

Exploring the Implications of Solar Energy Cost Uncertainty

Sita M. Syal (she/her)
CME 270 – Guest Lecture
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First – let's do an activity.

**Turn to your neighbor...
and ask them how they got
their name**

5 min



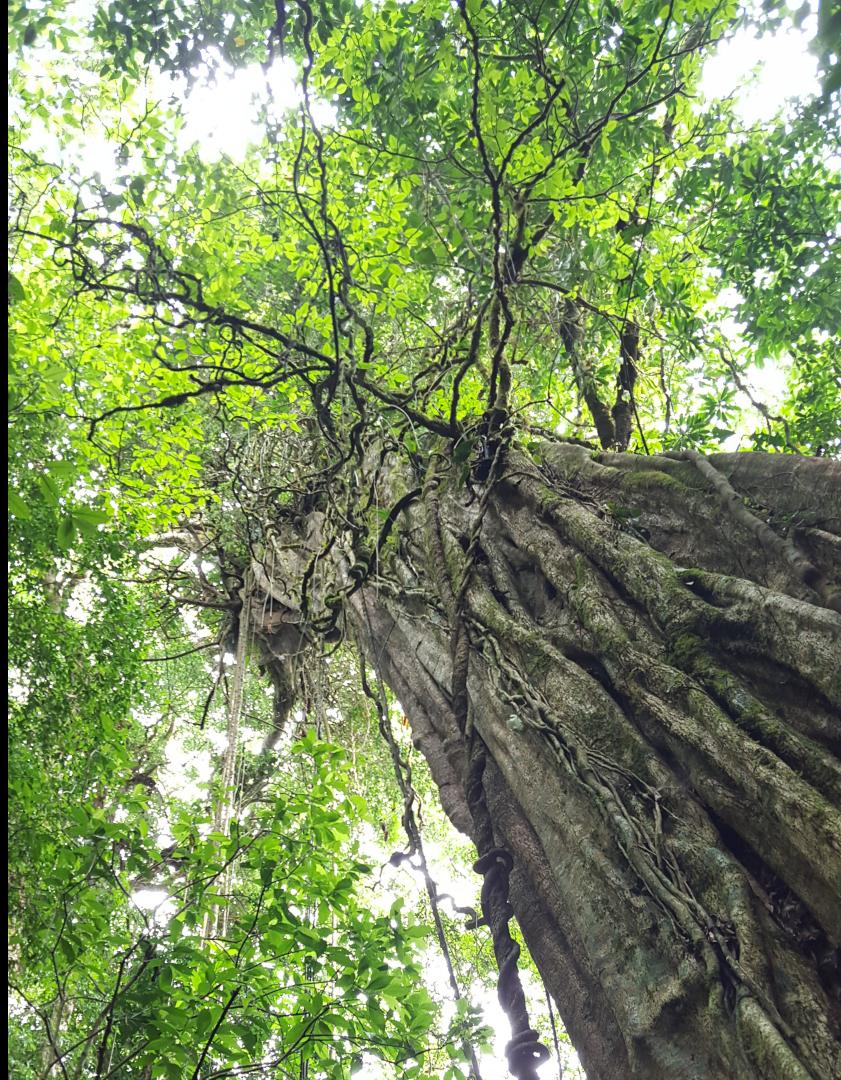
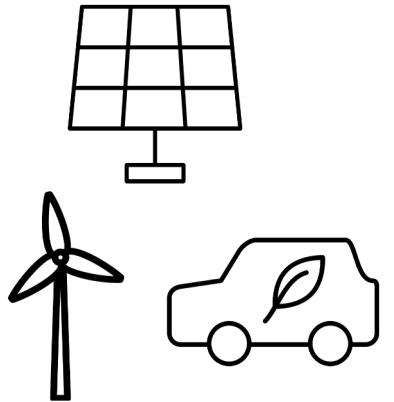


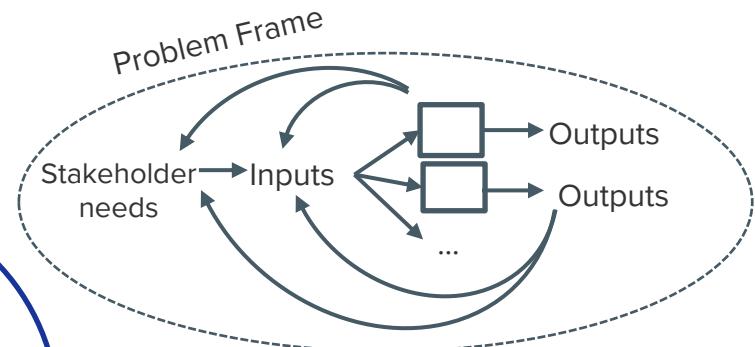
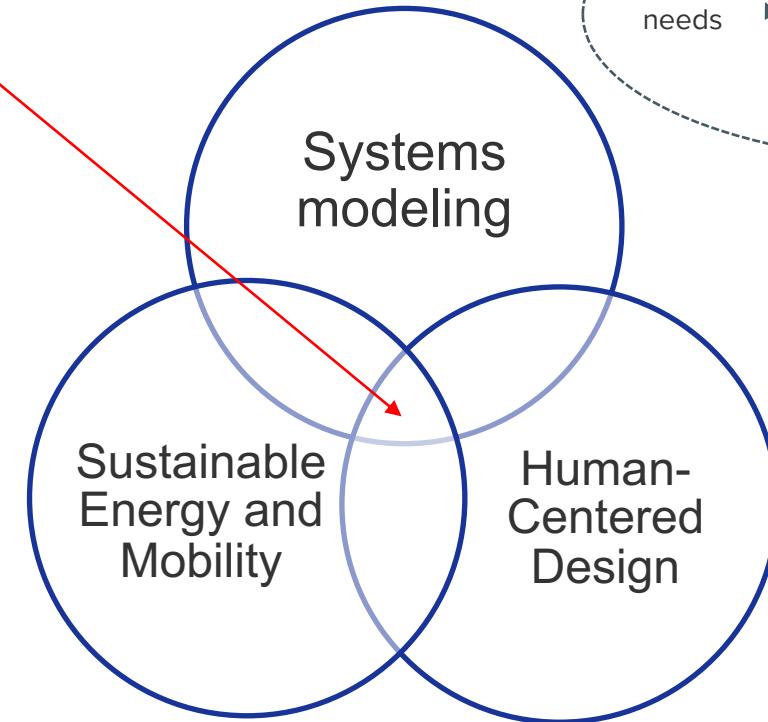
Image taken in Costa Rica

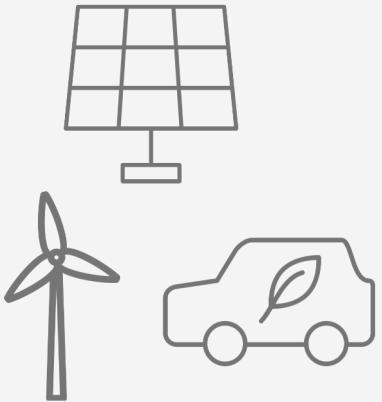


How are we going to make this transition fair?

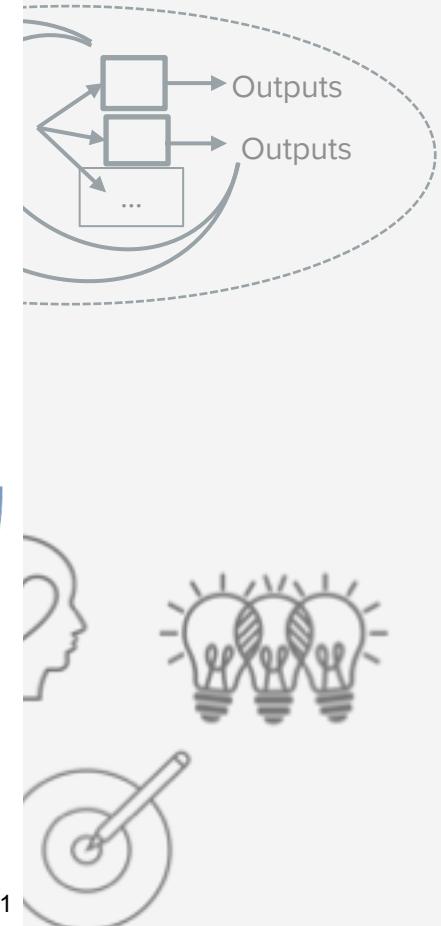
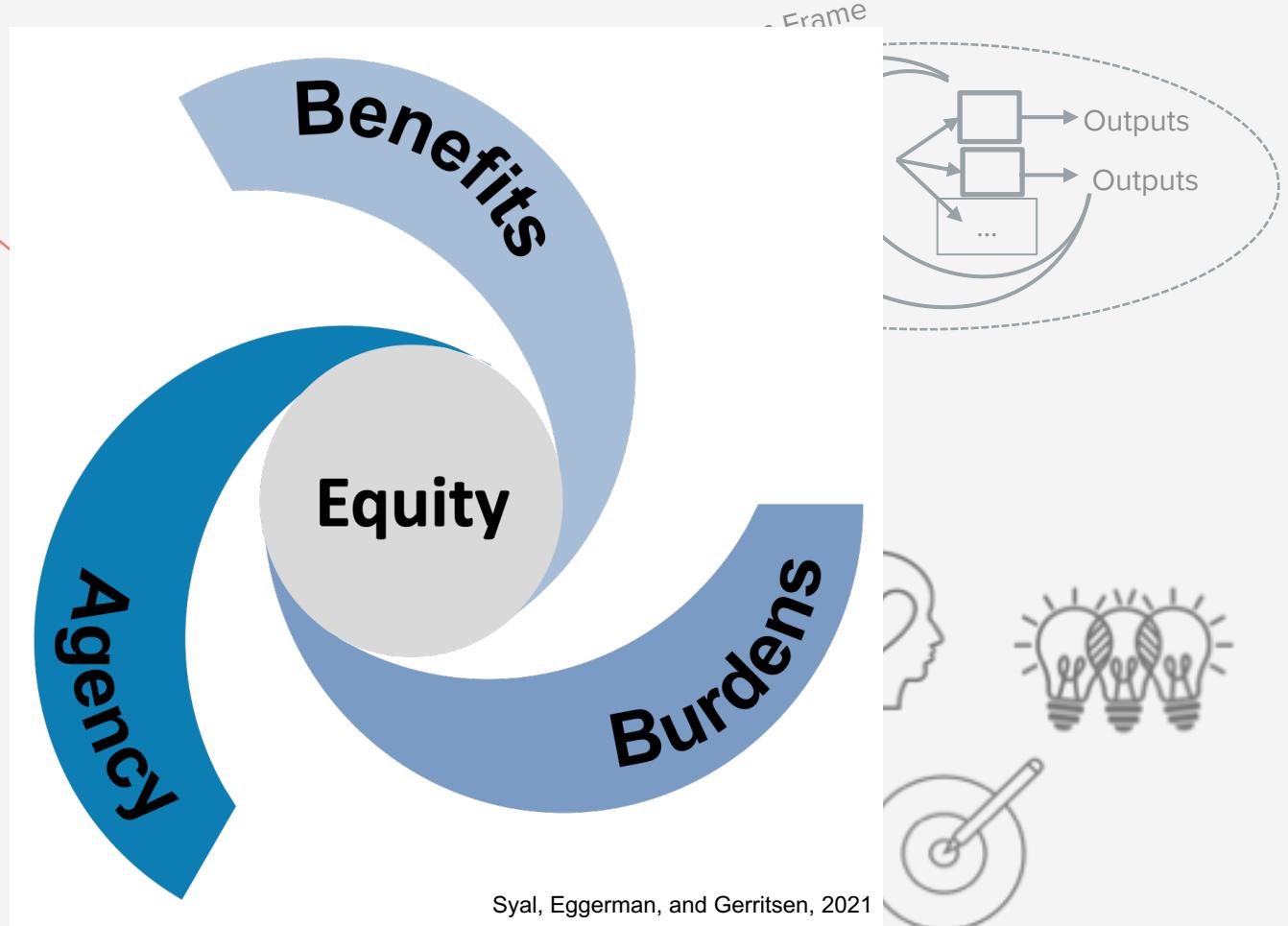


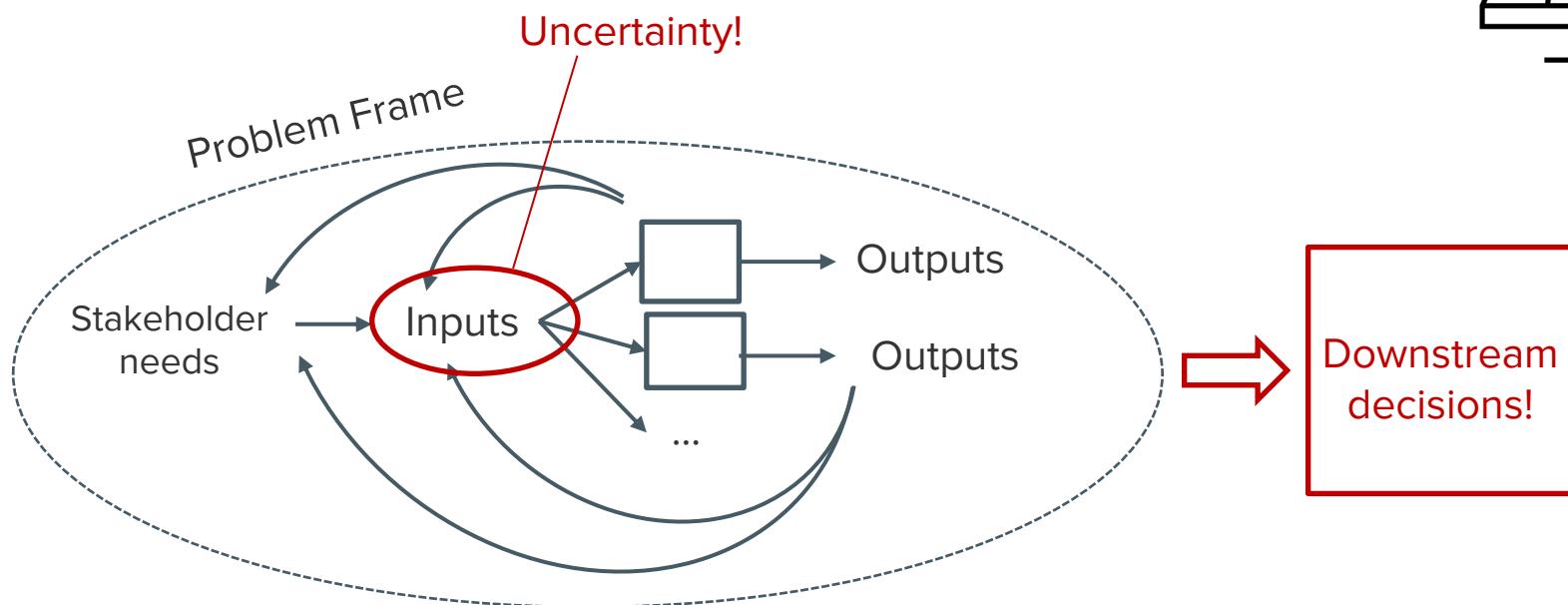
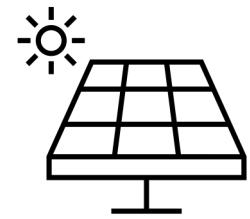
I work here





I work here





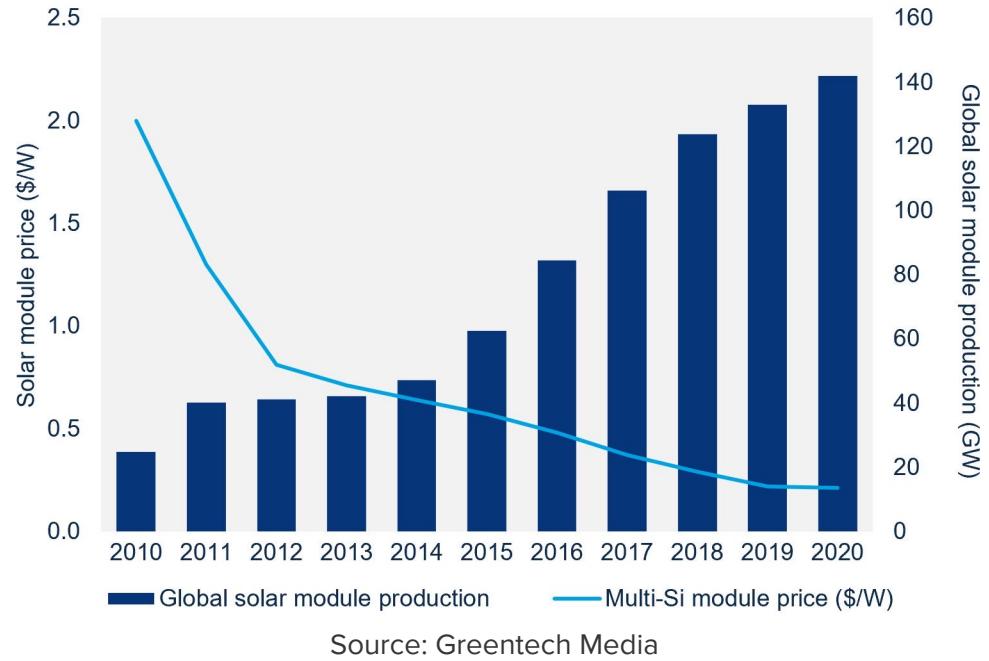
Most of the growth in U.S. solar photovoltaic (PV) sector is expected to come from utility-scale projects



Feldman, D., Zwerling, M., and Margolis, R., 2019, Q2/Q3 2019 Solar Industry Update, *National Renewable Energy Laboratory*.

Image Credit: Unsplash

Solar PV technology costs have decreased significantly in the last decade

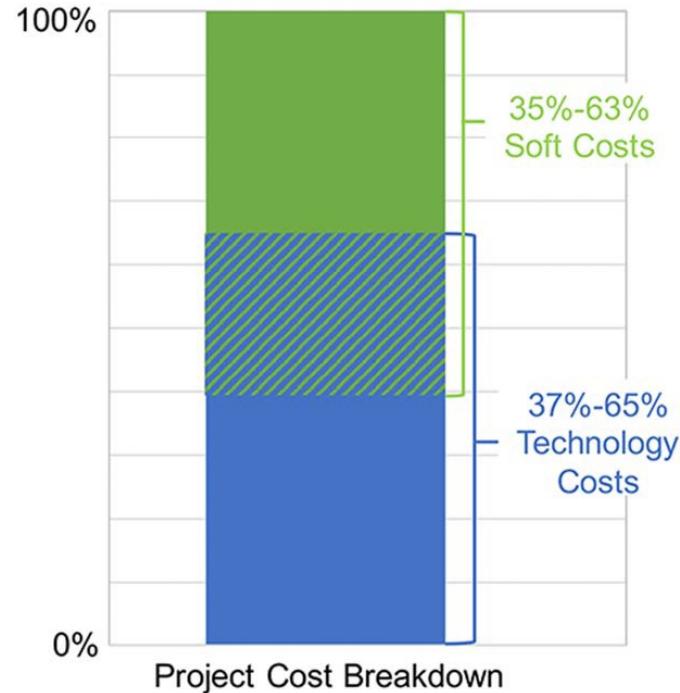


Yet solar professionals say most of their implementation barriers are "**financial in nature**"

Soft Costs are a significant barrier to implementing solar projects of all sizes

Soft costs: the non-technology costs of installing a solar project, such as customer acquisition, permitting, etc.

(Beck and Rai, 2020)



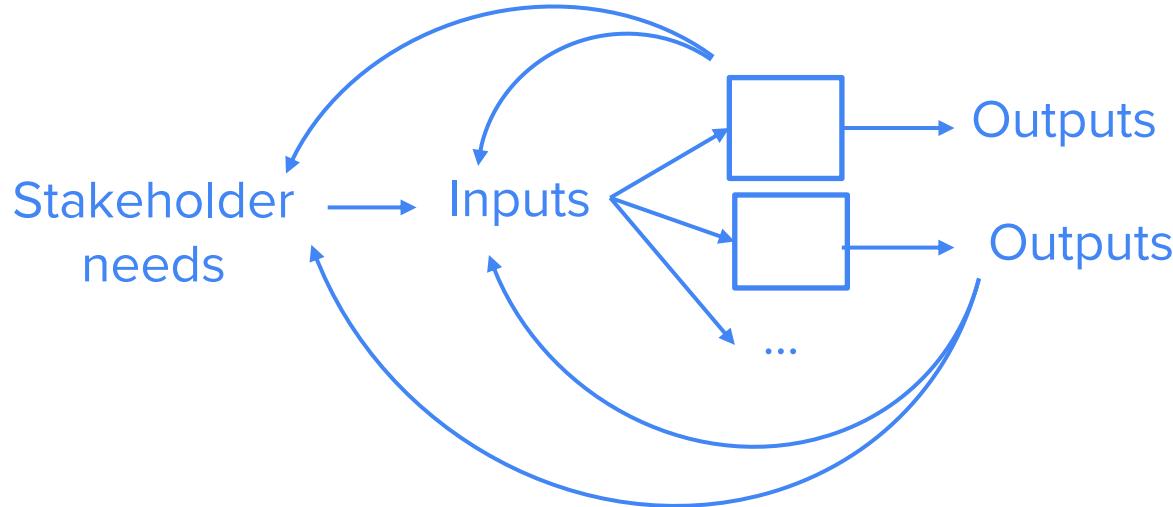
Source: National Renewable Energy Lab

Can we build a more effective cost model to capture soft costs?

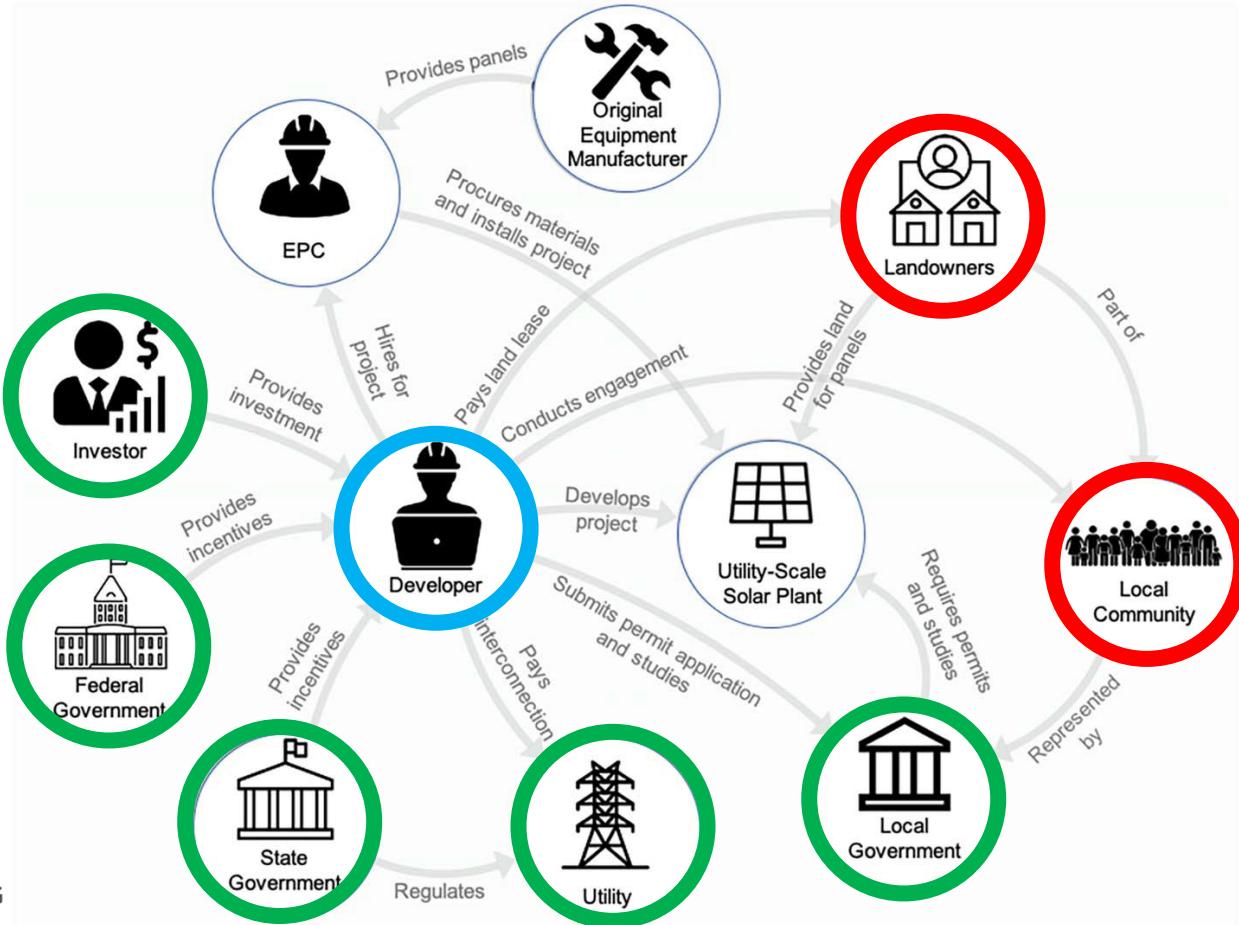
Instead of:



Create this:



Start with the Stakeholders



Model Output: Levelized Cost of Energy (LCOE)

$$LCOE = \frac{C_0 + \sum_{n=1}^N \frac{C_n}{(1 + d_m)^n}}{\sum_{n=1}^N \frac{Q_n}{(1 + d_r)^n}}$$

Total project costs

C_0 = Initial investment

C_n = Annual project costs

d_m = Nominal discount rate

N = Project lifetime

Total energy generated

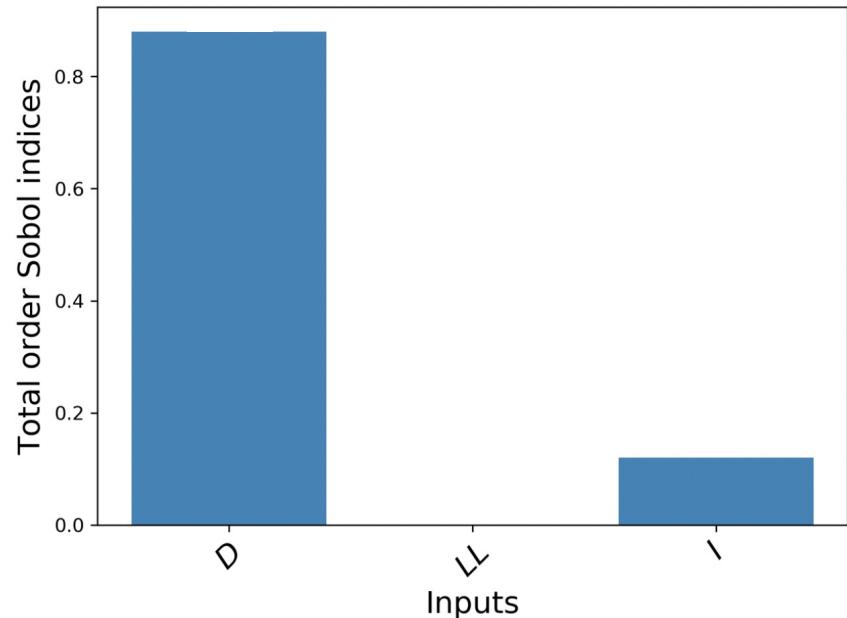
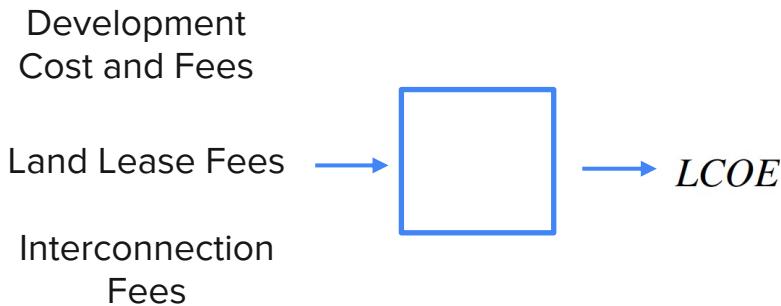
Q_n = Annual power generated

d_r = Real discount rate

Quantifying the influence of soft cost groups using Total-Order Sobol' indices

$$S_{Ti} = \frac{E(v(Y|X_{-i}))}{v_y}$$

(Saltelli et al., 2004)



Net Capacity Factor

Generation Equipment Cost

Development Cost and Fees

Interconnection Cost

Land Lease Cost

Balance of Plant Cost

Fixed Operations and Maintenance Costs

Project Degradation

Debt Parameters

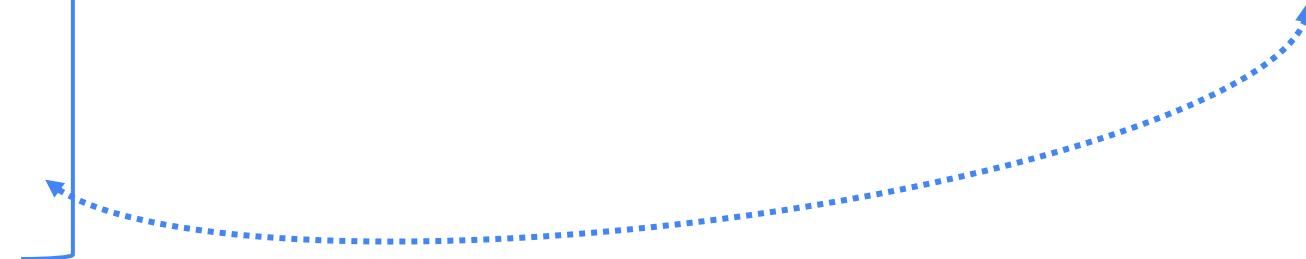
Real Discount Rate

Total project costs

Total energy generated

$$\frac{C_0 + \sum_{n=1}^N \frac{C_n}{(1+d_m)^n}}{\sum_{n=1}^N \frac{Q_n}{(1+d_r)^n}}$$

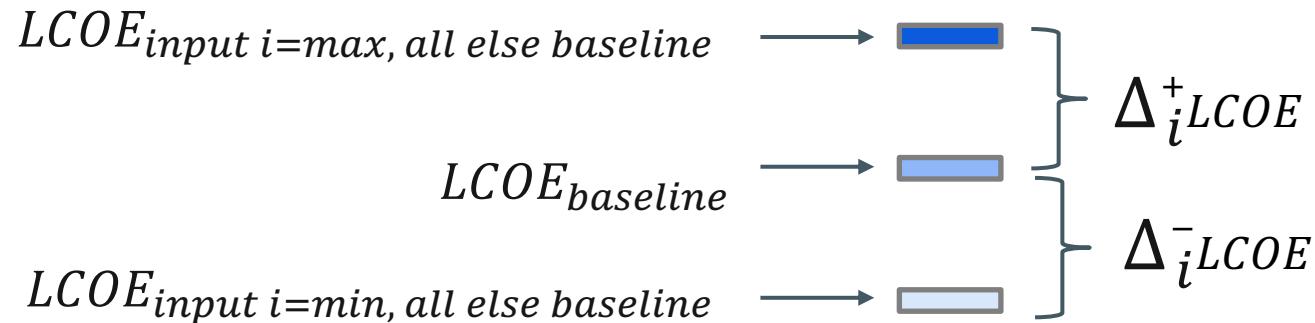
$LCOE$



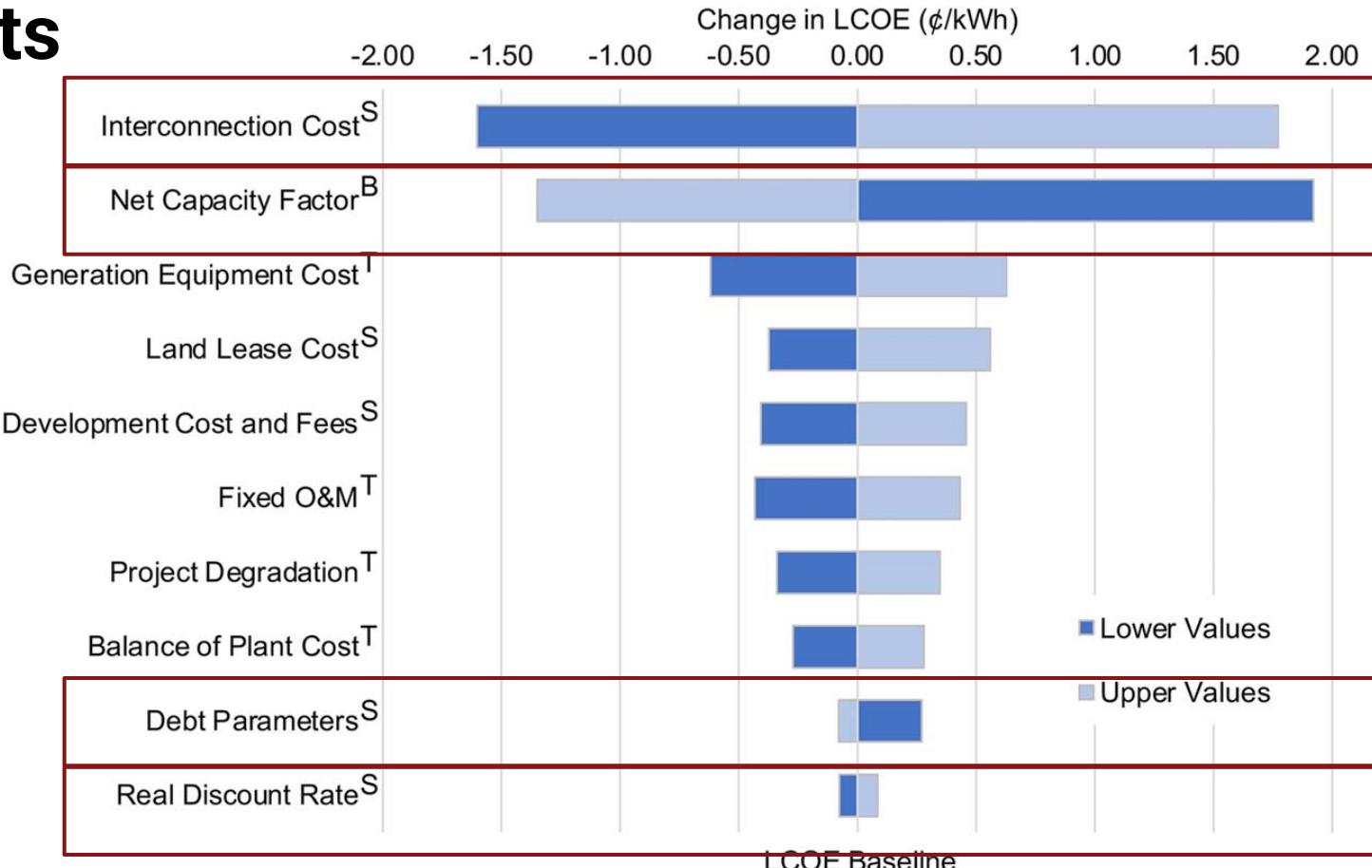
Quantifying the influence of each input using sensitivity analysis

$$\Delta_i^+ LCOE = f(x_i + \Delta_i^+ x, x_{\sim i}^0) - f(x^0)$$

$$\Delta_i^- LCOE = f(x^0) - f(x_i + \Delta_i^- x, x_{\sim i}^0)$$

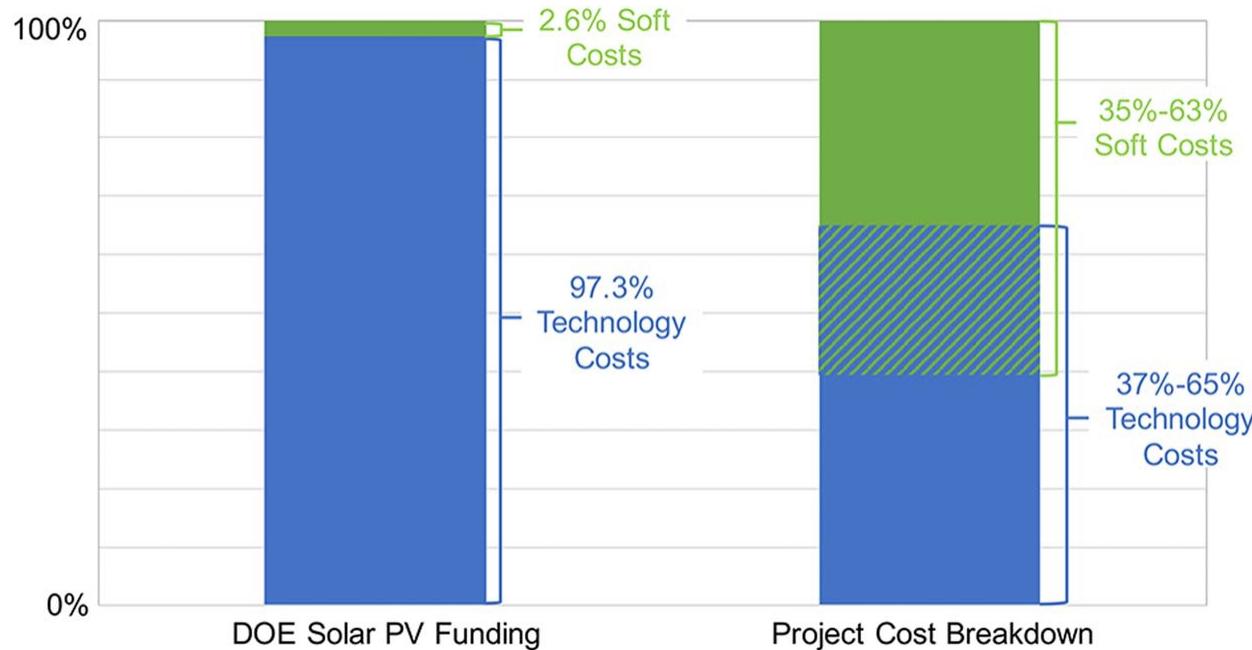


Results



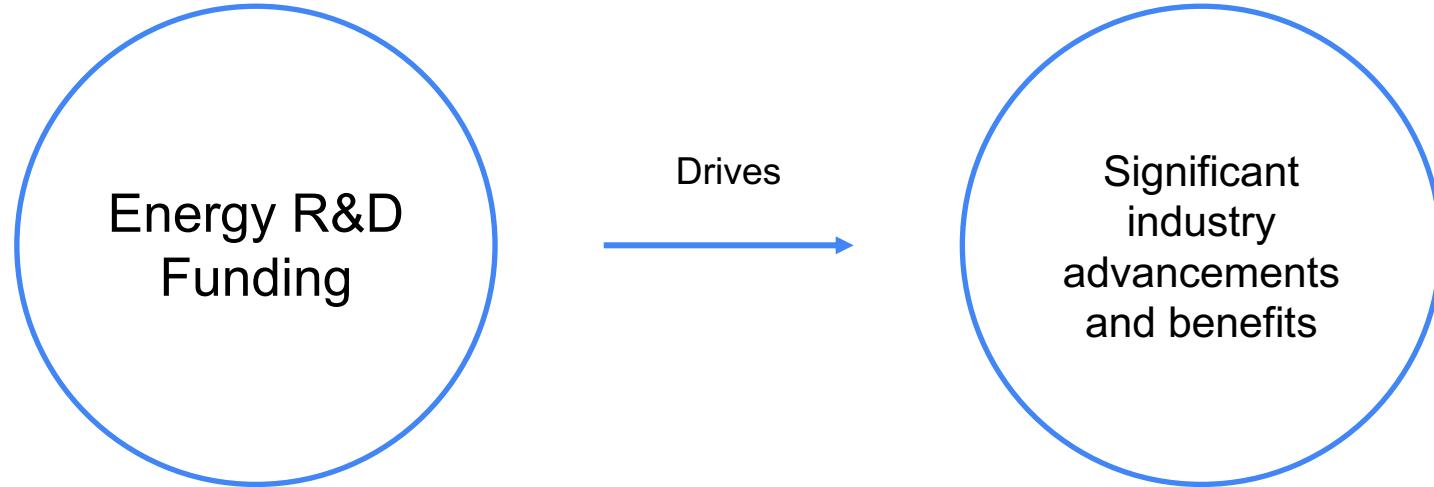
So, why does this matter?

Funding patterns for solar soft costs are majorly different than project costs



Source: Congressional Budgets, 2020

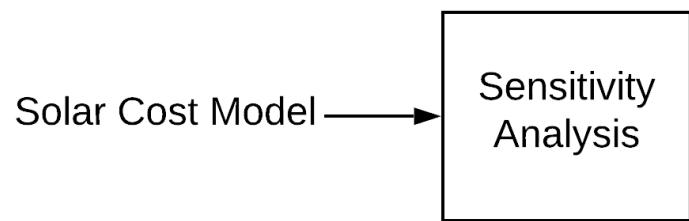
Source: NREL

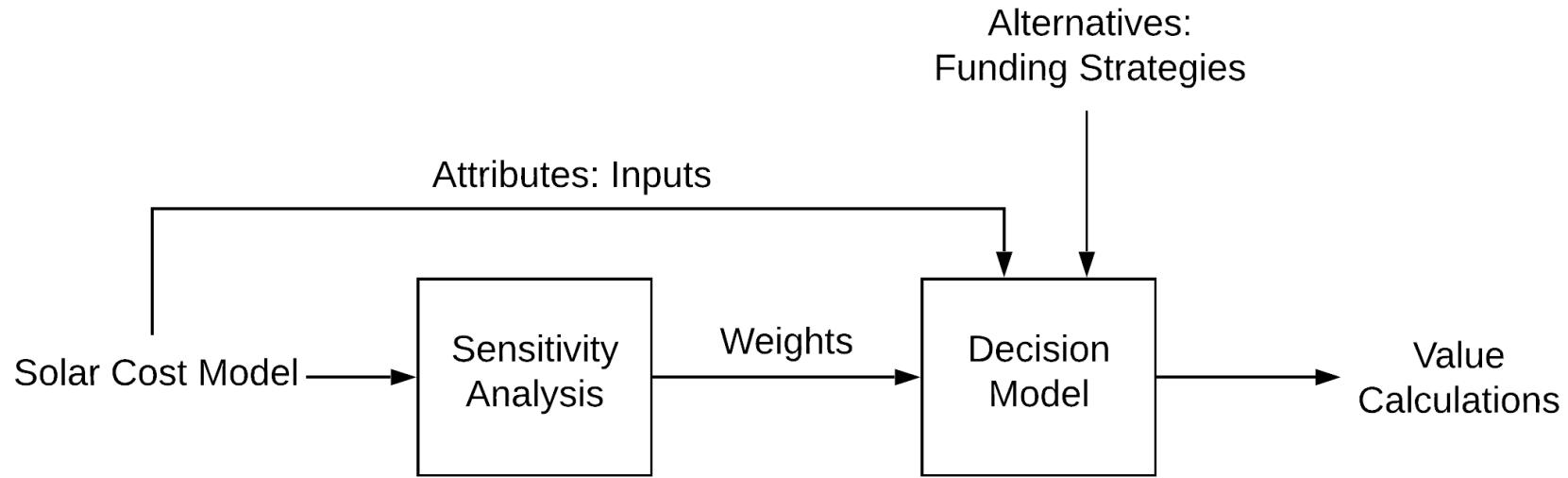


What drives these funding decisions?

(Clearly not industry trends)

(National Research Council, 2001)





Multi-Attribute Value Function

$$V_a = \sum_{i=1}^I w_i r_{ai}$$

V_a = Value of alternative a

w_i = weight of attribute i

r_{ai} = score for alternative a and attribute i

I = total number of attributes

Subject to the following condition:

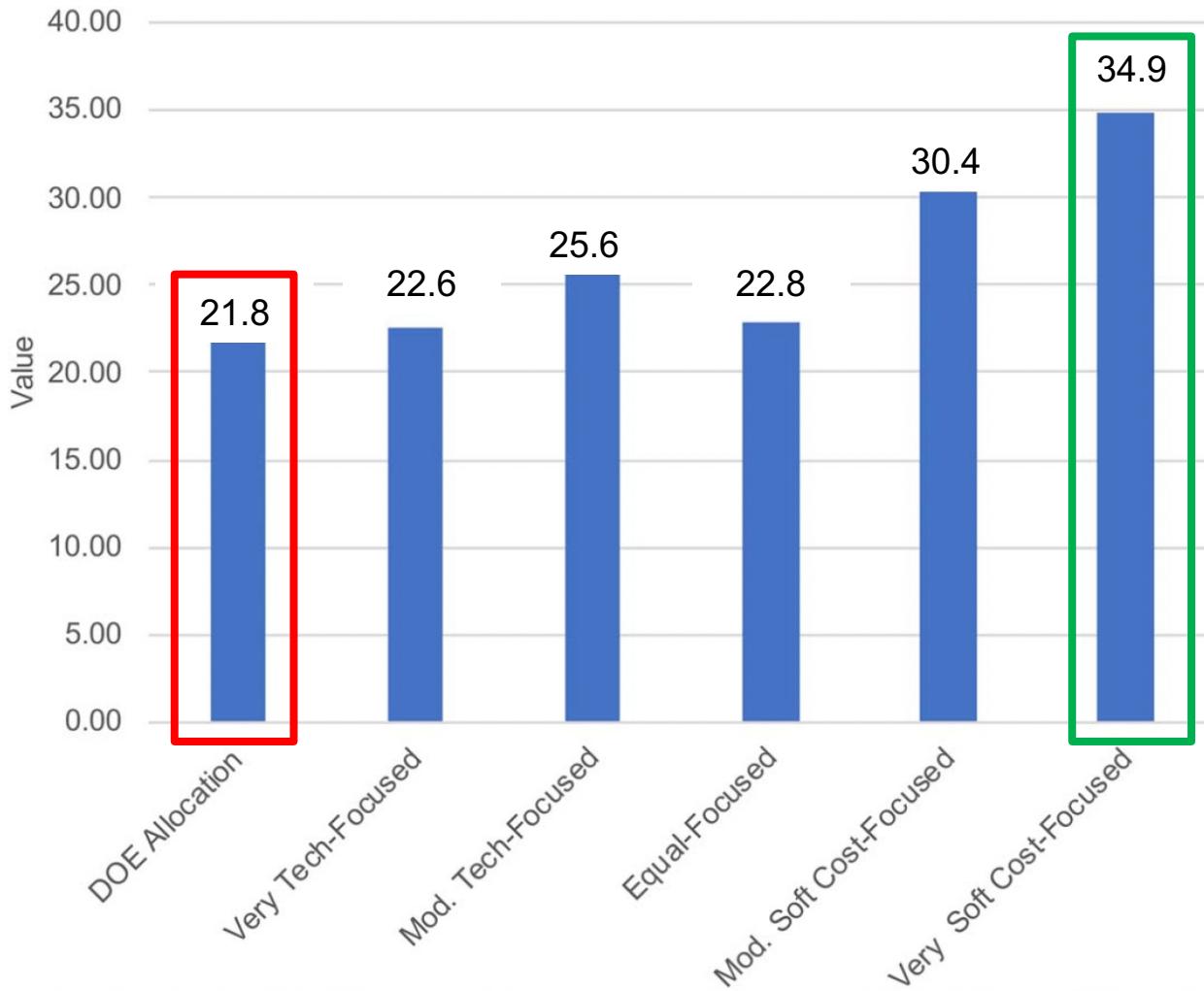
$$\sum_{i=1}^I w_i = 1$$

Inputs = Attributes

	Real discount rate	Generation equipment cost	Balance of plant cost	Interconnection cost	Development cost	Debt parameters	Fixed O&M	Land lease cost	Project degradation	Net capacity factor
Classification ->	Soft	Tech	Tech	Soft	Soft	Soft	Tech	Soft	Both	Tech
Weight -> Weights	0.013	0.102	0.045	0.274	0.071	0.028	0.070	0.076	0.266	0.056
Alternatives										
DOE allocation	\$1.0	\$100.0	\$50.0	\$2.0	\$2.0	\$2.0	\$30.0	\$1.0	\$20.0	\$20.0
Very technology-focused	\$1.0	\$70.0	\$40.0	\$1.0	\$1.0	\$1.0	\$41.0	\$1.0	\$30.0	\$42.0
Moderately technology-focused	\$10.0	\$50.0	\$20.0	\$20.0	\$10.0	\$10.0	\$35.0	\$10.0	\$30.0	\$33.0
Equal-focused	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8	\$22.8
Moderately soft cost-focused	\$21.0	\$15.0	\$8.0	\$50.0	\$38.0	\$20.0	\$8.0	\$30.0	\$30.0	\$8.0
Very soft cost-focused	\$15.0	\$1.0	\$1.0	\$70.0	\$55.0	\$15.0	\$1.0	\$38.0	\$30.0	\$2.0

Funding strategy = Alternatives

All dollar values are in \$M



Limitations

- Proprietary nature of solar industry -> Limited data
- Focus is on utility scale -> what about other scales?
- Narrow boundary conditions
- Did not consider private-sector funding
- Deterministic decision model

Key Learnings

Soft costs are **intertwined** with technology costs and influence LCOE in different ways

Start with stakeholders



Elevate stakeholder voices in qualitative models

Input cost uncertainties can help us **understand the problem context** and how we can **improve challenges** within that context

Open Questions

- Data inputs inherently biased: **where are the data from unsuccessful projects?**
- The sunniest places and the grid-connected places get the prioritized projects: **how to model cost to communities?**
- Funding decisions are complicated and full of politics: **how realistic is this decision model?**
- The decision model alternatives were purely hypothetical: **how to validate these decisions?**

Thank you!

syalsm@stanford.edu
www.sitamsyal.com

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Dr. Margot Gerritsen
Dr. Sheri Sheppard
Dr. Erin MacDonald
Zach del Rosario



All icons from the Noun Project

Check out the papers I referenced :

- Syal, S. M., Eggerman, K., & Gerritsen, M., 2021, "True Decommissioning: Removing Internal Combustion Engine Light-Duty Vehicles Permanently, Quickly, and Equitably," *engrXiv*, <https://doi.org/10.31224/osf.io/n2rjs>.
- Syal, S. M. & MacDonald, E. F., 2020, "Quantifying the Importance of Solar Soft costs: A New Method to Apply Sensitivity Analysis to a Value Function," *Journal of Mechanical Design*, 142(12), pp. 121405.
- Syal, S. M. & MacDonald, E. F., 2020, "Quantifying the Uncertainty of Solar Photovoltaic Soft Costs in the "Cost of Renewable Energy Spreadsheet Tool" (CREST) Model," *Proceedings of the Design Society: DESIGN 2020 Conference*, 1, pp. 2157-2166.