Application of epoch-era analysis to the selection of a distributed power generation system

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Adam M. Ross, and Alexander L. Pina
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Apr 4, 2019

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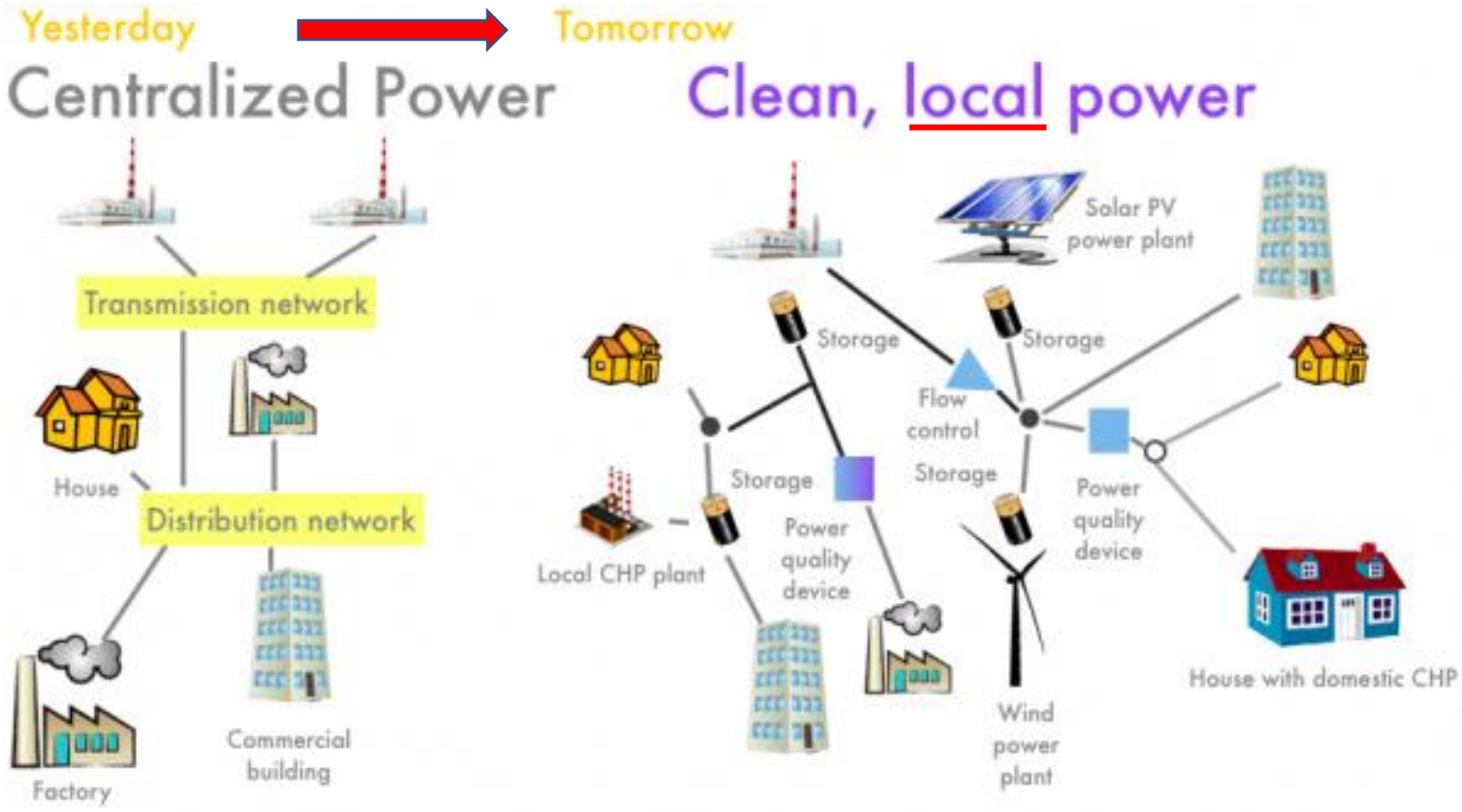
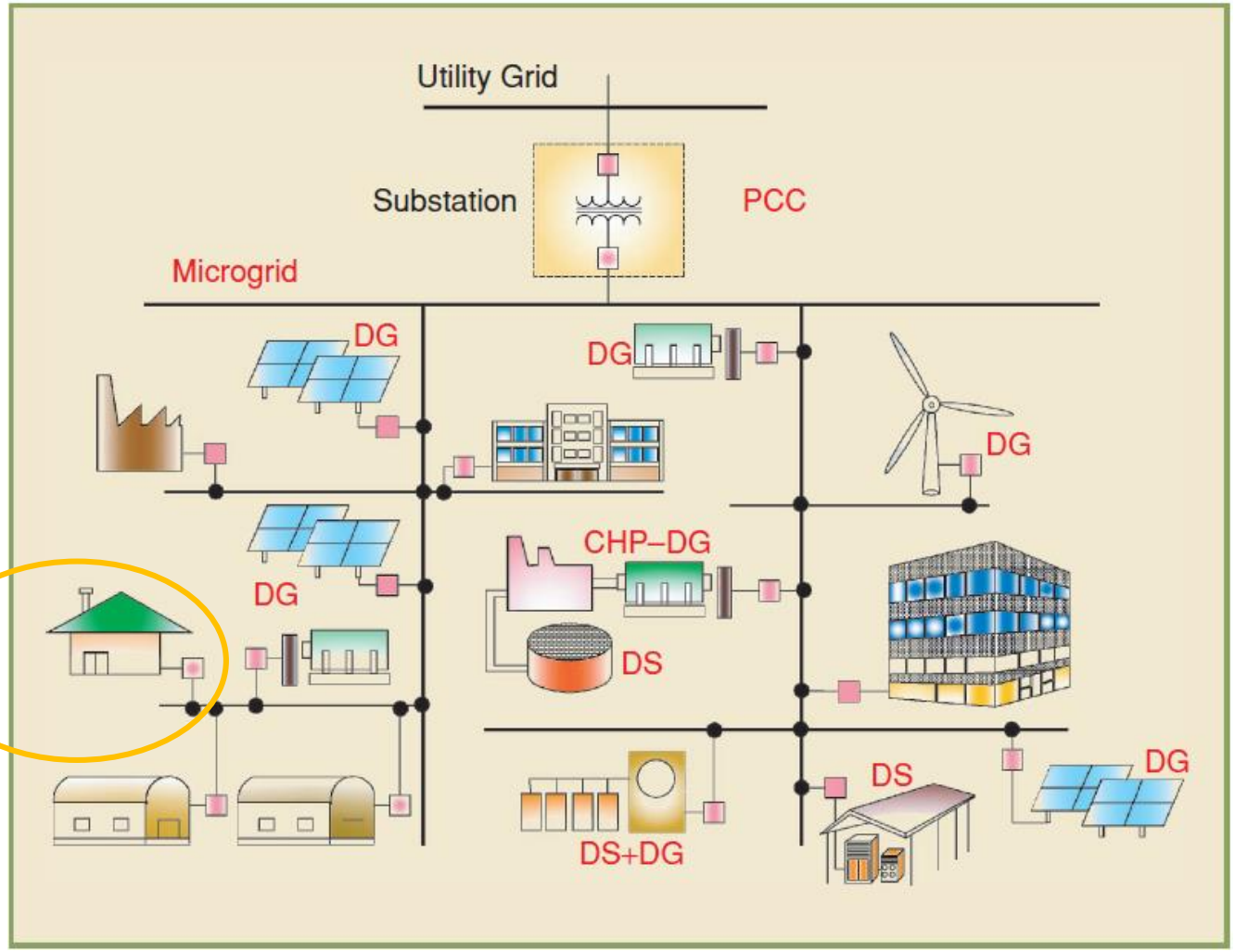
US Power Grid



Distribution is a core idea behind the grid of tomorrow

What is Distributed Generation?

Homeowners will play a supply role in the future



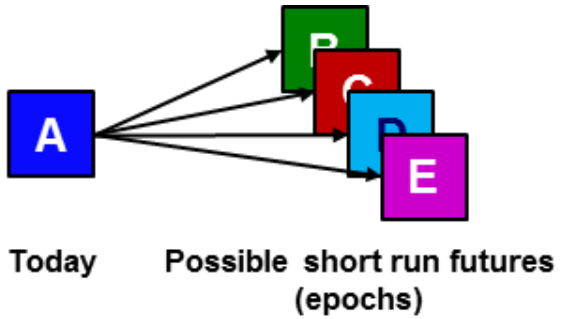
DG: Distributed Generation

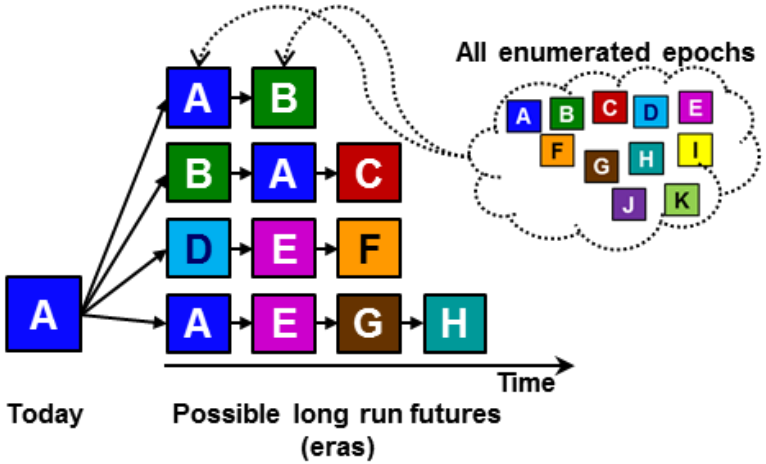
Challenge of Uncertainty

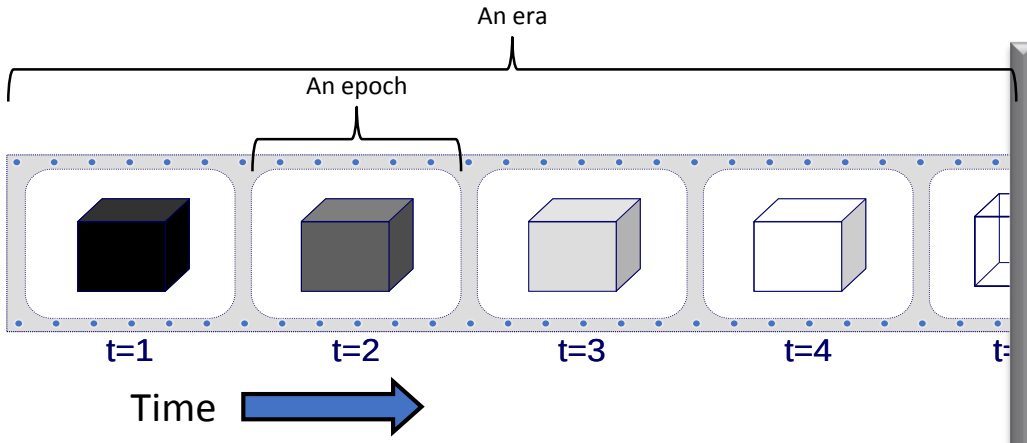
Key challenge for the homeowner

investing in a DG system will be expensive and uncertainties will impact the costs and benefits of this investment

Epoch-Era Analysis (EEA) is an approach that allows for the framing and analysis of the impact of short run (epoch) and long run (era) uncertainties on the value of alternative investments







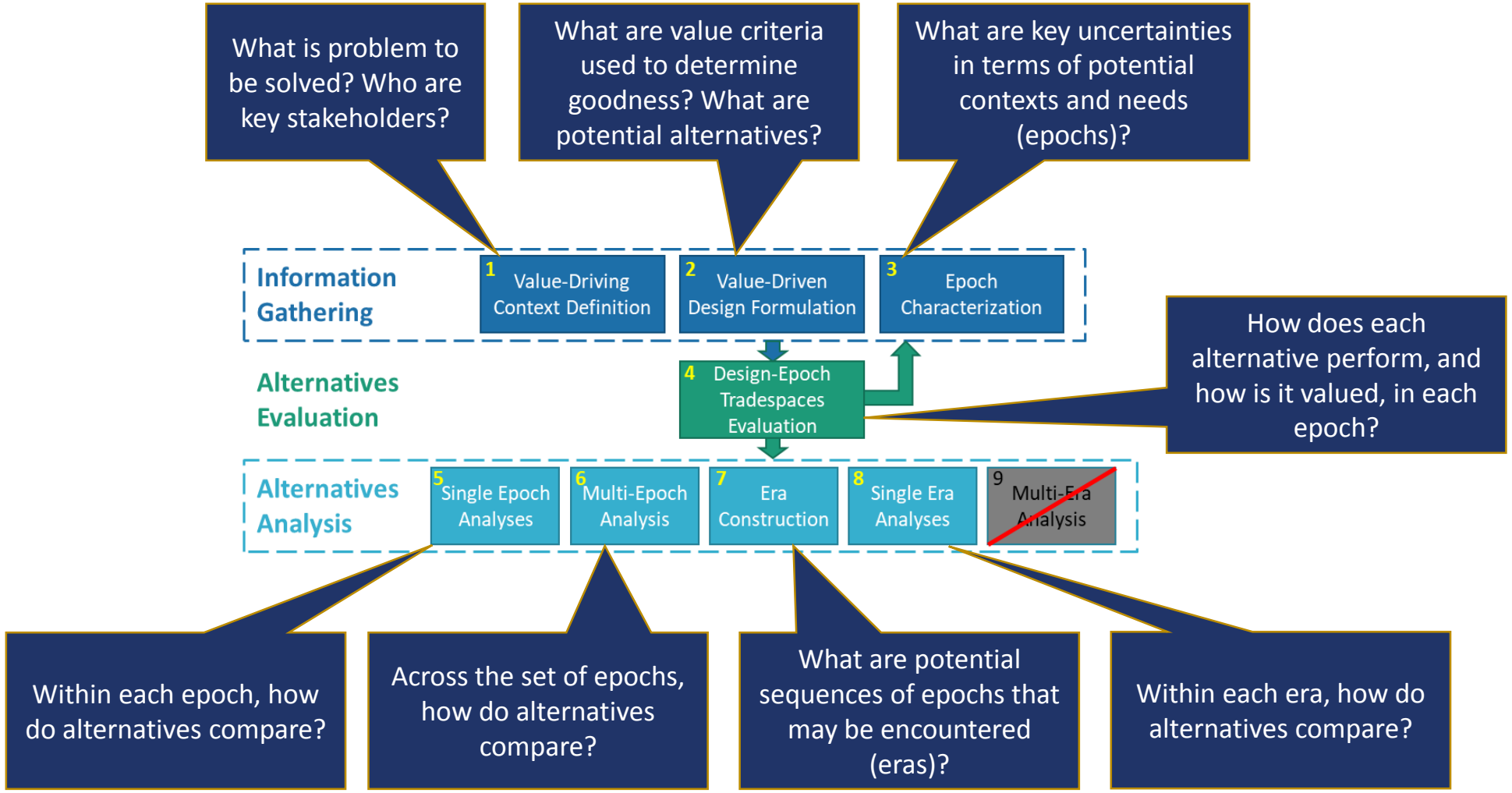
Guiding Research Questions

- Given an Epoch-Era Analysis formulation, which of the distributed generation power system choices available to the southern California homeowner provides the highest value across the greatest number of epochs and in a select number of potential era scenarios?

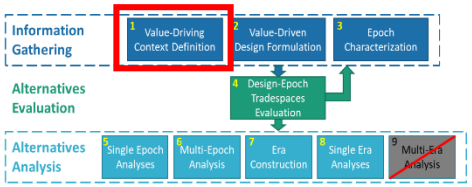
- Using the same Epoch-Era Analysis formulation, how does the highest value distributed generation choice for randomly selected homeowners differ from that of the highest value for the homeowner subset average?

Pina, A.L., *Applying Epoch-Era Analysis for Homeowner Selection of Distributed Generation Power Systems*, Master of Science in Engineering and Management, System Design and Management Program, MIT, June 2014.

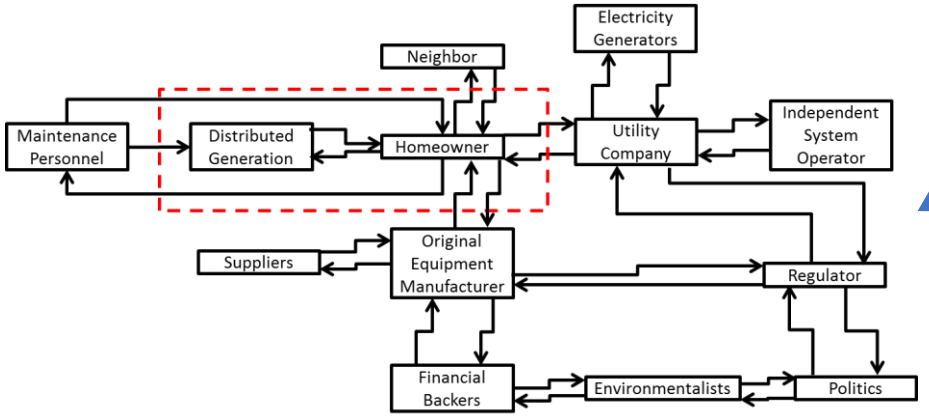
Approach: Responsive Systems Comparison Method (RSC)



Investigating the System Stakeholder Map

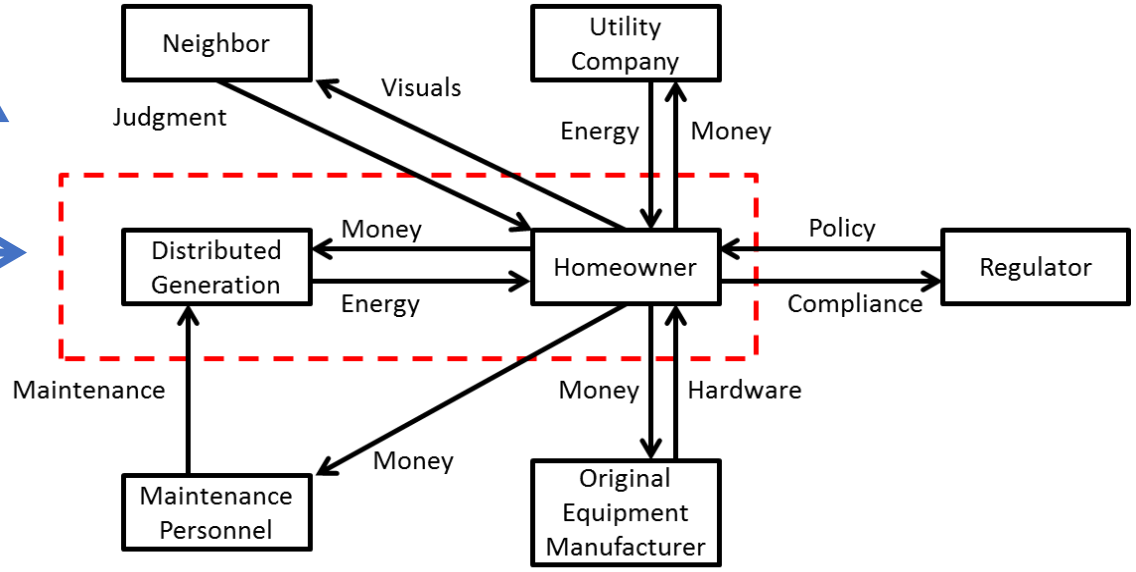


There are many potential stakeholders in the distributed generation system



Complex System Diagram

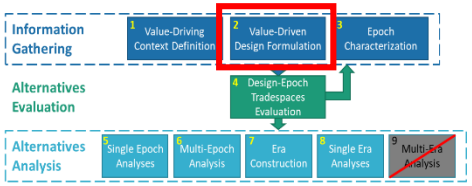
Simplified System Diagram



Simplifying the system diagram allows us to focus on the key relationships.

Chosen focus: the "Homeowner" perspective

Who is the homeowner?



Homeowner (San Jose, CA)		
Description	**Value**	**Units**
Electricity Cost	0.20	$/kWh
Yearly Energy Use	6480	kWh/yr
Daily Energy Use	17.75	kWh/day
DG Percentage	50%	
DG Daily Operation	2	hours
DG Capacity	4.44	kW

- What are they looking for?

Benefit criteria
- Aesthetic Appeal
- Maintenance Frequency
- Product Life
- Availability
- Space Required

Cost criteria
- Maintenance Cost
- Environmental Effect
- Initial Cost
- Operating Cost

Value Modeling

Attributes → SAE/SAU → MAE/MAU

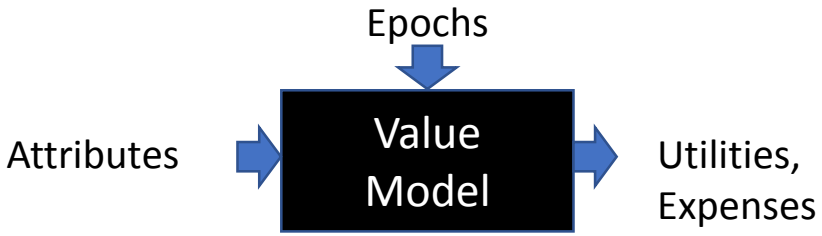
Transforming decision maker criteria into…
levels of satisfaction for each criterion into…
aggregate satisfaction across all criteria

<u>Benefit attributes (i.e., contributing to utility)</u>

- Aesthetic appeal – the system's appearance when considered part of their property [ordinal: 3 to 7]
- Maintenance frequency – the number of maintenance and service events per year that the system requires the homeowner or third party to replace, change, or fix systems or components [#/yr: 6 to 0]
- Product life – minimum number of years that the manufacturing or retailing companies specifies that the system is able to operate before replacement [yrs: 10 to 30]
- Availability – how easy is the system to acquire, by the homeowner, as a function of the number of outlets retailing the system for a given region [ordinal: 4 to 10]
- Space required – number of square meters required per kilowatt of system generation capacity [m^2: 125 to 0]

<u>Cost attributes (i.e., contributing to expense)</u>

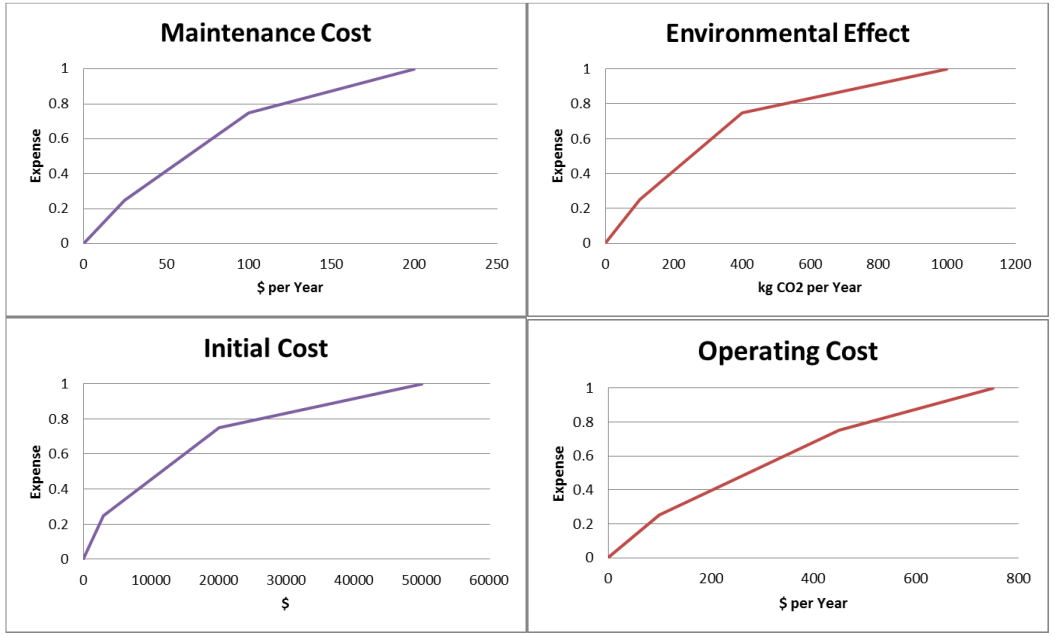
- Maintenance cost – the total cost in dollars per year required to keep the system operating at full efficiency including parts and labor hours invested by the homeowner or designated third party [$/yr: 200 to 0]
- Environmental effect – mass of carbon dioxide that is produced by the system during annual operation [kg CO2/yr: 1000 to 0]
- Initial cost – total cost that the homeowner must pay to acquire the system [$: 50,000 to 0]
- Operating cost – cost that the homeowner must pay to operate the system with specific focus on fuel or electric usage that is required to produce the homeowners desired amount of energy [$/yr: 750 to 0]



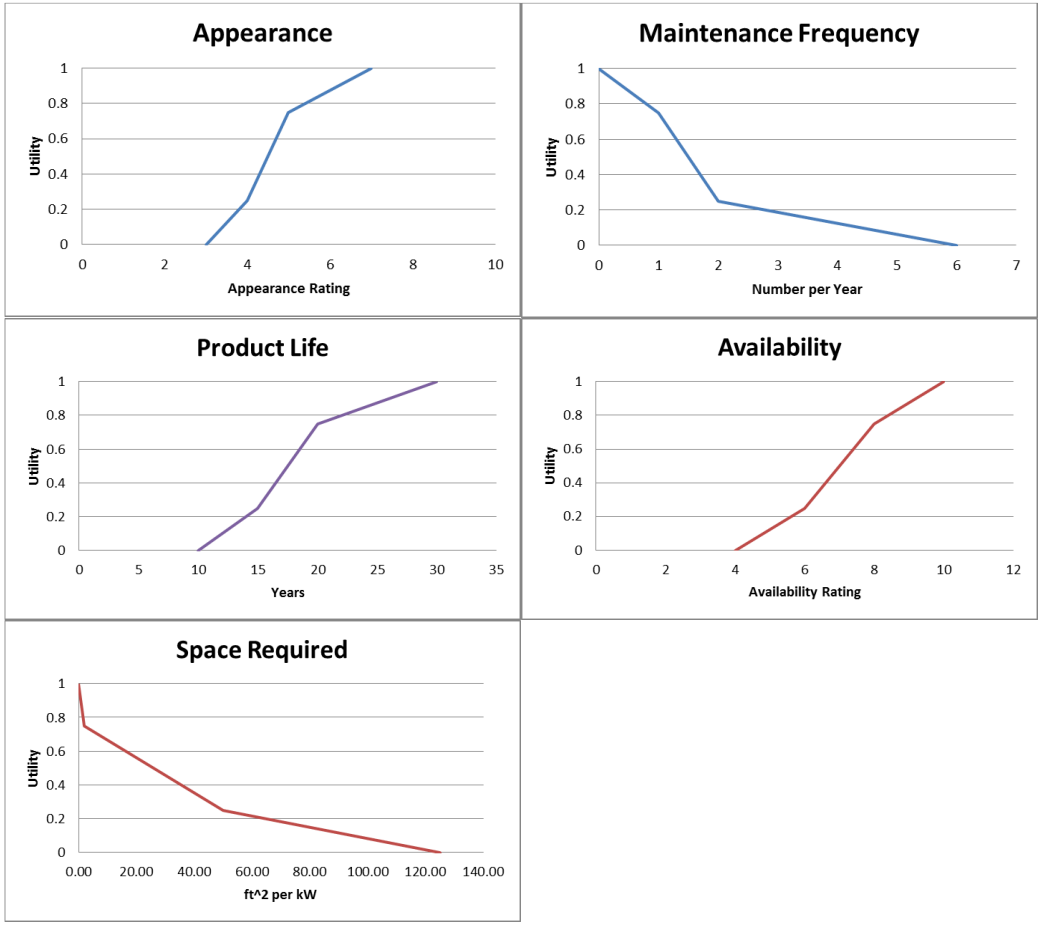
MAV = $\sum_i^n k_i SAV_i(X_i)$, where $\sum_i^n k_i = 1$
for V (value) is E (expense) or U (utility)

Utility and Expense Value Model

Single Attribute Expense (SAE) Curves



Single Attribute Utility (SAU) Curves

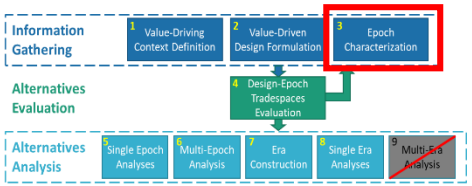


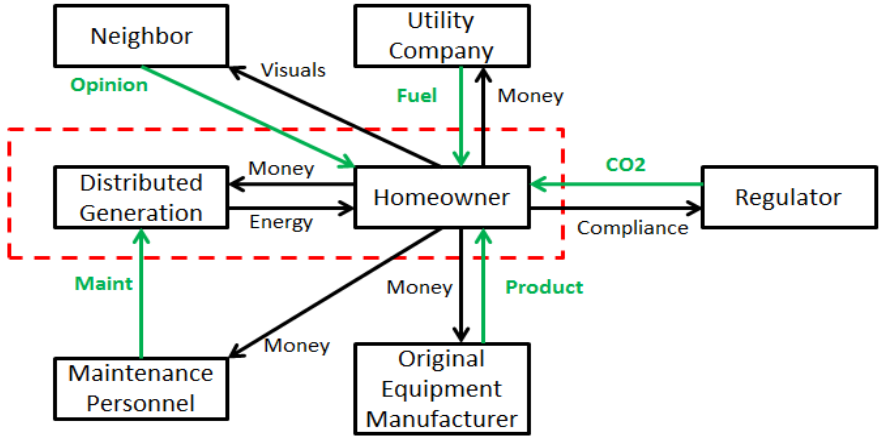
MAV = $\sum_i^n k_i SAV_i(X_i)$, where $\sum_i^n k_i = 1$
for V (value) is E (expense) or U (utility)

Alternatives

- None,
- Solar Photovoltaic
- Solar Thermal
- Wind Turbine
- Heat Pump
- Natural Gas Generator
- Diesel Generator
- Propane Generator
- Heating Oil
- Geothermal

Resulting Epochs





Inspecting the system boundary, we see five exogenous factors that pass through:

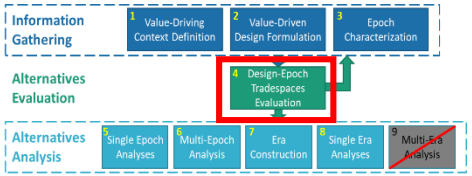
- **Fuel** (from utility company)
- **Maint** (from maintenance personnel)
- **Opinion** (from neighbor)
- **Product** (from original equipment manufacturer)
- **CO2** (from regulator)

These factors can be used to enumerate potential epochs for the system

Epoch Descriptions

Epoch Name	Epoch Descriptor Category	Epoch Descriptor	Range	Units
Price Fossil Fuel	Technology	Fuel	[1.0, 1.5, 2.0]	Multiplier
Cost of Maintenance	Social	Maint	[0.5, 1.0, 2.0]	Multiplier
Neighbor Opinion	Social	Opinion	[Disagree, Neutral, Agree]	Level
Product Available	Technology	Product	[2, 5, 10]	Choices
CO2 Regulations	Policy	CO2	[None, Cap, Ban]	Level

Evaluating the Alternatives



Data for each of the DG alternatives was collected for each cost and benefit attribute:

DG Choice	Description	Maintenance Cost ($/yr)	Environmental Effect (kg/yr)	Initial Cost ($)	Operating Cost ($/yr)	Aesthetic Appeal (0-10)	Maintenance Frequency (#/yr)	Product Life (yr)	Availability (0-10)	Space Required (m^2/kW)
1	None	0.00	0.00	0.00	0.00	0	0	0	0	0.00
2	Solar Photovoltaic	88.75	0.00	17750.00	33.56	5	1	25	10	57.47
3	Solar Thermal	133.13	0.00	26625.00	94.77	5	2	15	9	17.75
4	Wind Turbine	124.25	0.00	35500.00	38.88	3	3	20	9	110.94
5	Heat Pump	137.52	770.09	9485.69	93.15	6	1	20	8	0.23
6	Natural Gas Generator	67.55	586.71	2637.85	607.50	4	4	12.5	8	0.19
7	Diesel Generator	117.59	808.86	3439.06	998.05	4	4	12.5	7	0.26
8	Propane Generator	60.79	697.03	2928.75	2054.16	4	4	12.5	8	0.17
9	Heating Oil	37.82	808.86	1371.59	386.13	5	2	20	5	0.08
10	Geothermal	79.87	770.09	7437.86	173.82	7	3	25	6	117.12

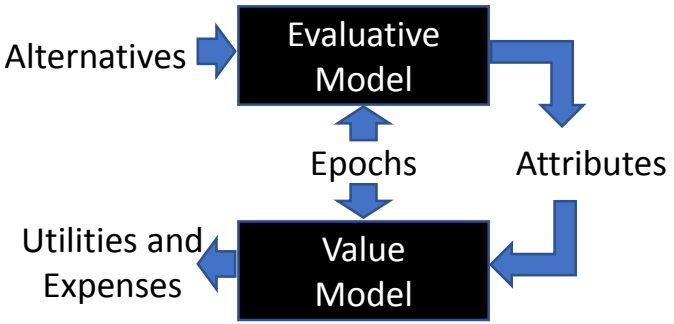
Epoch Descriptions				
Epoch Name	Epoch Descriptor Category	Epoch Descriptor	Range	Units
Price Fossil Fuel	Economic	Fuel	[1.0, 1.5, 2.0]	Multiplier
Cost of Maintenance	Technology	Maint	[0.5, 1.0, 2.0]	Multiplier
Neighbor Opinion	Social	Opinion	[Disagree, Neutral, Agree]	Level
Product Available	Economic	Product	[2, 5, 10]	Choices
CO2 Regulations	Policy	CO2	[None, Cap, Ban]	Level

Each exogenous factor level has weight factors that multiply the baseline attribute score, and change the k_i weights in MAE and MAU functions:

Epoch Weighting Factor										
Exogenous Factor	Attributes	Maintenance Cost ($/year)	Environmental Effect (kg CO2/year)	Initial Cost ($)	Operating Cost ($/year)	Aesthetic Appeal	Maintenance Frequency (#/year)	Product Life (years)	Availability	Space Required (m^2/kW)
Fuel 1.0X		1.0	1.0	1.0	**1.0**	1.0	1.0	1.0	1.0	1.0
Fuel 1.5X		1.0	1.0	1.0	**1.5**	1.0	1.0	1.0	1.0	1.0
Fuel 2.0X		1.0	1.0	1.0	**2.0**	1.0	1.0	1.0	1.0	1.0
Maint 1.0X		**1.0**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maint 0.5X		**0.5**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maint 2.0X		**2.0**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Opinion Neutral		1.0	1.0	1.0	1.0	**1.0**	1.0	1.0	1.0	1.0
Opinion Disagree		1.0	1.0	1.0	1.0	**0.5**	1.0	1.0	1.0	1.0
Opinion Agree		1.0	1.0	1.0	1.0	**2.0**	1.0	1.0	1.0	1.0
Product 10		1.0	1.0	1.0	1.0	1.0	1.0	1.0	**1.0**	1.0
Product 5		1.0	1.0	1.0	1.0	1.0	1.0	1.0	**2.0**	1.0
Product 2		1.0	1.0	1.0	1.0	1.0	1.0	1.0	**5.0**	1.0
CO2 None		1.0	**1.0**	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CO2 Cap		1.0	**2.0**	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CO2 Ban		1.0	**10.0**	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Expense Attribute K Factor					
Exogenous Factor	Expense	Maintenance Cost ($/year)	Environmental Effect (kg CO2/year)	Initial Cost ($)	Operating Cost ($/year)
Fuel 1.0X		0.233	0.086	0.353	0.328
Fuel 1.5X		0.205	0.123	0.311	0.361
Fuel 2.0X		0.193	0.126	0.294	0.387
Maint 1.0X		0.233	0.086	0.353	0.328
Maint 0.5X		0.248	0.103	0.350	0.299
Maint 2.0X		0.299	0.128	0.316	0.256
Opinion Neutral		0.233	0.086	0.353	0.328
Opinion Disagree		0.226	0.165	0.330	0.278
Opinion Agree		0.248	0.111	0.342	0.299
Product 10		0.233	0.086	0.353	0.328
Product 5		0.238	0.148	0.344	0.270
Product 2		0.231	0.162	0.368	0.239
CO2 None		0.233	0.086	0.353	0.328
CO2 Cap		0.174	0.289	0.314	0.223
CO2 Ban		0.198	0.331	0.256	0.215

Utility Attribute K Factor						
Exogenous Factor	Utility	Aesthetic Appeal	Maintenance Frequency (#/year)	Product Life (years)	Availability	Space Required (m^2/kW)
Fuel 1.0X		0.040	0.230	0.240	0.210	0.280
Fuel 1.5X		0.032	0.245	0.245	0.202	0.277
Fuel 2.0X		0.031	0.227	0.247	0.237	0.258
Maint 1.0X		0.040	0.230	0.240	0.210	0.280
Maint 0.5X		0.030	0.253	0.222	0.242	0.253
Maint 2.0X		0.030	0.273	0.263	0.172	0.263
Opinion Neutral		0.040	0.230	0.240	0.210	0.280
Opinion Disagree		0.198	0.208	0.178	0.149	0.267
Opinion Agree		0.061	0.242	0.212	0.182	0.303
Product 10		0.040	0.230	0.240	0.210	0.280
Product 5		0.074	0.181	0.298	0.213	0.234
Product 2		0.051	0.121	0.283	0.232	0.313
CO2 None		0.040	0.230	0.240	0.210	0.280
CO2 Cap		0.053	0.126	0.305	0.168	0.347
CO2 Ban		0.063	0.158	0.295	0.189	0.295



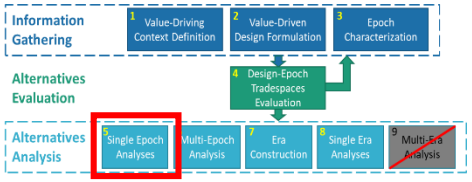
Simple Evaluative Model

Baseline Attribute Scores X Epoch Weighting Factors = Epoch-specific Attribute Scores

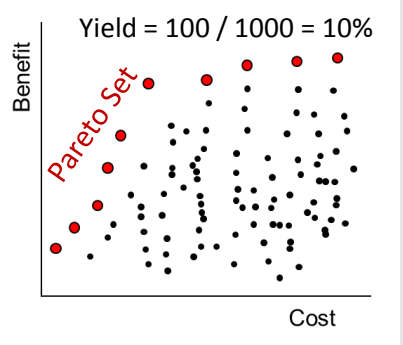
Assumptions:

- Exogenous factors impact attributes independently
- Exogenous factors will change one at a time

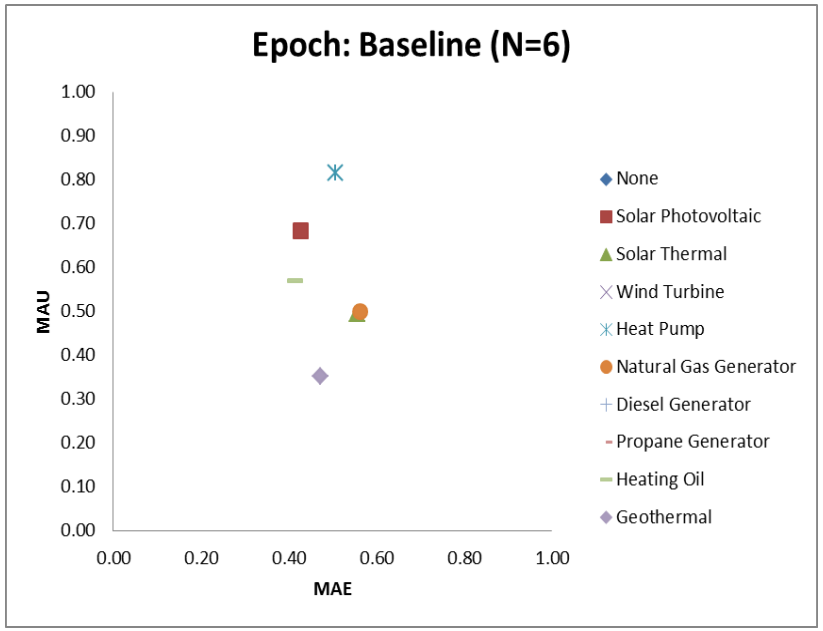
Epoch Benefit-Cost Scatterplots

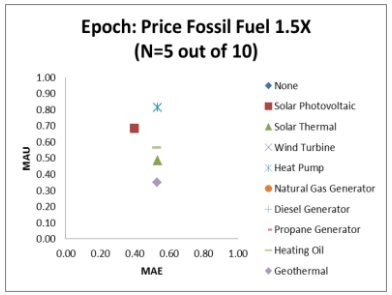


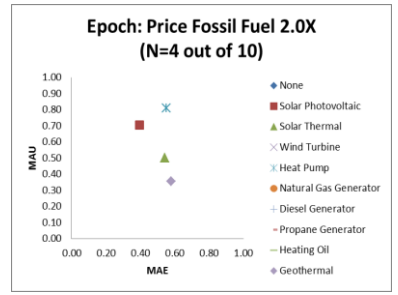
Tradespace Concept

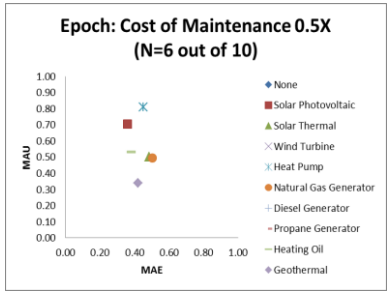


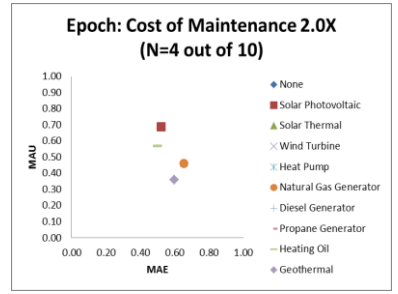
Within an epoch, what are "best value" solutions?

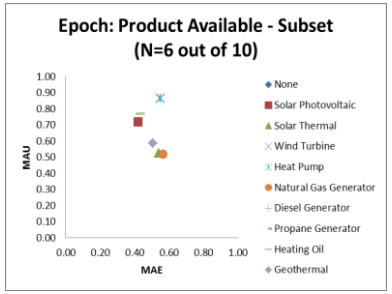


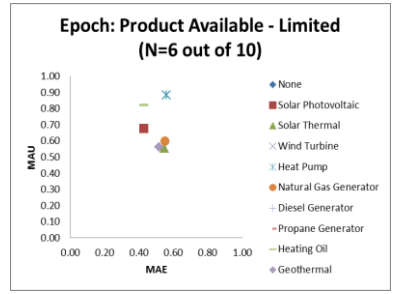






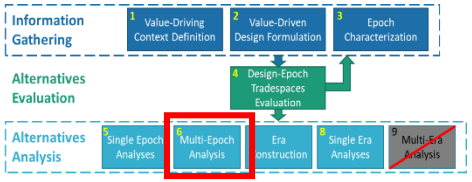






Use tradespace scatterplot to identify tradeoffs and "good" designs within an epoch

All Epoch Cases



MAE	Price Fossil Fuel 1x	Price Fossil Fuel 1.5x	Price Fossil Fuel 2x	Cost of Maintenance 1x	Cost of Maintenance 0.5x	Cost of Maintenance 2x	Neighbor Opinion - Nuetral	Neighbor Opinion - Disagree	Neighbor Opinion - Agree	Product Available - All	Product Available - Subset	Product Available - Two	Regulation - None	Regulation - CO2 Cap	Regulation - CO2 Ban
None	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Solar Photovoltaic	0.426	0.397	0.396	0.426	0.359	0.520	0.426	0.402	0.426	0.426	0.419	0.427	0.426	0.351	0.327
Solar Thermal	0.556	0.533	0.544	0.556	0.484	-1.000	0.556	0.520	0.553	0.556	0.539	0.545	0.556	0.450	0.422
Wind Turbine	0.531	0.493	0.490	0.531	0.460	-1.000	0.531	0.501	0.531	0.531	0.522	0.533	0.531	0.438	0.407
Heat Pump	0.506	0.532	0.551	0.506	0.451	-1.000	0.506	0.551	0.530	0.506	0.549	0.559	0.506	-1.000	-1.000
Natural Gas Generator	0.562	-1.000	-1.000	0.562	0.502	0.652	0.562	0.575	0.563	0.562	0.563	0.549	0.562	-1.000	-1.000
Diesel Generator	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
Propane Generator	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
Heating Oil	0.414	0.527	-1.000	0.414	0.378	0.499	0.414	0.449	0.422	0.414	0.433	0.427	0.414	-1.000	-1.000
Geothermal	0.472	0.529	0.578	0.472	0.419	0.596	0.472	0.513	0.490	0.472	0.507	0.514	0.472	-1.000	-1.000

MAU	Price Fossil Fuel 1x	Price Fossil Fuel 1.5x	Price Fossil Fuel 2x	Cost of Maintenance 1x	Cost of Maintenance 0.5x	Cost of Maintenance 2x	Neighbor Opinion - Nuetral	Neighbor Opinion - Disagree	Neighbor Opinion - Agree	Product Available - All	Product Available - Subset	Product Available - Two	Regulation - None	Regulation - CO2 Cap	Regulation - CO2 Ban
None	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
Solar Photovoltaic	0.686	0.686	0.705	0.686	0.706	0.688	0.686	-1.000	0.617	0.686	0.718	0.679	0.686	0.648	0.680
Solar Thermal	0.495	0.485	0.500	0.495	0.501	0.461	0.495	-1.000	0.450	0.495	0.525	0.555	0.495	0.498	0.499
Wind Turbine	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	0.431	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000
Heat Pump	0.817	0.815	0.811	0.817	0.810	0.812	0.817	-1.000	0.771	0.817	0.864	0.884	0.817	0.833	0.823
Natural Gas Generator	0.500	0.491	0.496	0.500	0.495	0.460	0.500	-1.000	0.489	0.500	0.520	0.601	0.500	0.533	0.502
Diesel Generator	0.444	0.438	0.435	0.444	0.432	0.414	0.444	-1.000	0.441	0.444	0.518	0.598	0.444	0.487	0.452
Propane Generator	0.500	0.491	0.497	0.500	0.496	0.460	0.500	-1.000	0.490	0.500	0.520	0.602	0.500	0.533	0.503
Heating Oil	0.571	0.568	0.550	0.571	0.533	0.569	0.571	-1.000	0.542	0.571	0.769	0.823	0.571	0.665	0.623
Geothermal	0.353	0.350	0.356	0.353	0.339	0.361	0.353	0.264	0.284	0.353	0.588	0.561	0.353	0.395	0.406

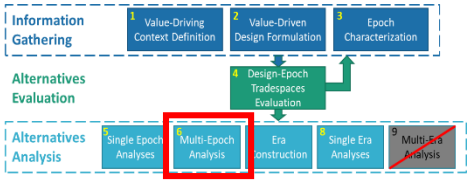
An alternative MUST meet minimum acceptability levels in both MAE and MAU in order to be feasible

Feasibility Matrix	Epoch	Price Fossil Fuel 1x	Price Fossil Fuel 1.5x	Price Fossil Fuel 2x	Cost of Maintenance 1x	Cost of Maintenance 0.5x	Cost of Maintenance 2x	Neighbor Opinion - Nuetral	Neighbor Opinion - Disagree	Neighbor Opinion - Agree	Product Available - All	Product Available - Subset	Product Available - Two	Regulation - None	Regulation - CO2 Cap	Regulation - CO2 Ban
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
None	1	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas
Solar Photovoltaic	2	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Infeas	Feas	Feas	Feas	Feas	Feas	Feas	Feas
Solar Thermal	3	Feas	Feas	Feas	Feas	Feas	Infeas	Feas	Infeas	Feas	Feas	Feas	Feas	Feas	Feas	Feas
Wind Turbine	4	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Feas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas
Heat Pump	5	Feas	Feas	Feas	Feas	Feas	Infeas	Feas	Infeas	Feas	Feas	Feas	Feas	Feas	Infeas	Infeas
Natural Gas Generator	6	Feas	Infeas	Infeas	Feas	Feas	Feas	Feas	Infeas	Feas	Feas	Feas	Feas	Feas	Infeas	Infeas
Diesel Generator	7	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas
Propane Generator	8	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas	Infeas
Heating Oil	9	Feas	Feas	Infeas	Feas	Feas	Feas	Feas	Infeas	Feas	Feas	Feas	Feas	Feas	Infeas	Infeas
Geothermal	10	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Feas	Infeas	Infeas

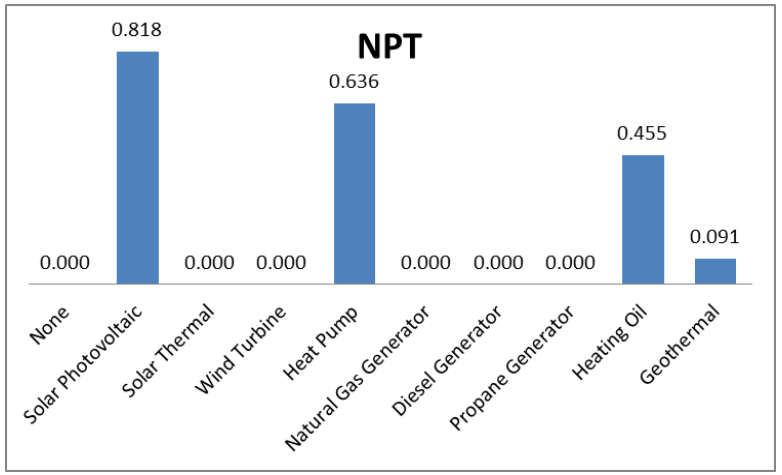
Poor Alternatives

Difficult epoch

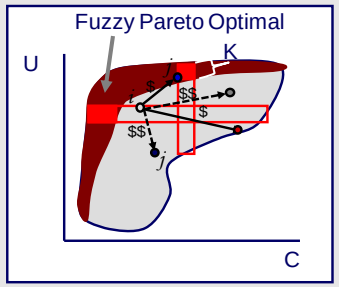
Sensitivity to the Epochs

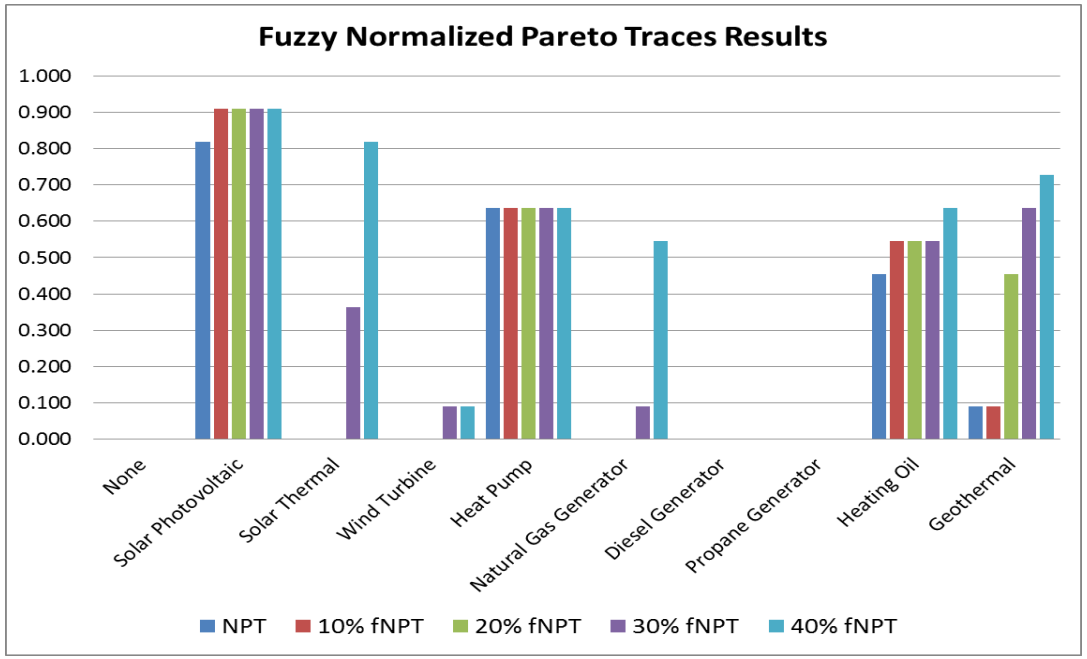


Across what fraction of epochs is a solution "best value"?



Tradespace Concept

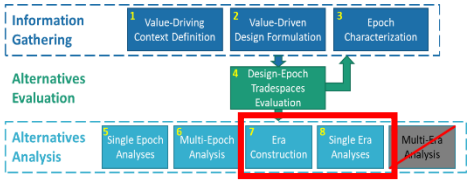




Used to find *passively value robust alternatives*

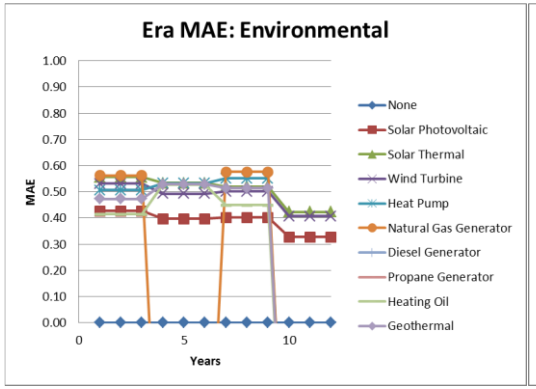
fNPT is the fuzzy Normalized Pareto Trace

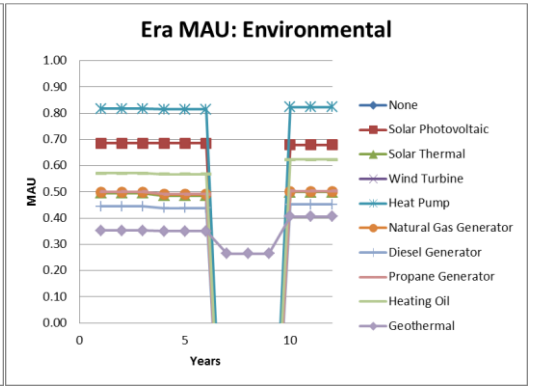
Shifts Over Time: Across Eras

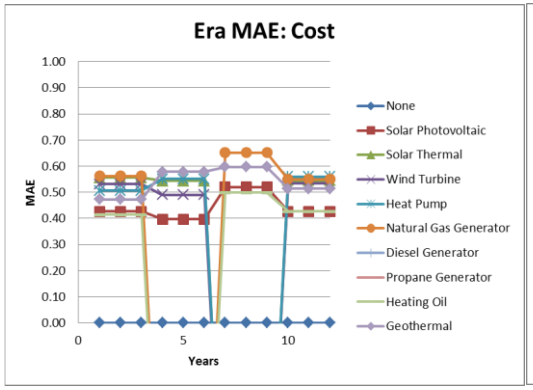


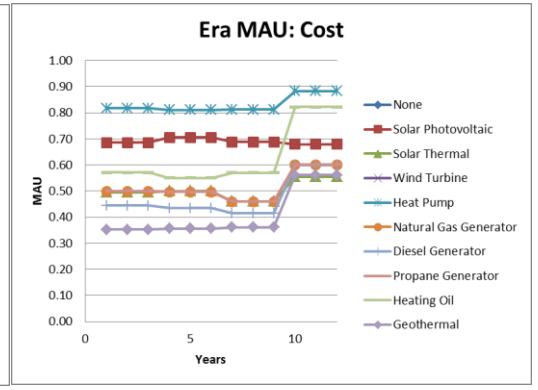
How do solutions perform across time shifting uncertainties?

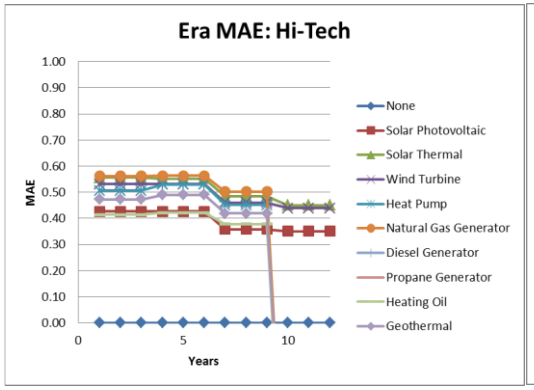
Era Descriptions				
Era Name	Era Descriptor Category	Era Descriptor	Epoch Sequence	Duration per Epoch
Era1	Policy	Environment	1) Baseline	3 years
			2) Fossil Fuel 1.5X	
			3) Neighbor Disagree	
			4) Regulation - CO2 Ban	
Era2	Economic	Cost	1) Baseline	3 years
			2) Fossil Fuel 2.0X	
			3) Maintenance 2.0X	
			4) Limited Product Available	
Era1	Technology	Hi-Tech	1) Baseline	3 years
			2) Neighbor Agrees	
			3) Maintenance 0.5X	
			4) Regulation - CO2 Cap	

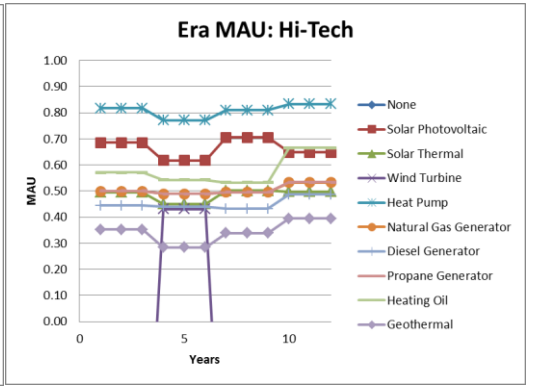








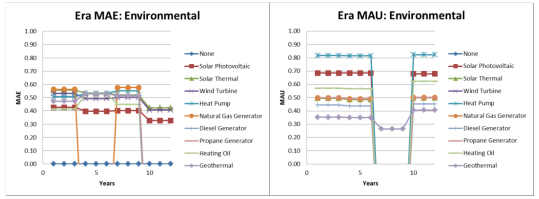


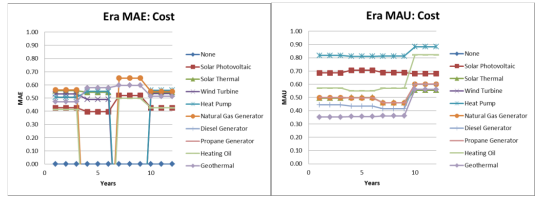


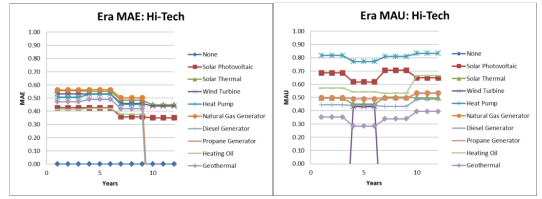
Operational Value

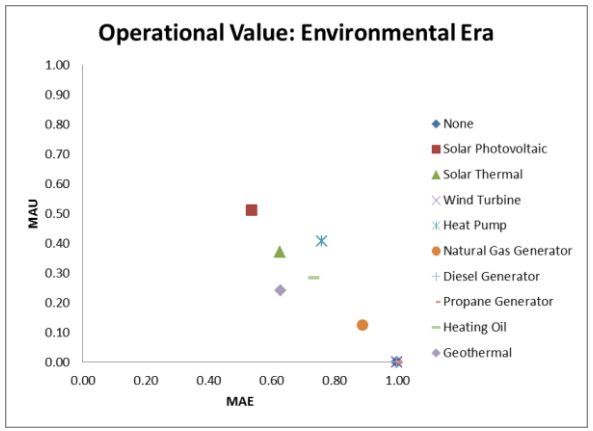
It can be useful to summarize trajectory data via an aggregation function
Pro: simplify analysis
Con: must make assumptions

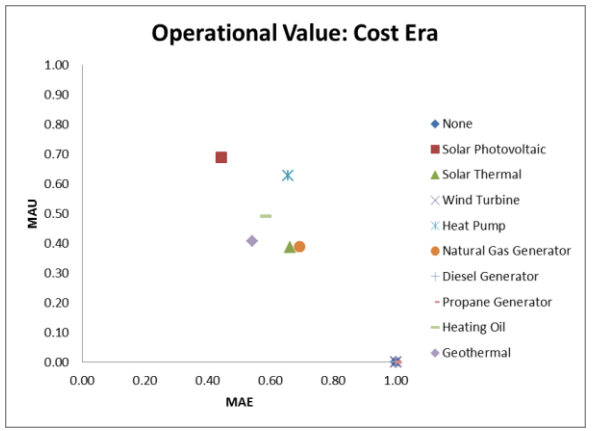
Operational value: time-weighted average MAV, penalizing infeasibility at a point in time with 0 or 1 score for MAU/MAE respectively

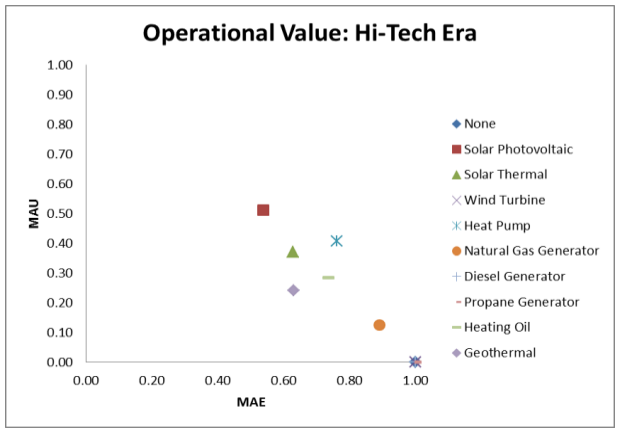




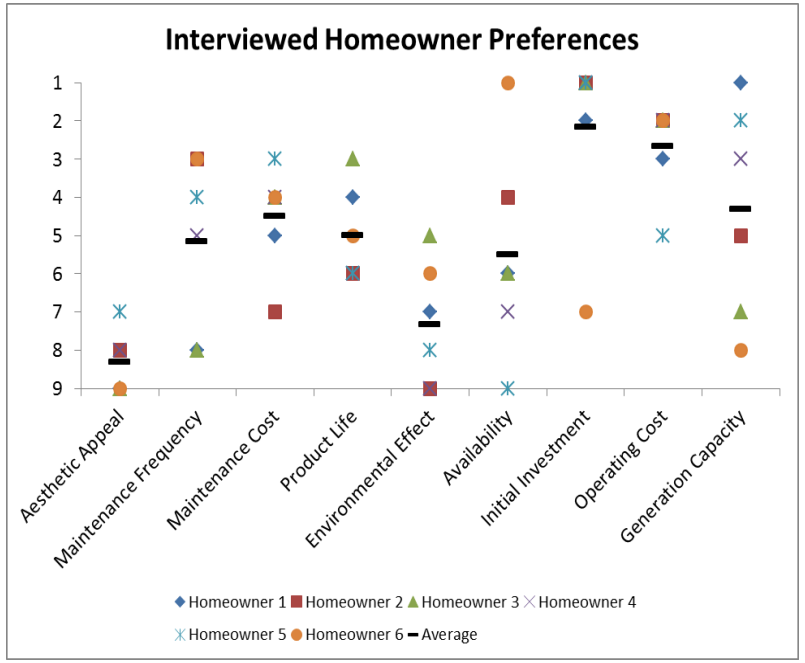




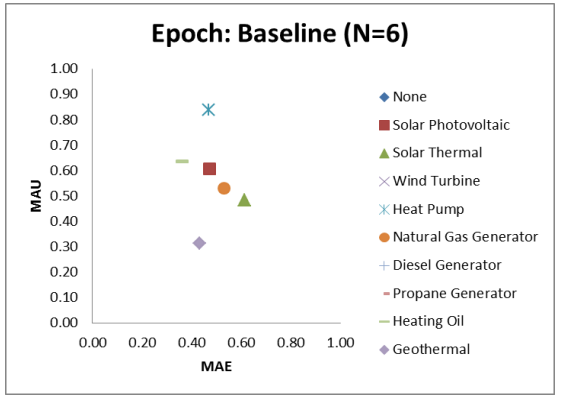




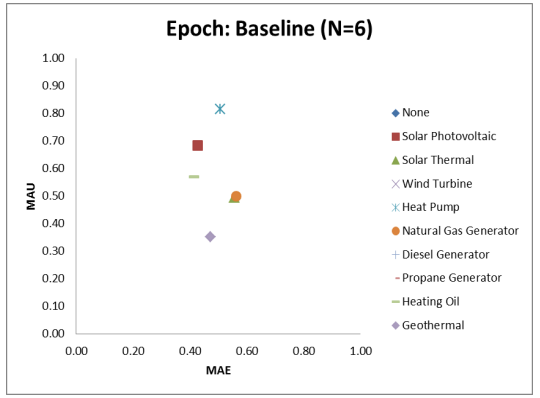
Trades Across Homeowners

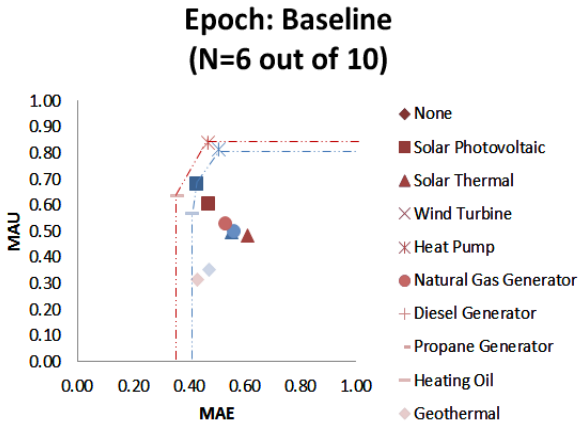


Homeowner 4



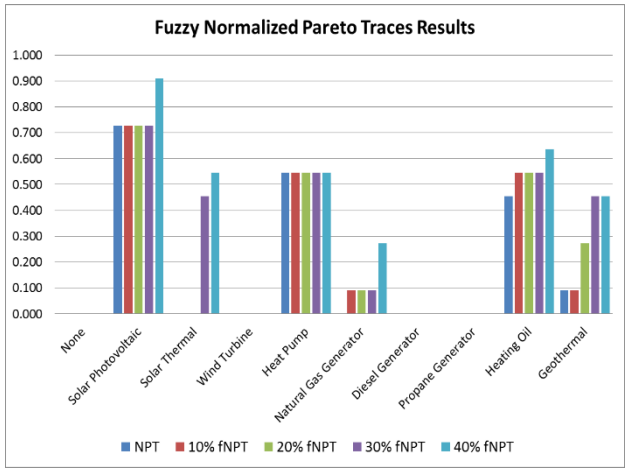
The "Average" Homeowner



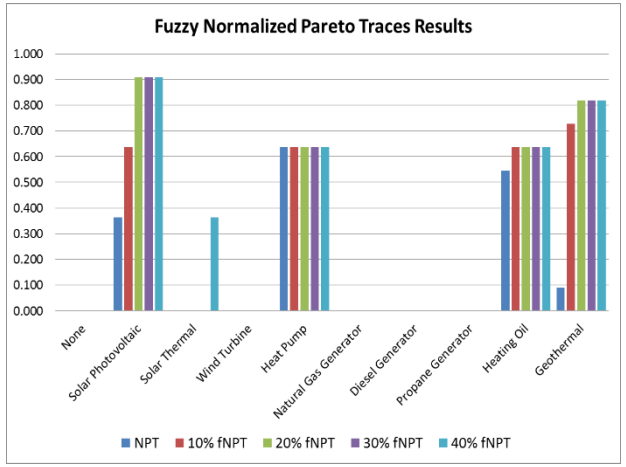


Average for All?

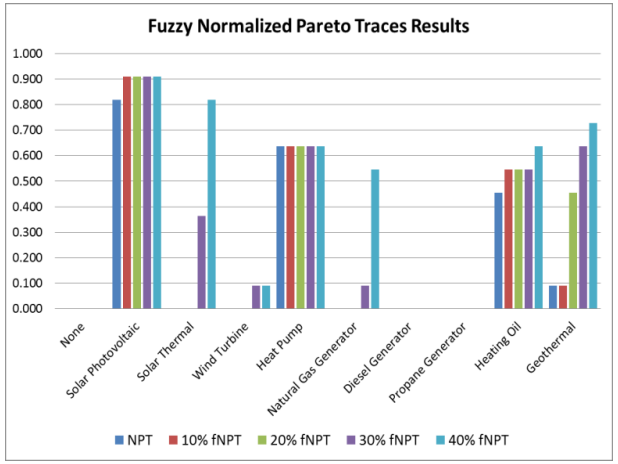
Homeowner 4



Homeowner 2

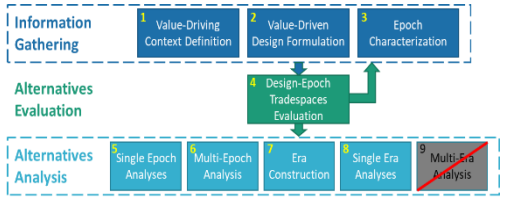


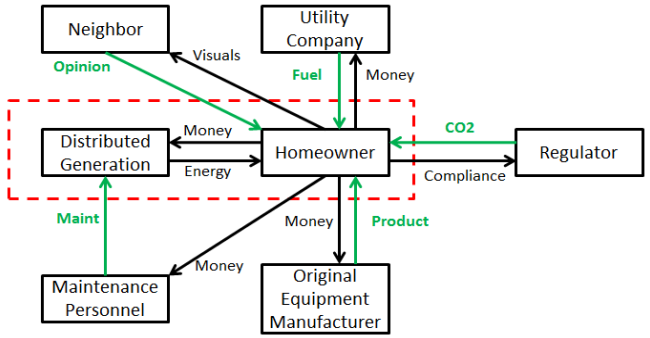
The "Average" Homeowner



Dsitrubted Generation Selection							
Homeowner	Rank	Normalized Pareto Trace			Operational Value		
		0% Fuzzy	10% Fuzzy	20% Fuzzy	Environmental Era	Cost Era	Hi-Tech Era
Average Homeowner	1st	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV
	2nd	Heat Pump	Heat Pump	Heat Pump	Solar Thermal	Geothermal	Solar Thermal
	3rd	Heating Oil	Heating Oil	Heating Oil	Geothermal	Heating Oil	Geothermal
Homeowner 4	1st	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV
	2nd	Heat Pump	Heat Pump	Heat Pump	Solar Thermal	Heating Oil	Solar Thermal
	3rd	Heating Oil	Heating Oil	Heating Oil	Geothermal	Geothermal	Geothermal
Homeowner 2	1st	Heat Pump	Geothermal	Solar PV	Solar PV	Geothermal	Solar PV
	2nd	Heating Oil	Heat Pump	Geothermal	Geothermal	Solar PV	Geothermal
	3rd	Solar PV	Heating Oil	Heat Pump	Solar Thermal	Heating Oil	Solar Thermal

Discussion





Epoch Descriptions				
Epoch Name	Epoch Descriptor Category	Epoch Descriptor	Range	Units
Price Fossil Fuel	Economic	Fuel	[1.0, 1.5, 2.0]	Multiplier
Cost of Maintenance	Technology	Maint	[0.5, 1.0, 2.0]	Multiplier
Neighbor Opinion	Social	Opinion	[Disagree, Neutral, Agree]	Level
Product Available	Economic	Product	[2, 5, 10]	Choices
CO2 Regulations	Policy	CO2	[None, Cap, Ban]	Level

Era Descriptions				
Era Name	Era Descriptor Category	Era Descriptor	Epoch Sequence	Duration per Epoch
Era1	Policy	Environment	1) Baseline 2) Fossil Fuel 1.5X 3) Neighbor Disagree 4) Regulation - CO2 Ban	3 years
Era2	Economic	Cost	1) Baseline 2) Fossil Fuel 2.0X 3) Maintenance 2.0X 4) Limited Product Available	3 years
Era1	Technology	Hi-Tech	1) Baseline 2) Neighbor Agrees 3) Maintenance 0.5X 4) Regulation - CO2 Cap	3 years

Dsitrubted Generation Selection							
Homeowner	Rank	Normalized Pareto Trace			Operational Value		
		0% Fuzzy	10% Fuzzy	20% Fuzzy	Environmental Era	Cost Era	Hi-Tech Era
Average Homeowner	1st	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV
	2nd	Heat Pump	Heat Pump	Heat Pump	Solar Thermal	Geothermal	Solar Thermal
	3rd	Heating Oil	Heating Oil	Heating Oil	Geothermal	Heating Oil	Geothermal
Homeowner 4	1st	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV	Solar PV
	2nd	Heat Pump	Heat Pump	Heat Pump	Solar Thermal	Heating Oil	Solar Thermal
	3rd	Heating Oil	Heating Oil	Heating Oil	Geothermal	Geothermal	Geothermal
Homeowner 2	1st	Heat Pump	Geothermal	Solar PV	Solar PV	Geothermal	Solar PV
	2nd	Heating Oil	Heat Pump	Geothermal	Geothermal	Solar PV	Geothermal
	3rd	Solar PV	Heating Oil	Heat Pump	Solar Thermal	Heating Oil	Solar Thermal

- EEA approach structured investigation of “robust” decisions across 2 timescales for uncertainty: point futures (epochs) and time-series futures (eras)
  - Different rankings for alternatives for epoch vs era robustness
- The values for decision makers are key in directing “best” solutions
  - Care must be taken in recognizing difference between “average” and custom preferences
  - When possible, decision makers are better off if treated as distinct

References

1. Pina AL, Applying Epoch-Era Analysis for Homeowner Selection of Distributed Generation Power Systems, Master of Science in Engineering and Management, System Design and Management Program, MIT, June 2014.
2. IPCC Third Assessment Report, Retrieved from GRID Arendal: http://www.grida.no/publications/other/ipcc_tar/, 2001.
3. Ross AM, and Rhodes DH. Using natural value-centric time scales for conceptualizing system timelines through epoch-era analysis. INCOSE Int'l Symp. (INCOSE08). Utrecht, the Netherlands, 2008.
4. Ross AM, Rhodes DH, and Hastings DE. Using Pareto Trace to Determine System Passive Value Robustness. 3rd IEEE Sys Conf. (SysCon09), Vancouver, 2009.
5. Schaffner M, Wu MS, Ross AM, and Rhodes DH. Enabling Design for Affordability: An Epoch-Era Analysis Approach. 10th Acquisition Research Symposium Acquisition Management. Monterey: Naval Postgraduate School. 2013. pp. 262-279.
6. Schaffner, MA, Ross AM, and Rhodes DH. A Method for Selecting Affordable System Concepts: A Case Application to Naval Ship Design. Conf on Sys Eng Research (CSER14). Redondo Beach, CA. 2014.

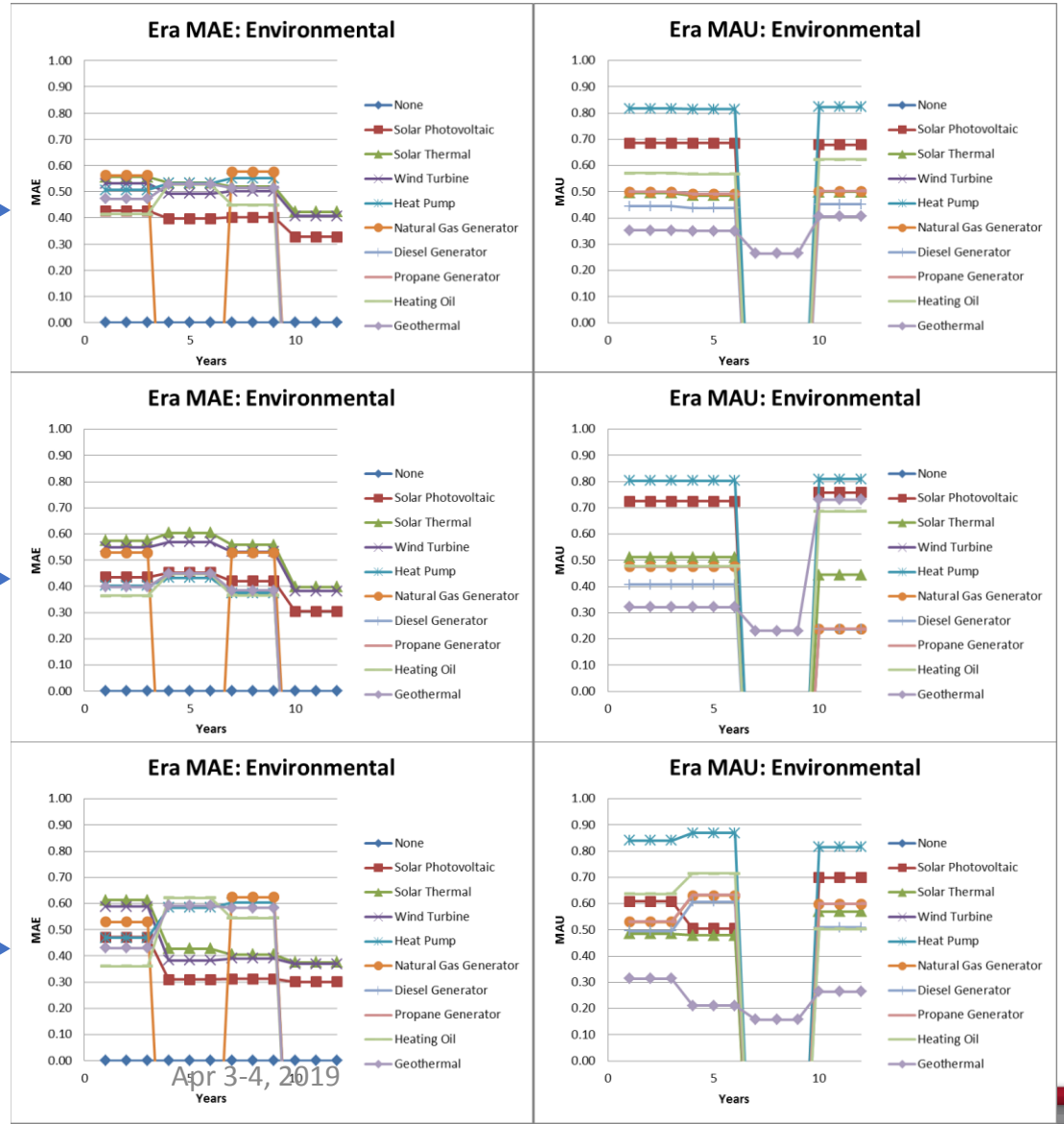
Questions?

Era Swing (1 of 3)

The "Average" Homeowner

Homeowner 2

Homeowner 4

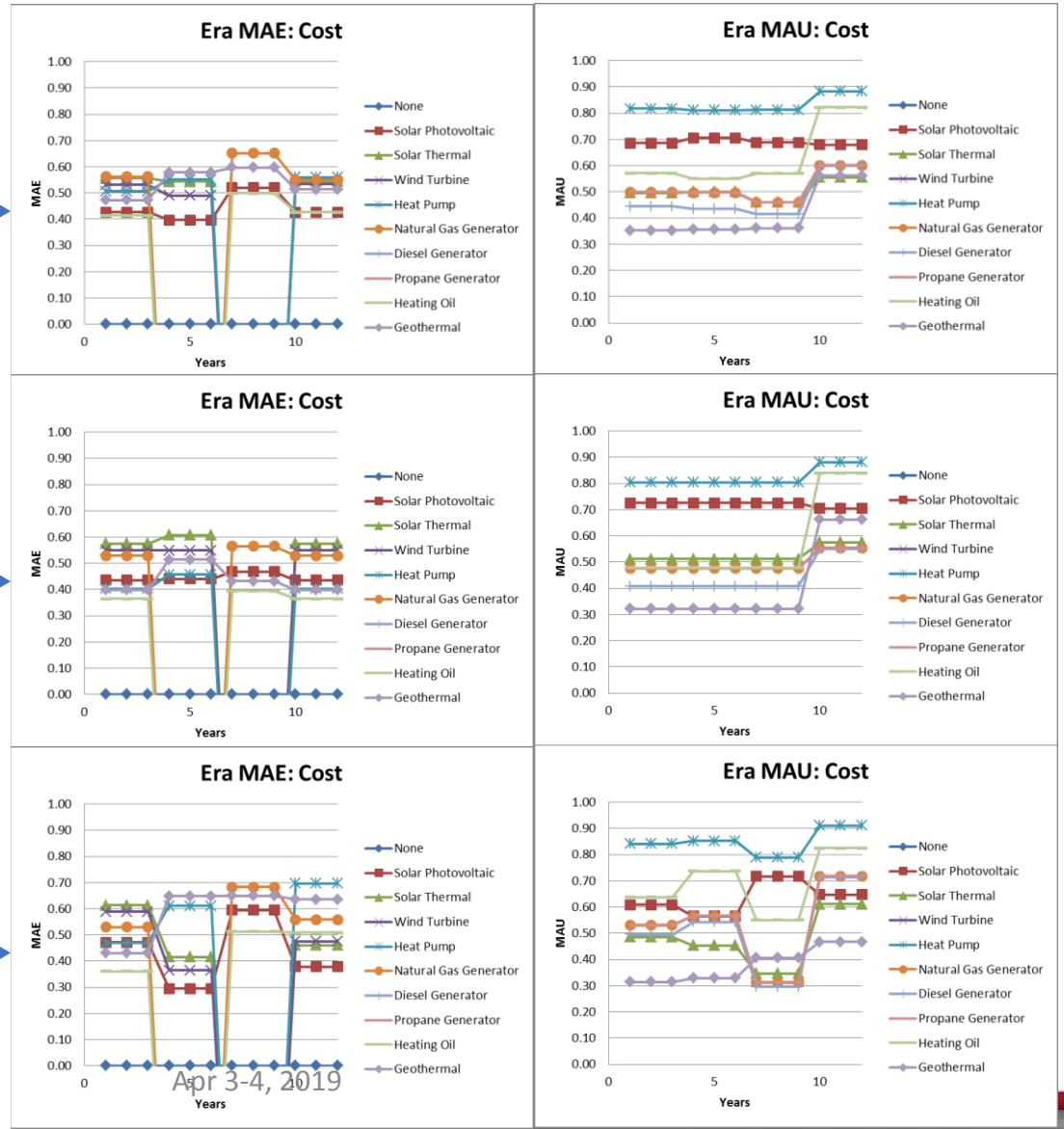


Era Swing (2 of 3)

The "Average" Homeowner

Homeowner 2

Homeowner 4



Era Swing (3 of 3)

The "Average" Homeowner

Homeowner 2

Homeowner 4