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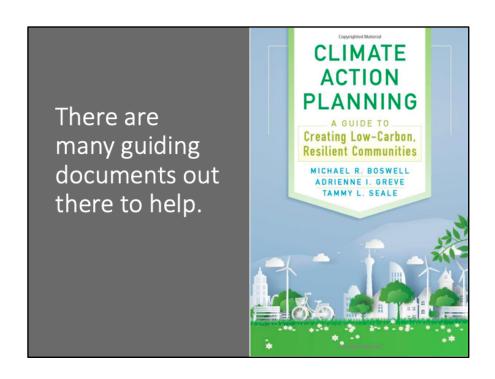
Dr. Tyler Quiring, University of Maine

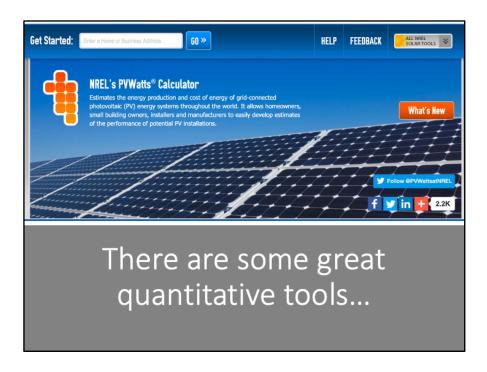




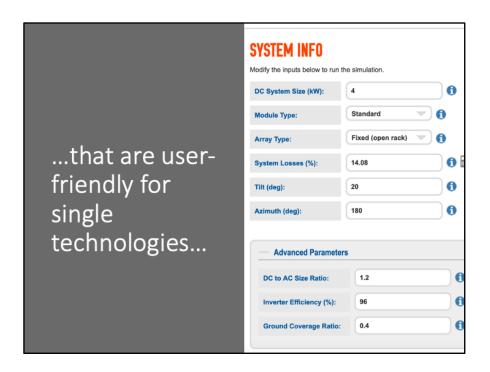




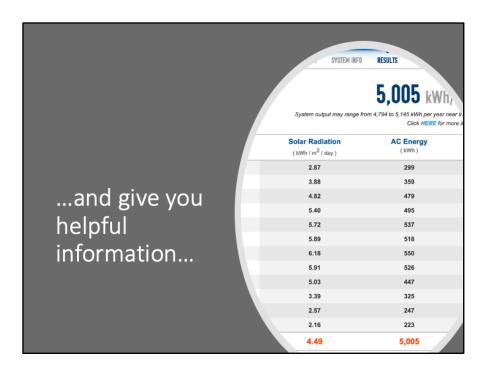




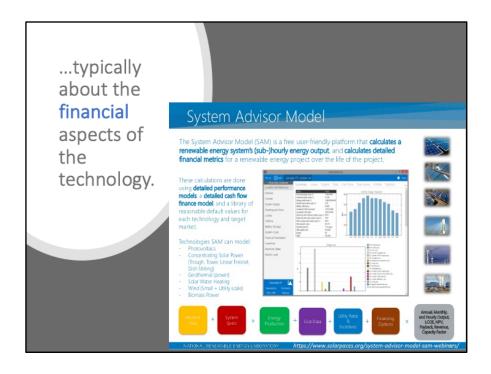
Like the National Renewable Energy Laboratory's PVWatts, which allows you to type in an address, and...



Enter some pretty simple parameters to find out



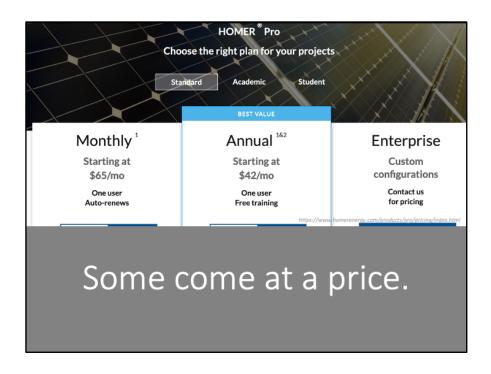
The annual electricity production and monetary savings from a solar photovoltaic array



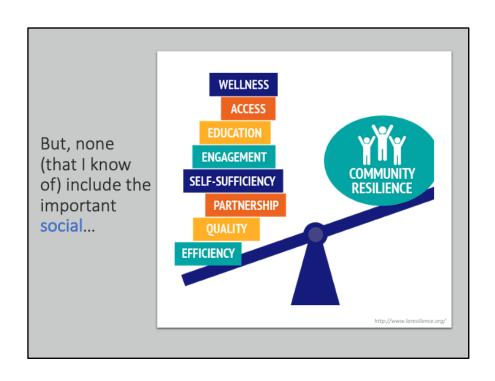
The System Advisor Model, or SAM, also developed by NREL, allows project-specific modeling for solar, wind, and other renewable energy projects.

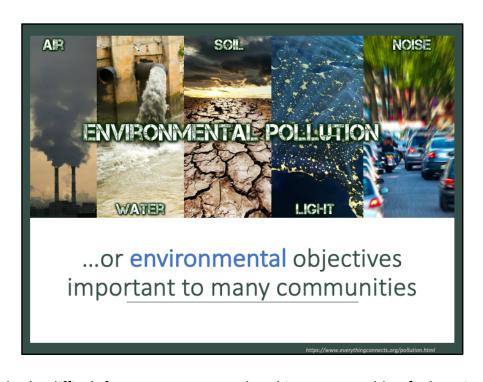


So does Homer, but I believe Homer may allow for more integration of different technologies than SAM



Unfortunately, you typically have to pay for Homer – although it looks like there is a Beta-testing version currently available for free.





It can also be difficult for someone not used to this energy world to find, navigate and use the many tools that are out there.

### Research Questions









How are local community groups making decisions about energy?

What knowledge do they have and are they seeking?

What outcomes are they trying to achieve?

Is there a role for participatory multicriteria decision analysis?

# What is Participatory Multi-Criteria Decision Analysis (MCDA)?

### **MODEL**

- Quantitative representation of complex decision
- Multiple decision criteria (things you care about)
- Multiple decision alternatives (choices you are considering)
- Transparent way to rank choices based on DATA and PREFERENCES without needing to apply \$ values
- Many possible methods
- Limited practical use in energy decisionmaking

### **PROCESS**

- People identify decision criteria & alternatives
- People identify relative preferences for decision criteria
- People use the model individually AND as a group
- Discussion identifies shared or negotiated group preferences
- Individual and group results are compared/discussed
- People participate in iterative design of model & process

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Participatory MCDA refers to both a model AND a stakeholder-engaged process. The model is a quantitative representation of a complex decision with multiple decision criteria and alternatives and can take many different forms depending on the method selected. Ideally it is a TRANSPARENT way to rank choices based on data AND user preferences, without the need to apply dollar values. The PROCESS has to do with the people – engaged in identifying criteria and alternatives, using the model in individual AND group settings, and helping with iterative design of the model and process.

### Multi-Criteria Decision Analysis (MCDA)

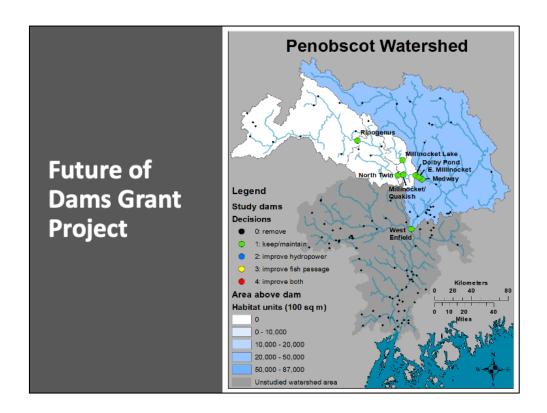
Umbrella term for a suite of mathematical **models** and stakeholder-engagement **processes** that **quantitatively** consider multiple decision **criteria** and **alternatives** without requiring monetization

#### **FIVE MAIN STEPS**

- 1. Identify Decision ALTERNATIVES & CRITERIA
- 2. Collect DATA on Decision Alternatives & Criteria (Decision MATRIX)
- 3. Make data comparable (NORMALIZATION)
- 4. Elicit PREFERENCES from stakeholders about Decision Criteria (and sometimes Alternatives)
- Mathematically combine Data and Preferences to produce a RANKING and/or SCORF

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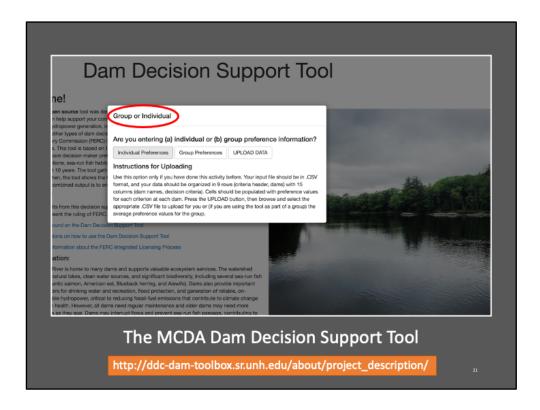
MCDA has 5 main steps: identify alternatives and criteria, collect data on them to create a decision matrix, normalize data to be comparable, elicit decision-maker preferences, and mathematically combine data and preferences to produce a ranking or score.



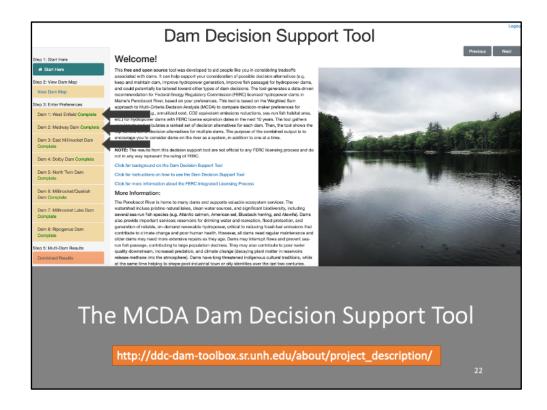
We used this approach during a 4-yr multi-state, multi-disciplinary collaboration between researchers and stakeholders in Maine, New Hampshire, and Rhode Island. Our little piece of this giant research collaborative focused on using participatory MCDA with actual decision-makers and stakeholders in decisions about hydropower dams coming up for relicensing along the Penobscot River in Maine.

Decision Criteria	Keep and Maintain Dam	Improve Fish Passage	Improve Hydropower Capacity	Improv Hydro A Fish Pass
Sea-run fish habitat area (100 square m)	24,200	55,480	24,200	55,
River recreation area (square km)	12	12	12	
Reservoir storage (100,000 acre feet)	0	0	0	
Annuitized project costs (\$2018 chousands/yr)	949	1,067	949	1,
Breach Damage Potential	2	2	2	
Number of Properties Impacted	0	0	0	
Annual Electricity Generation (GWh/yr)*	73	73	73	
CO2 Emissions Reduction (kilotonne/yr)	10	10	10	

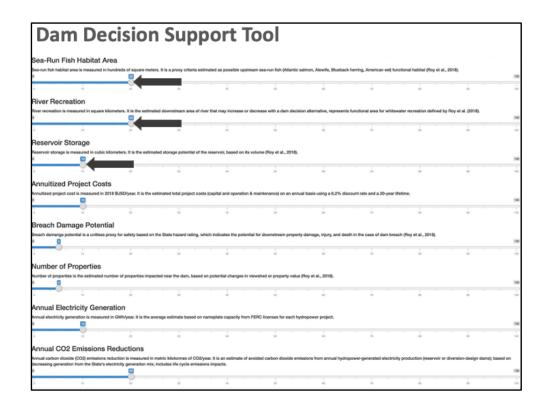
We conducted a series of interviews, surveys, and group discussions during the first 2 years of the project that, among other things, helped us identify the set of decision alternatives (partially shown along the top – read) and decision criteria (partially shown (down the side – read) and associated quantitative data (shown within the cells) for each of the 8 dams we were focusing on. We used these data as the basis to create a MCDA Dam Decision Support Tool.



A free online tool that allows users to enter preferences related to dam decisions as a group activity or as an individual.



Users step through these individual dam pages entering their own preferences for different decision criteria from the decision matrix shown previously.



On each page, they move slider bars to indicate their relative preference for things like fish habitat area versus river recreation, reservoir storage, etc. All preferences have to add to 100%, so the user is forced to make tradeoffs in their preference points for different criteria.

# Underlying calculations (weighted sum)

### West Enfield Dam FERC No. P-2600 : RAW DECISION MATRIX

Decision Criteria	Keep and Maintain Dam	Improve Fish Passage	Improve Hydropower Capacity	Improve Hydro AND Fish Passage	Remove Dam
Sea-run fish habitat area (100 square m)	24,200	55,480	24,200	55,480	86,750
River recreation area (square km)	12	12	12	12	12-26
Reservoir storage (100,000 acre feet)	0	0	0	0	0
Annuitized project costs (\$2018 thousands/yr)	949	1,067	949	1,067	179
Breach Damage Potential	2	2	2	2	0
Number of Properties Impacted	0	0	0	0	5
Annual Electricity Generation (GWh/yr)*	73	73	73	73	0
CO2 Emissions Reduction (kilotonne/yr)	10	10	10	10	0

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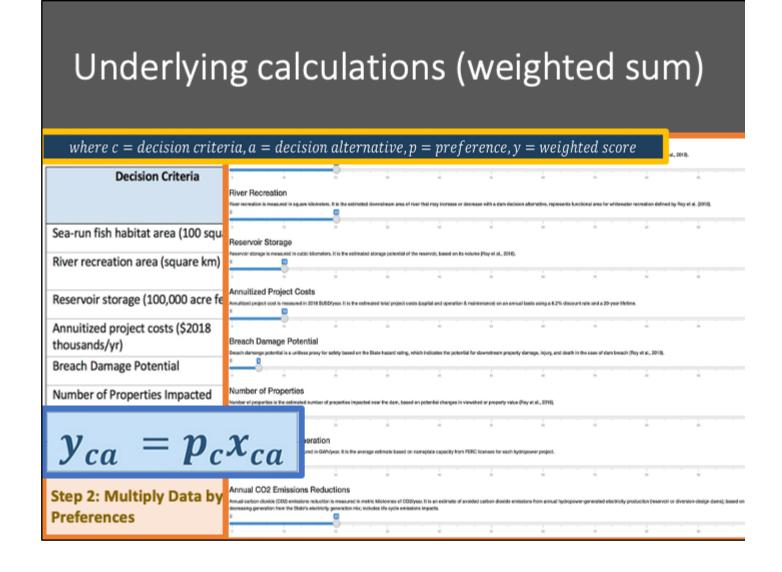
While the user is simply moving slider bars to show their own preferences, behind the scenes, the model is putting these decision matrices full of data to work.

# Underlying calculations (weighted sum)

### West Enfield Dam FERC No. P-2600: RAW DECISION MATRIX

Decision Criteria	Maintain Fish Passage Hydro		Improve Hydropower Capacity	Improve Hydro AND Fish Passage	Remove Dam		
Sea-run fish habitat area (100 square m)	0	0.5	0	0.5	1		
River recreation area (square km)	0	0	0	0	1		
Reservoir storage (100,000 acre feet)	1	0	0	0	0		
Annuitized project costs (\$2018 thousands/yr)	0.1	0	0.1	0	1		
Breach Damage Potential	0	0	0	0	1		
Number of Properties Impacted	1	1	1	1	0		
Annual Electricity Generation (GWh/yr)*	1	1	1	1 1			
CO2 Emissions Reduction (kilotonne/yr)	1	1	$x = \frac{x}{x_n}$	$\frac{x_i - x_{min}}{-x_{min}}$ , wh	here x <sub>max</sub> is prej		
	Step 1	: Normalizat	ion $x = 1 -$	$x_i - x_{min}$			

First, the model normalizes the decision matrix to essentially remove the unit values because you can't add square meters to acre-feet to dollars, for example. It normalizes the data using these equations (click), which essentially boil down to the ratio between the difference between each value in a row and the ideal value in that row (i.e., the greatest value for fish habitat, the smallest value for project cost) and the difference between the maximum and minimum values in that row.

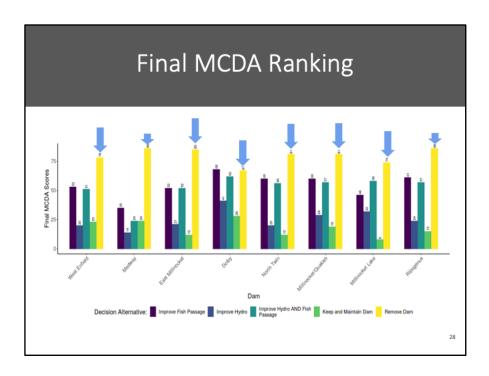


Next, the model takes those preferences the user entered using the slider bars and multiplies them by the normalized data (click).

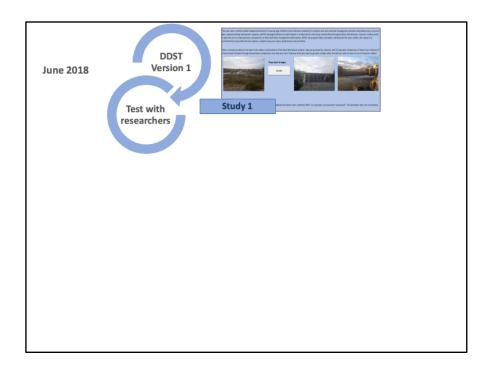
# Underlying calculations (weighted sum)

where $c = decision\ criteria$ , $a = decision\ alternative$ , $p = preference$ , $y = weighted\ score$								
Decision Criteria	Keep and Maintain Dam	Improve Fish Passage	Improve Hydropower Capacity	Improve Hydro AND Fish Passage	Remove Dan			
Sea-run fish habitat area (100 square m)	0	10	0	10	2			
River recreation area (square km)	0	0	0	0	2			
Reservoir storage (100,000 acre feet)	10	0	0	0				
Annuitized project costs (\$2018 thousands/yr)	1.3	0	$y_{ca}$	0	1			
Breach Damage Potential	0	0	Jea 0	0				
	5	5	5	5				
$ y_{ca}  = p_c x_{ca}$	10	10	$Y_{\alpha} =$	$\sum y_{ca}$				
	20	20	- a					
Step 3: Aggregation	46	45	36	45	5			

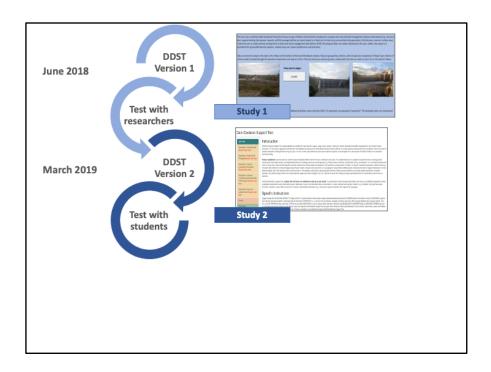
Finally, the model adds up all of the products of normalized data and preferences in each column and finds a total score for each decision alternative (shown here on the bottom in blue). From these results, the user can see which decision alternative received the highest score based on their own preferences combined with the scientific data associated with the decision alternatives and criteria. In this example, the winner is remove dam with the highest score of 55, while improve hydropower capacity receives the lowest score of 36. Another user might see that improve hydropower capacity has the highest score, especially if they specified a high preference weight for annual electricity generation.



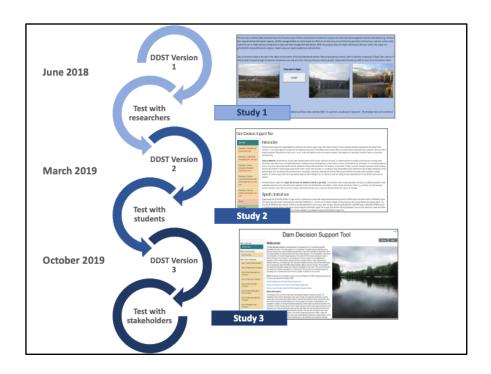
Although these calculations are all going on in the background, the user does not have to wade through all of these calculations and instead instantly sees a series of graphs and tables that help them understand how the model arrived at this ranking of decision alternatives based on the preferences they put in the model and the underlying scientific data. This graph of example results is for a hypothetical user that entered EQUAL for all 14 decision criteria in the model. The arrows on this slide are pointing to the highest ranked decision alternatives for each of the 8 dams. In this hypothetical example, the equal preferences result in the decision alternatives "Remove dam" or "improve fish passage" being the most preferred option for each dam.



We tested and revised and tested again this model through a series of 3 participatory workshops. The first one was in June 2018. We had developed an Excel-based model that we tested with other researchers that worked on the Future of Dams grant with us but in other research areas.



We used the feedback from that workshop to redesign the model as a web-based model that was much more user friendly. We tested that version out with students in one of my energy classes at UMaine in March 2019.



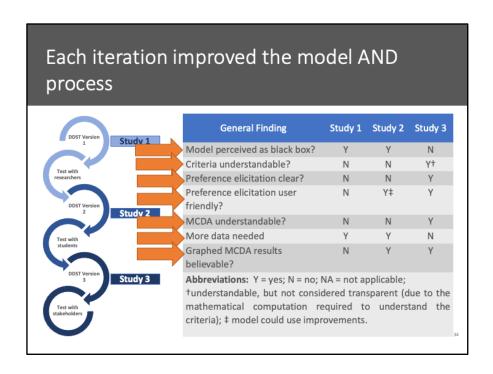
We then used the feedback and observations from that workshop to further improve the model and finally held a stakeholder workshop in October 2019 with people from state and federal agencies, citizens of a tribal nation, and members of non-profit organizations and the private sector, all of whom were actively engaged in decisions about Penobscot River dams, especially one of the dams that had just started it's 5-year relicensing process 2 months before. As you can see, this was an iterative process, which began well before the first workshop when we interviewed stakeholders about which decision criteria and alternatives were important to them.

	Full-Day Agenda (Study 3)	
8:30-9:00 9:00 -9:30 9:30-10:00 10:00-10:15 10:15-10:45 10:45-12:00 12:00-12:30 12:30-1:00 1:00-1:20 1:20-1:30 1:30-3:30 3:30-4:00 4:00-4:30	Breakfast & mingle Introductions Group introduction activity Coffee Break Introduction to MCDA Individual Preference Elicitation Activity Lunch Reflection on morning activities Instructions for Group Negotiation Process Snacks Group Negotiation Process Reflection on Group Negotiation Process Post-Survey	
4:30-5:30	Optional Social Hour	32

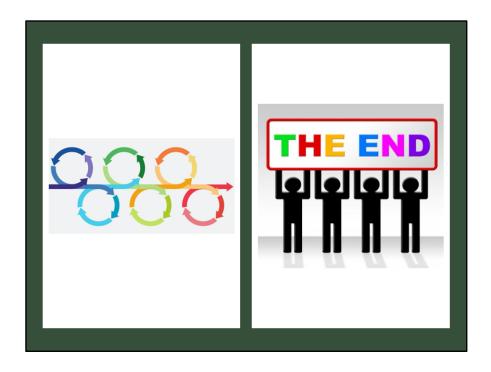
This work did not just focus on model-building, however. It also focused on developing, implementing, and refining a participatory process that enabled the user to learn about the model (click), interact with the model as an individual with researcher support and guidance (click), and then use the model as a guiding tool in a group negotiation process (click) that directed the group toward consensus (if possible) or agreement (if consensus was not possible) on a set of group preferences for decision criteria.

Daı	m De	cisior	Supp	ort T	ool					
1	ish Habitat An									
Sea-Run F Sea-run fish habit ii			rs. It is a proxy criteria est	timated as possible upstre	am sea-run fish (Atlantic	salmon, Alewife, Bluebaci	k herring, American eel) fi	unctional habitat (Roy et al.	, 2018).	YES
	10		1 1	1 1	1 1	1 1		1 4	1 1	1 100
River Recr	reation									
River recreation is	s measured in square kill	ometers. It is the estimat	ted downstream area of ri	ver that may increase or d	lecrease with a dam decis	ion alternative, represent	s functional area for white	swater recreation defined by	y Roy et al. (2018).	100
	10	<del></del> -			1 00	1 1	70			100
Reservoir	Storage									
		lometers. It is the estima	ited storage potential of the	he reservoir, based on its	rolume (Ploy et al., 2018).					
					1 1	1 1 1	· 1	1 1	1 1 1	
Annuitized	Project Costs		-	-		-	-			-
			stimated total project cos	ts (capital and operation 8	i maintenance) on an annu	al basis using a 6.2% dis	count rate and a 20-year	lifetime.		
¢										386
Donnah Da	" Detection			-	10		70	**	**	100
	mage Potentia potential is a unitiess pr		the State hazard rating, w	hich indicates the potenti	al for downstream propert	y damage, injury, and dea	oth in the case of dam bro	nach (Roy et al., 2018).		
										386
	10	10	-	*	10		19	**	**	100
	f Properties	mbor of properties impa	that oner the dam, based	on potential changes in v	invested or property value	Story of al., 2018.				
6 B	ties is the esumaneum.	moer or properties impe	oled near the dam, based	on potential charges in v	lewaned or property value	gridy ot ac., 20 rep.				300
:	10	20	20	-	10		70	00	80	100
	ectricity General									
Annual electricity o	generation is measured	in GWh/year, It is the av	erage estimate based on	nameplate capacity from I	FERC licenses for each hy	dropower project.				300
	10	20	in in		100		70		100	100
Annual CC	2 Emissions F	Reductions								
			metric kilotonnes of CO2/ includes life cycle emissi		roided carbon dioxide em	ssions from annual hydro	power-generated electric	city production (reservoir or	diversion-design dams);	based on
										386
0	10	20	30	40	80	60	70	60	90	100

Basically, AFTER everyone completed this slider-bar activity individually, the model automatically averaged the preferences for everyone in the group and set the slider bars for a group negotiation at the average preferences of the individuals as a starting point for the group negotiation. Then, the participants were led through a facilitated discussion of each decision criteria to decide if the slider bar should be moved from this starting point. Although the plan had been to go through this process for all 8 dams, we only ended up having time to finish the group negotiation process for one of the dams, but the group was able to reach agreement, if not consensus, on that dam.



With each iteration, we documented results through the models themselves, preand post-surveys of the participants, and researcher observations. This table comes from a combination of interpretations drawn from all of these activities. The multiple iterations improved participant understanding of the model (click), criteria (click), and MCDA (click). In addition, by the 3<sup>rd</sup> workshop, it seemed like we had finally gotten the data correct (click), and participants believed in the results (click). They also found the preference elicitation clear (click) and the model user-friendly (click).

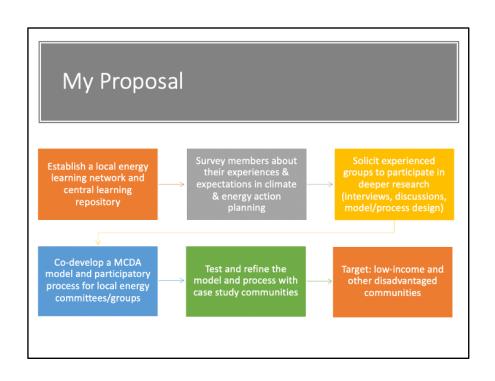


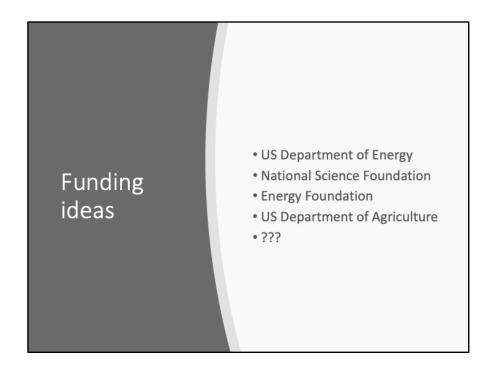
Although we would have loved to have tested the model and process with more groups and continued improving it through more iterations, all things must come to an end, and that particular grant ended this past summer.

Images from: https://projectagency.co.uk/project-governance/do-you-hold-end-of-project-reviews/, https://towardsdatascience.com/iterate-your-r-code-efficiently-3c621998eaea



Going forward, what I would like to do is build on this work with hydropower in New England and apply it to supporting decision-making at the local level about renewable energy, energy efficiency, and other sustainability action. This is a picture of the website for VECAN – the Vermont Energy & Climate Action Network, which is a network of municipal energy committees across the state of Vermont. I would like to tap into the knowledge in this network and also united the knowledge of other energy committees in New England and beyond that have been implementing climate action plans, renewable energy goals, and taking other sustainability action. I would like to unite as many of these groups and committees as possible into kind of an extended version of VECAN and...





I am currently in search of funding for this work. I have identified some potential sources of funding but would welcome any suggestions.



I would like to also acknowledge the funding and support I received for the Future of Dams work.

