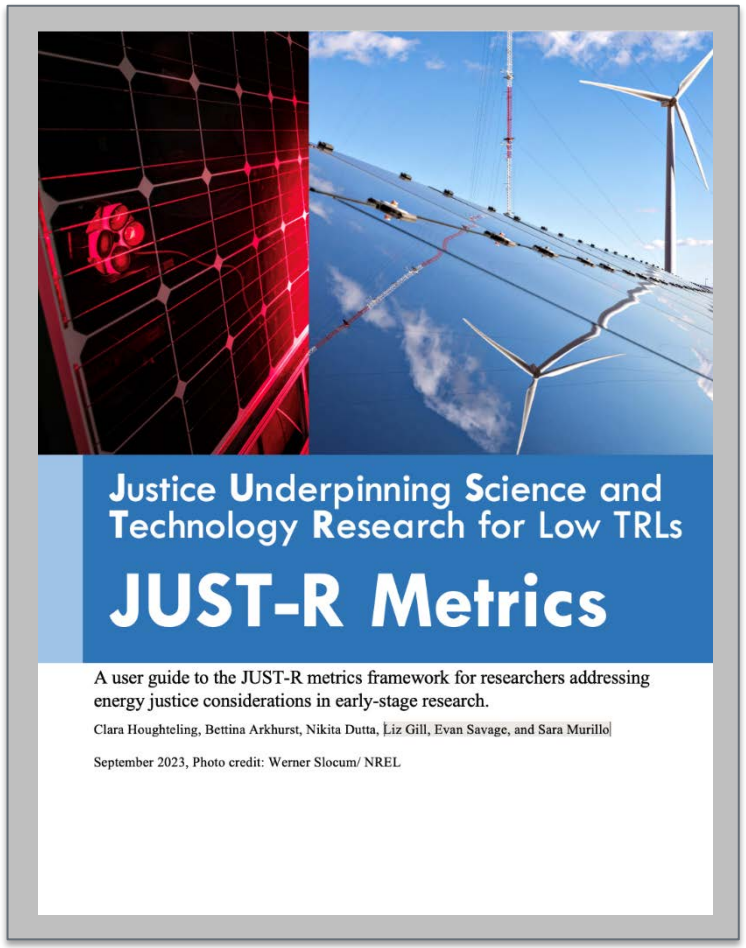
Offline tool supports selecting relevant metrics & assessing throughout a project

Offline Tool

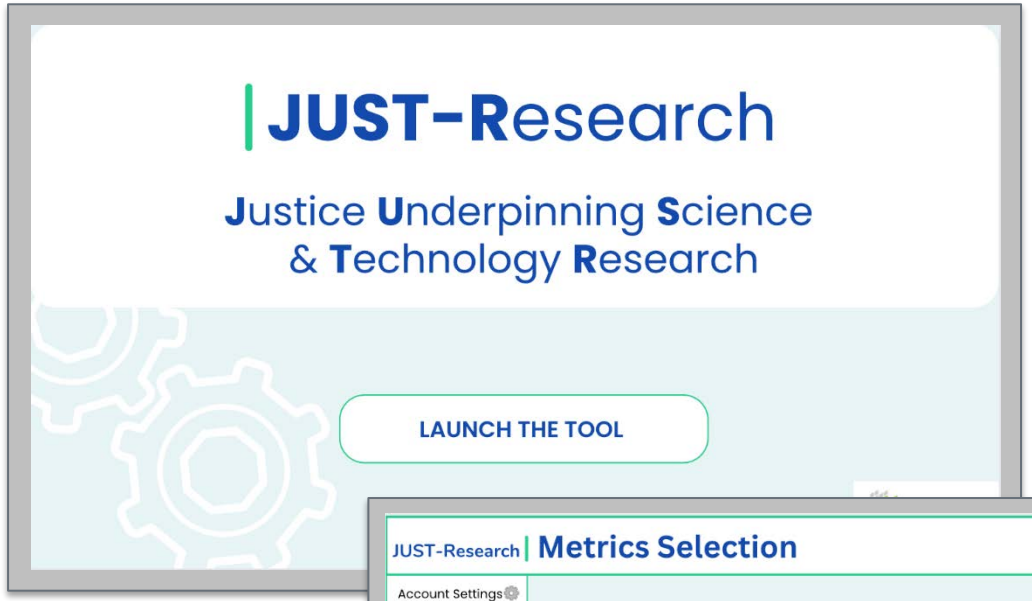


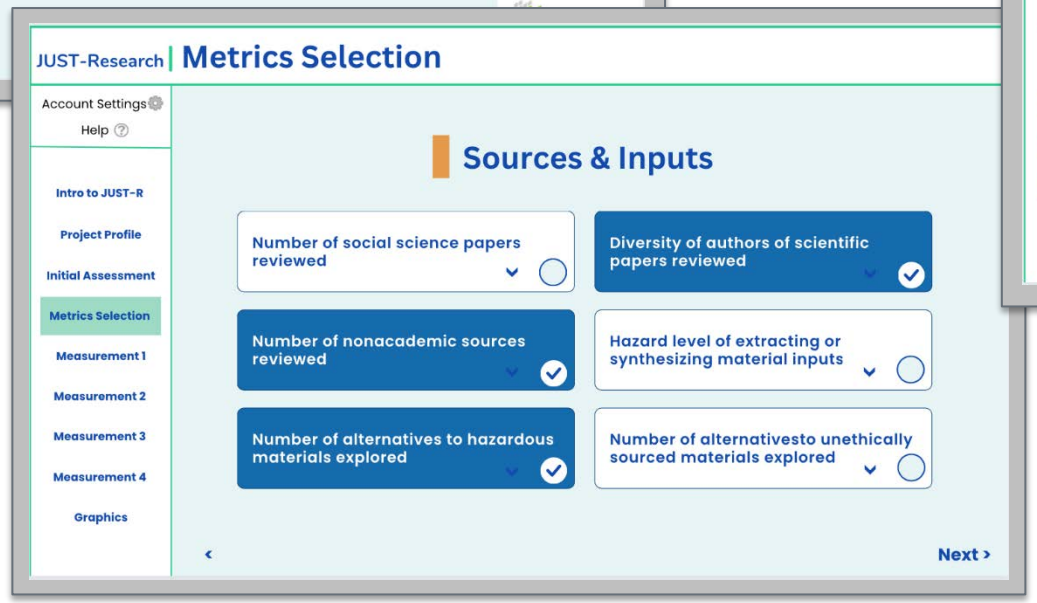
J17

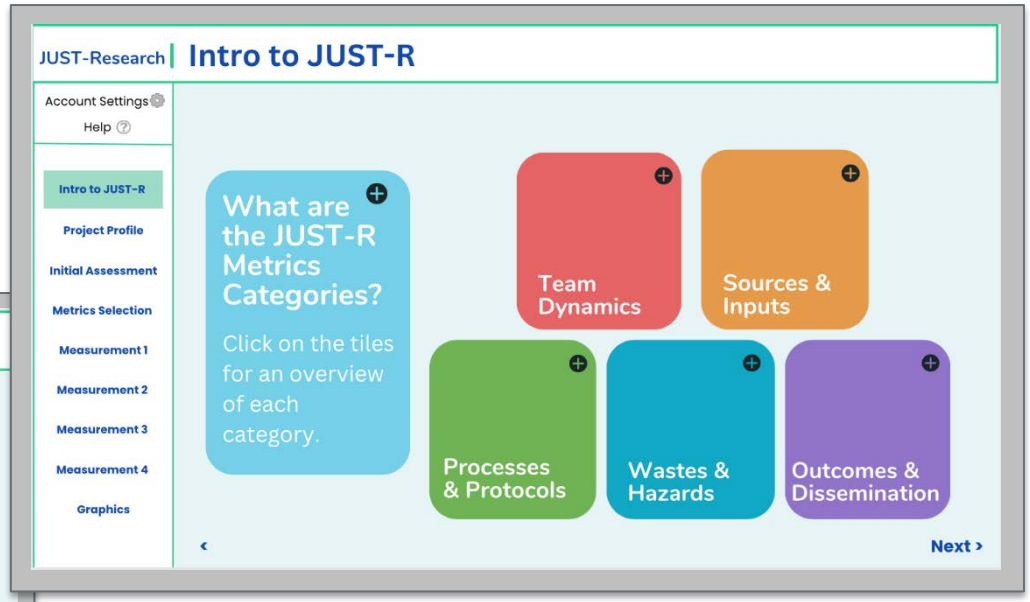
	A	C	D	E	F	G	H	I	J	K
1										Complete By:
2					Planning					
3	Metric Selection	Metric	Units		Pre-assessment	Target	Action Plan	Potential Barriers	Notes	Measure 1
5	Selected	Accountability level	Varies	↑						
6	Selected	Capability to communicate with stakeholders	Varies	↑						
7	Selected	Percentage of team members who believe it is important to consider/address issues related to social justice/inclusion in their work and/or methodologies	Percentage (%)	↑						
8	Selected	Number of social science papers reviewed	Number of Papers	↑						
9	Selected	Diversity of authors of scientific papers reviewed	Varies	↑						
10	Selected	Number of nonacademic sources reviewed	Number of Sources	↑						
11	Selected	Hazard level of extracting or synthesizing material inputs	Varies	↓						
12	Selected	Number of alternatives explored to hazardous materials	Number of Alternatives	↑						
13	Selected	Number of alternatives explored to unethically sourced materials	Number of Alternatives	↑						
14	Selected	Estimated energy consumed during project activities	Consumption/Time (e.g., kWh/year)	↓						
15	Selected	Number of alternatives explored to energy-intensive processes	Number of Alternatives	↑						
16	Selected	Number of environmental parameters tested	Number of Tested Parameters	↑						
17	Selected	Number of nontechnological solutions explored to solve key problems in project	Number of Nontechnological Solutions	↑						
18	Selected	Estimated financial cost of managing waste generated by project	Currency/Time (e.g., $/year)	↓						
19	Selected	Hazard level of project processes	Varies	↓						
20	Selected	Hazard level of managing waste	Varies	↓						
21	Selected	Extent to which hazards would increase at industrial scale	Varies	↓						
22	Selected	Number of alternatives explored to waste-intensive processes	Number of Alternatives	↑						

Online tool planned for development in 2025

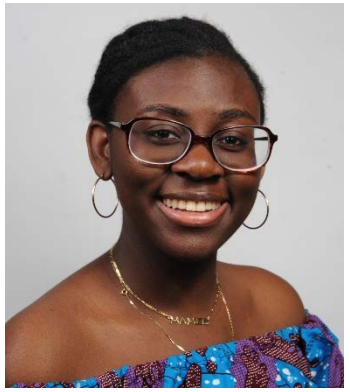
Online Tool







Acknowledgements



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Evan Savage
Accelerated Deployment & Decision Support

Jamie Cutlip-Gorman
Accelerated Deployment & Decision Support

Kate Anderson
NREL Strategy Lead

Further Information:

JUST-R Tool Homepage

JUST-R Framework:
DOI: 10.1016/j.joule.2023.01.007

JUST-R Case Study Evaluations:
DOI: 10.3389/fenvs.2023.1206013

Thank you!

www.nrel.gov

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