IOWA STATE UNIVERSITY
Department of Industrial and Manufacturing Systems Engineering

Engineering Economics Applied to Electricity Generation Decisions with Uncertainty

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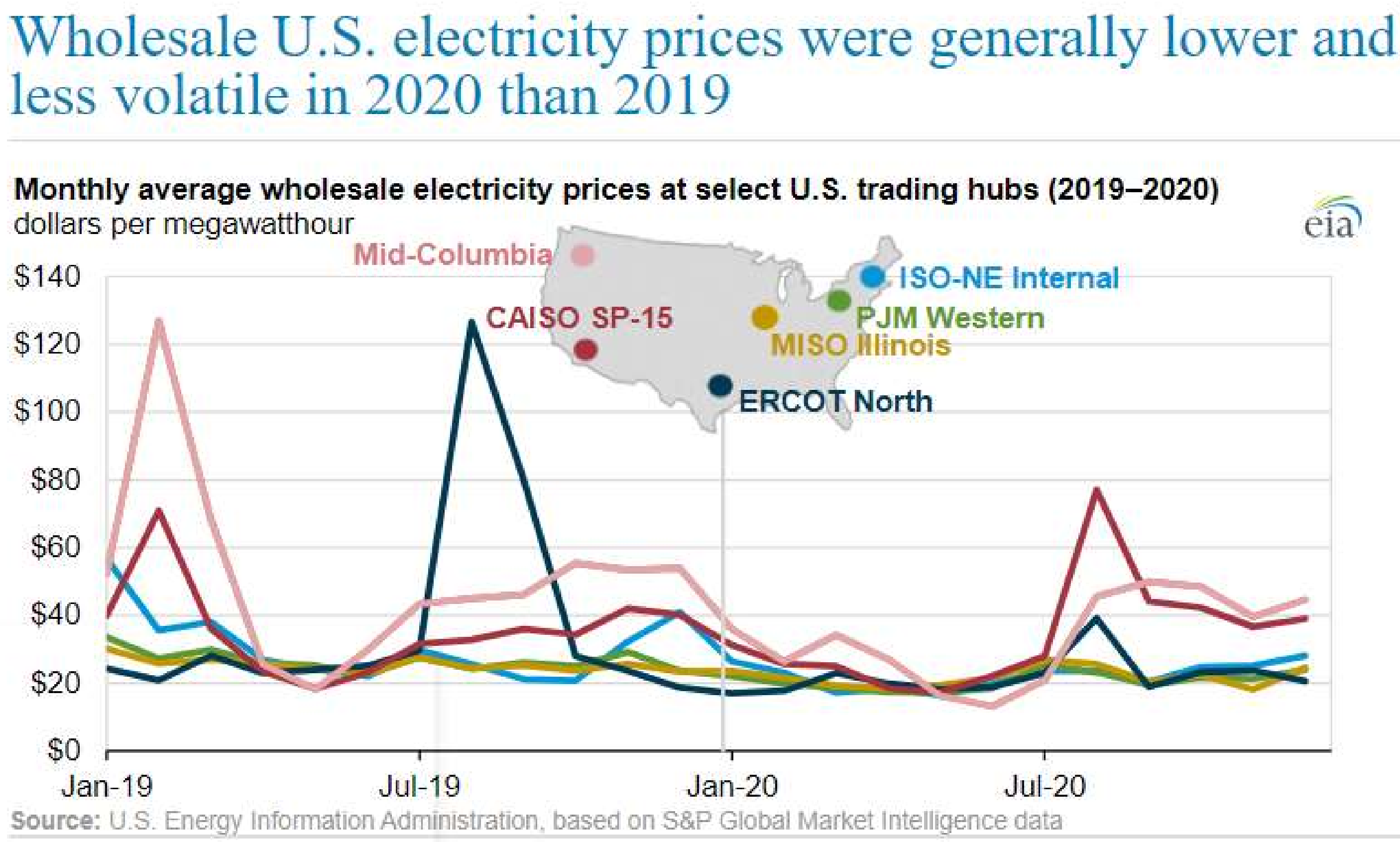
Value of renewable energy sources

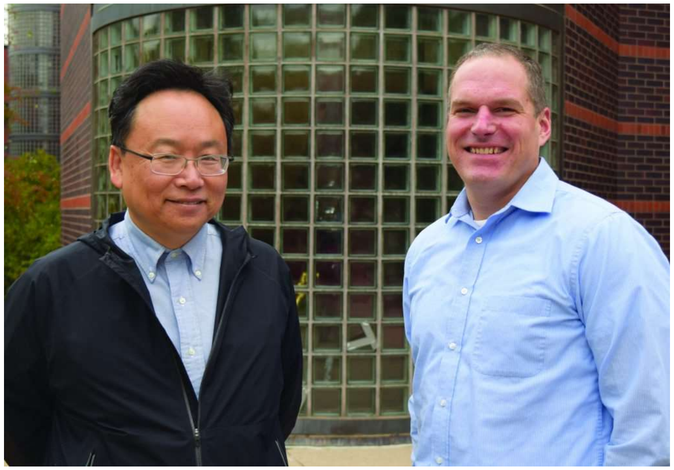
Uncertainty



Solar and Wind Energy Using Engineering Economics Theory (SWEEET)

- Study the economic viability of incorporating more solar and wind into Iowa's electrical grid
- Renewable resources to better serve rural and underserved areas
- Funded by Iowa Energy Center

www.imse.iastate.edu/sweeet



Outline

1. Optimal power flow and locational marginal price (LMP)
2. Valuing future sources of electricity generation
3. Valuation without hedging

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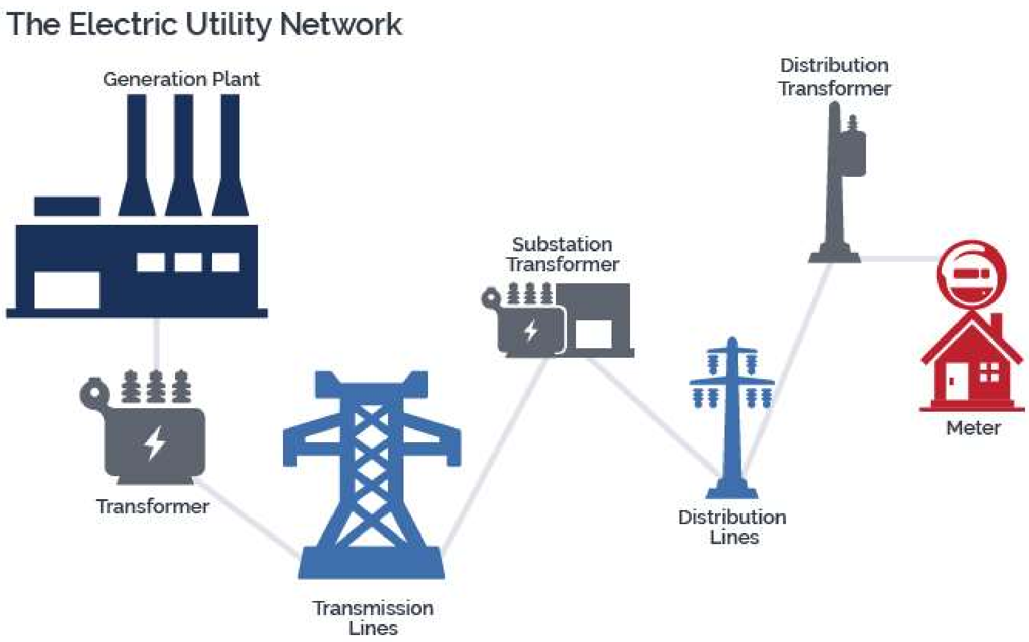
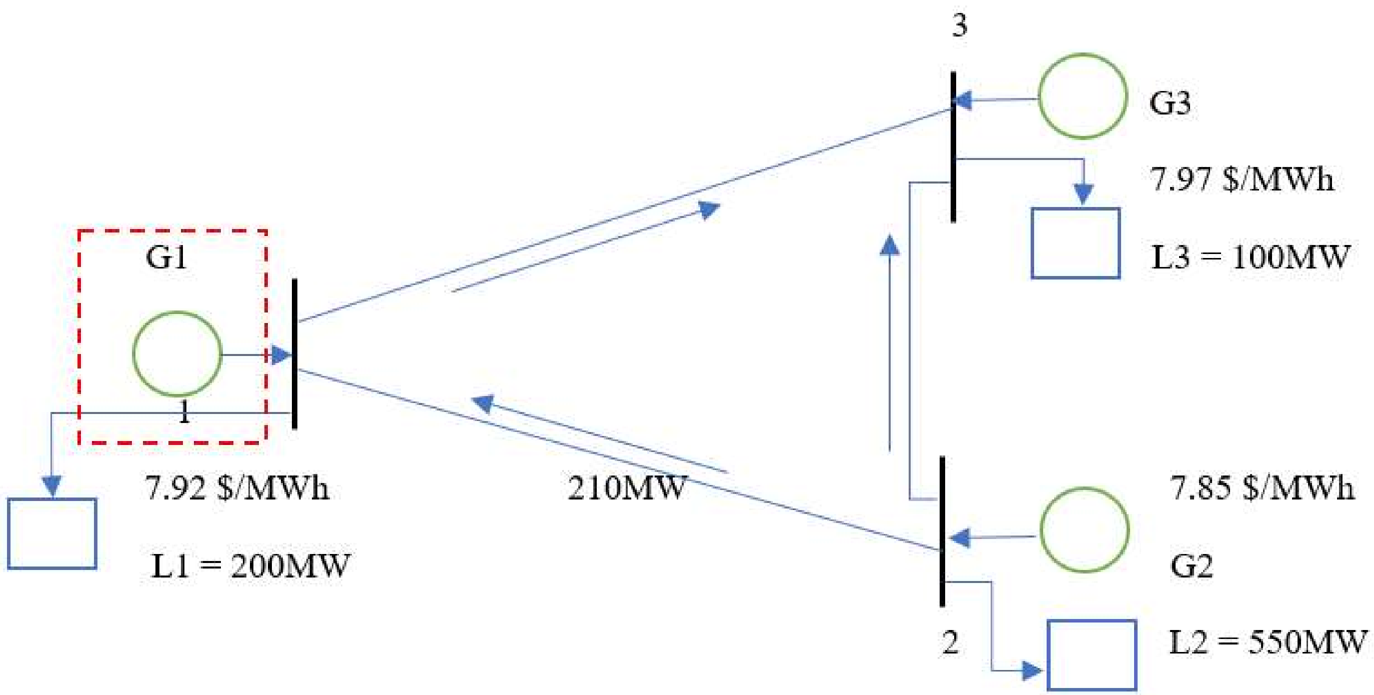
Optimal power flow model

- Determine best operating levels for electric power plants
- Objective: minimize cost while meeting demand
- Constraints of transmission network



Example

- Load
- Generation units
- Maximum generation capacity
- Generation cost
- Transmission capacity
- Line reactance



Excel tool inputs

	Load	Generation units available	Max generation capacity	Generation cost ($/MWh)
Bus 1	270	1		$7.92
Bus 2	550	1		$7.85
Bus 3	100	1		$7.97

Transmission Capacity	(leave blank if no transmission capacity)		
From \ To	**Bus 1**	**Bus 2**	**Bus 3**
Bus 1		210	
Bus 2	210		
Bus 3			

Line Reactance	(leave blank if no transmision from one bus to another bus)		
From \ To	**Bus 1**	**Bus 2**	**Bus 3**
Bus 1		0.1	0.125
Bus 2	0.1		0.2
Bus 3			

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Excel tool outputs

Calucate
Optimal Power Flow

	Cost per hour	$7,225.98
Decision variables	Generator 1	56.9
	Generator 2	863.1
	Generator 3	0.0
	Phase angle 1	0
	Phase angle 2	0.21
	Phase angle 3	0.0038

DC power flow formulation		Location marginal price (LMP)	
Bus 1	270	Bus 1	$7.920
Bus 2	550	Bus 2	$7.850
Bus 3	100	Bus 3	$7.893

Power flow

From \ To	Bus 1	Bus 2	Bus 3
Bus 1		-210.0	-3.1
Bus 2	210.0		103.1
Bus 3	0.0	0.0	

Locational marginal price (LMP)

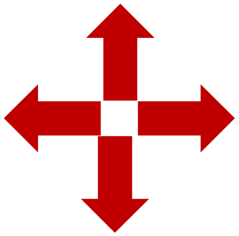
- Price for electricity energy at each load zone
- Calculated from the optimal flow model
  - Reflects operating characteristics of network
  - Constraints on the transmission system
  - Losses from physical limits of the transmission system
- LMPs differ among locations: Transmission and reserve constraints prevent the cheapest MW of electricity from reaching all locations

Real option

- Gives firms the right but not obligation to undertake business opportunities
- Projects involve tangible assets

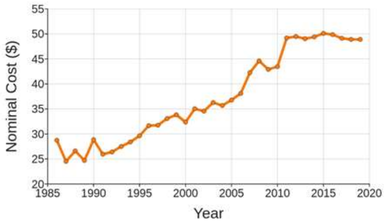
Timing / waiting option

Wait for new data – learn more before investing



Growth option

Consider the strategic value of the project



Abandon / switch / install option

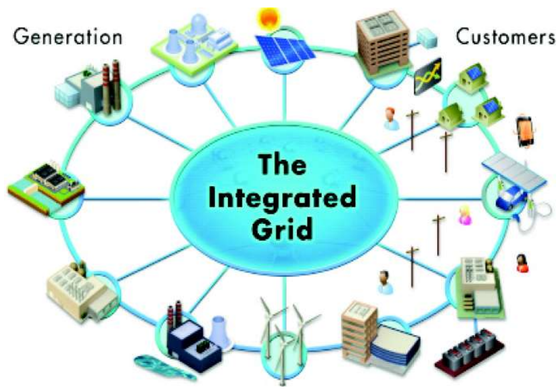
Consider the flexibility of the assets

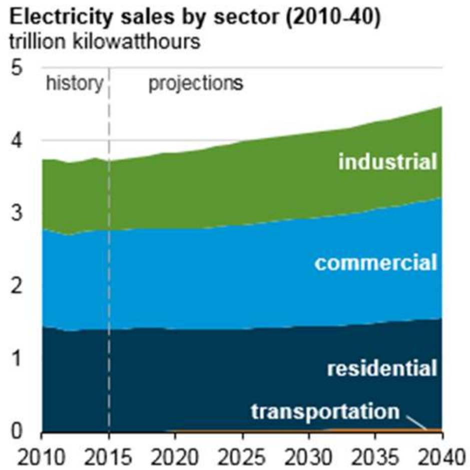
Option valuation

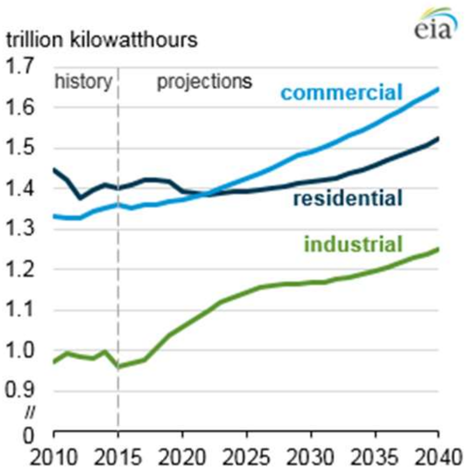
- Option valuation is a process to evaluate the option
- Option value expresses the project’s worth
- Our option here is to add a generator to the network

Motivation

- Adding a new generation source to an existing electrical network is a critical part of power planning
- Obtaining the permit for new generation can be lengthy and expensive
- Electricity demand is uncertain and variable

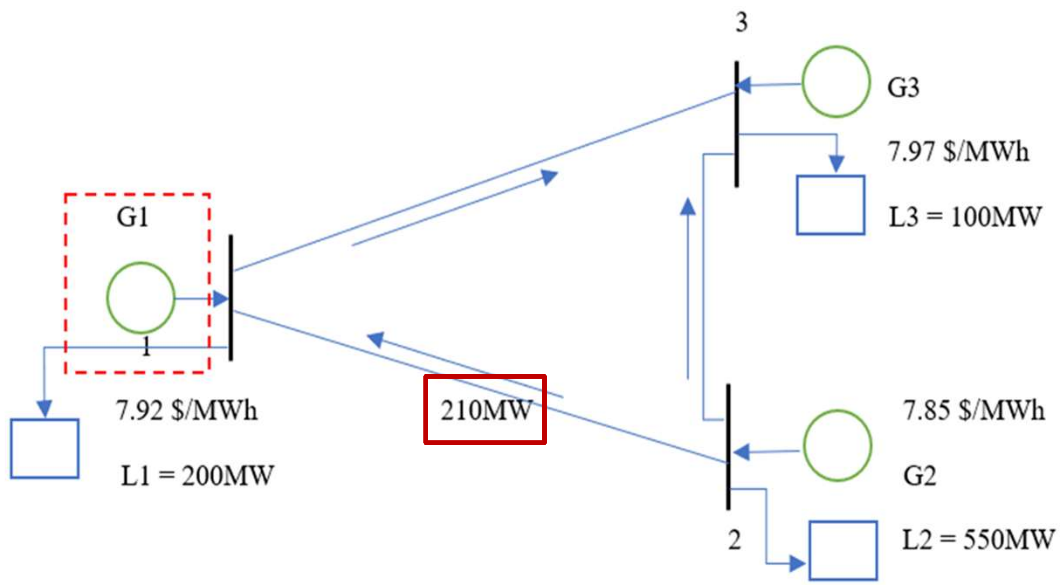






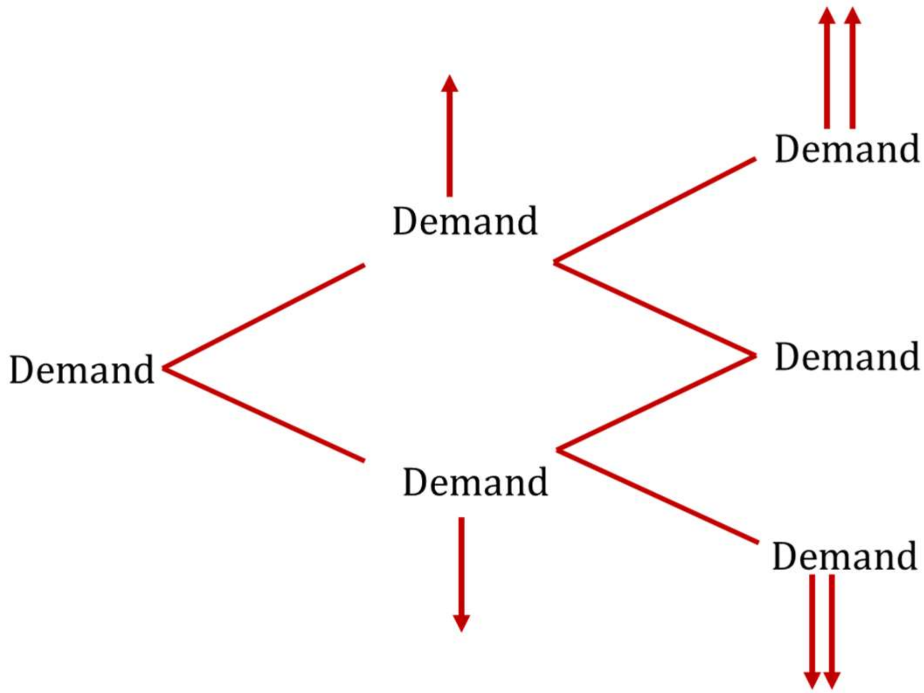
3- bus network for option valuation

- **Case 1:** Bus 1 will have no generator and the demand at this node will be satisfied by generators 2 and/or 3
- **Case 2:** We will add a generator at bus 1 and the total demand will be met by the combination of all three generators



Demand evolution at bus 1

- Demand at bus 1 is uncertain
- If demand increases after one period, the initial demand will be multiplied with an up factor
- If demand decreases after one period, the initial demand will be multiplied with a down factor
- These factors are derived from the volatility in electricity demand



Demand Lattice

- Initial demand at bus 1 = 200 MW
- Time period span = 1 year
- Number of time periods = 5
- Volatility = 30%/year
- Up factor = 1.35
- Down factor = 0.741

Time	0	1	2	3	4	5
						896
					664	
				492		492
			364		364	
		270		270		270
	200		200		200	
		148		148		148
			110		110	
				81		81
					60	
						45

Framework of option valuation

Mapping demand over the modelling horizon using a binomial lattice

Framework of option valuation

Mapping demand over the modelling horizon using a binomial lattice

↓

Calculating the cost paid by the community at bus 1 to fulfil their electricity demand based on the locational marginal price for case 1 and 2

↓

Computing the net benefit by subtracting the cost of case 1 from case 2

↓

Calculating the total benefit of adding a generator at a certain period

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Evaluating the exercise value and hold value at the end period, then determining the option value as max(exercise value, hold value)

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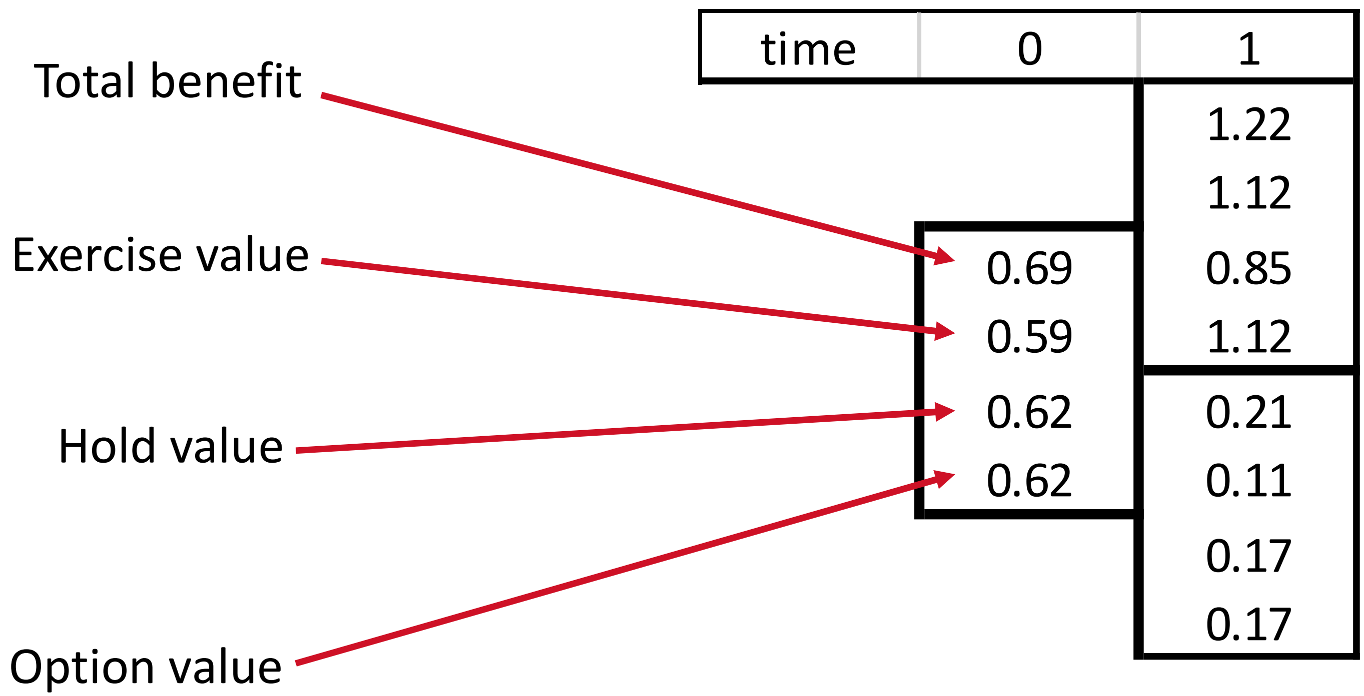
Determining the option value at time 0 by repeatedly calculating the expected value and discounting it

Option value tree

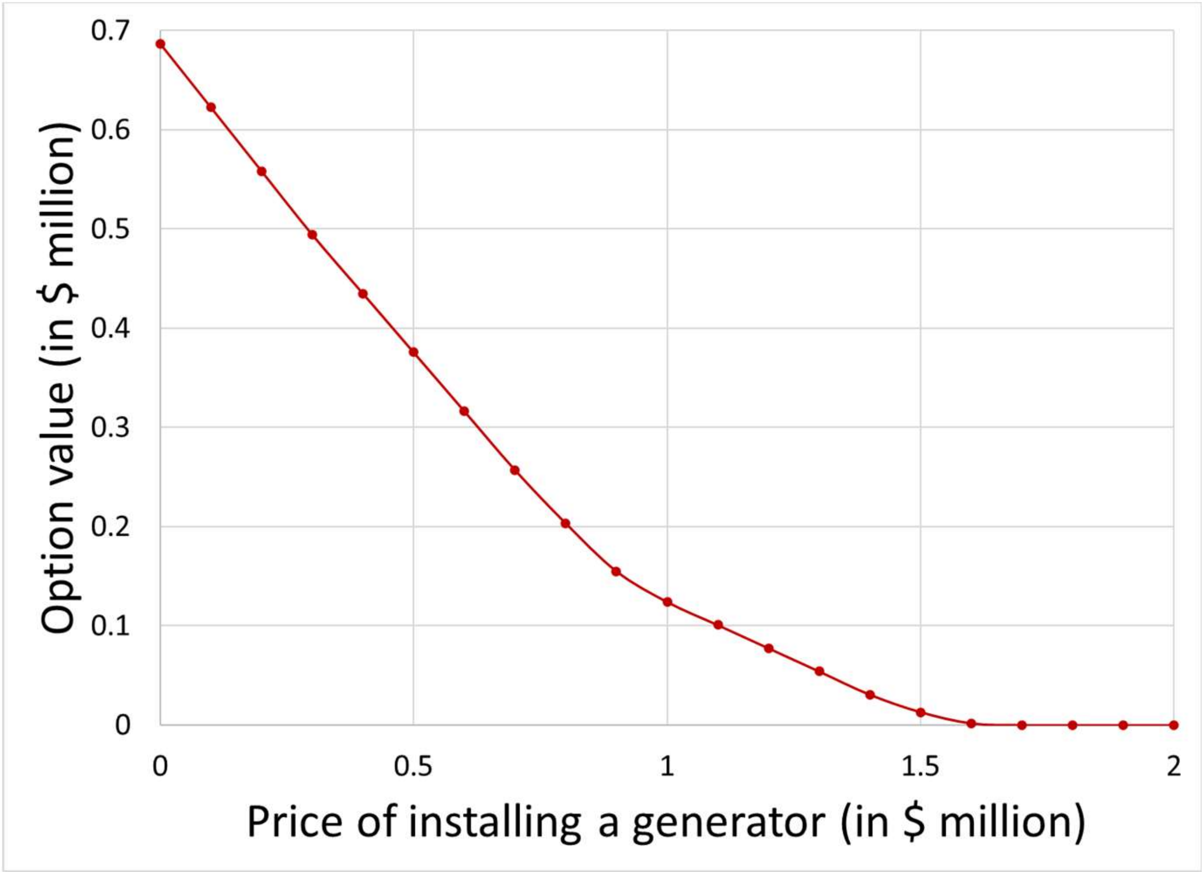


Option value tree

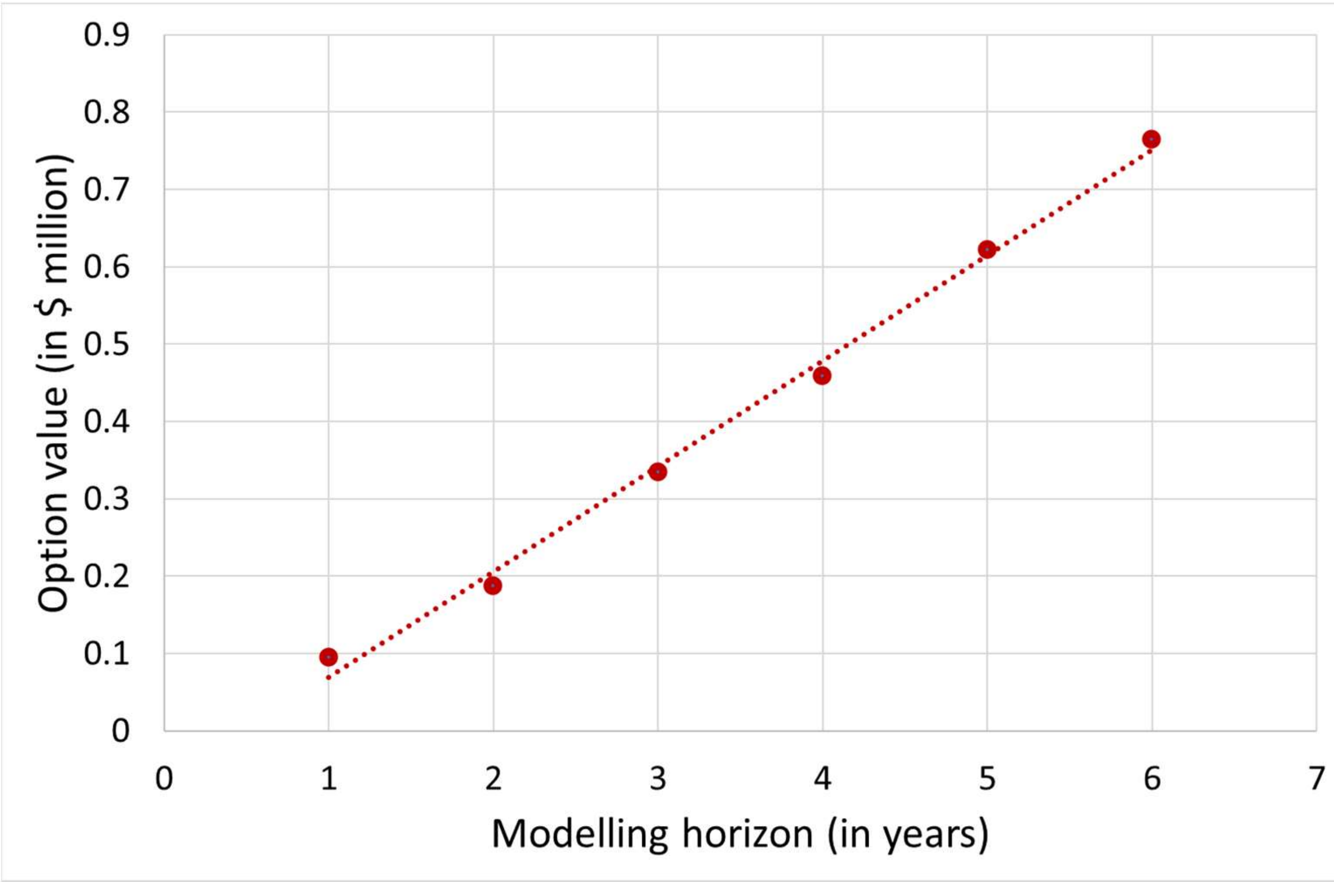
- Hold → Wait for another year to make a decision
- Add → Add a generator now

time	0	1	2	3	4	5
						0.98
						0.88
					1.45	0.00
					1.35	0.88
				1.62	0.63	0.54
		Add		1.52	1.35	0.44
			1.53	0.98	0.80	0.00
	Hold		1.43	1.52	0.70	0.44
		1.22	1.04	0.75	0.30	0.30
		1.12	1.43	0.65	0.70	0.20
	[illegible]	0.85	0.39	0.38	0.14	0.00
	[illegible]	1.12	0.29	0.65	0.04	0.20
	0.62	0.21	0.33	0.07	0.09	0.00
	0.62	0.11	0.33	0.00	0.09	0.00
		0.17	0.03	0.05	0.00	0.00
		0.17	0.00	0.05	0.00	0.00
			0.02	0.00	0.00	0.00
		Hold	0.02	0.00	0.00	0.00
				0.00	0.00	0.00
				0.00	0.00	0.00
					0.00	0.00
					0.00	0.00
						0.00
						0.00

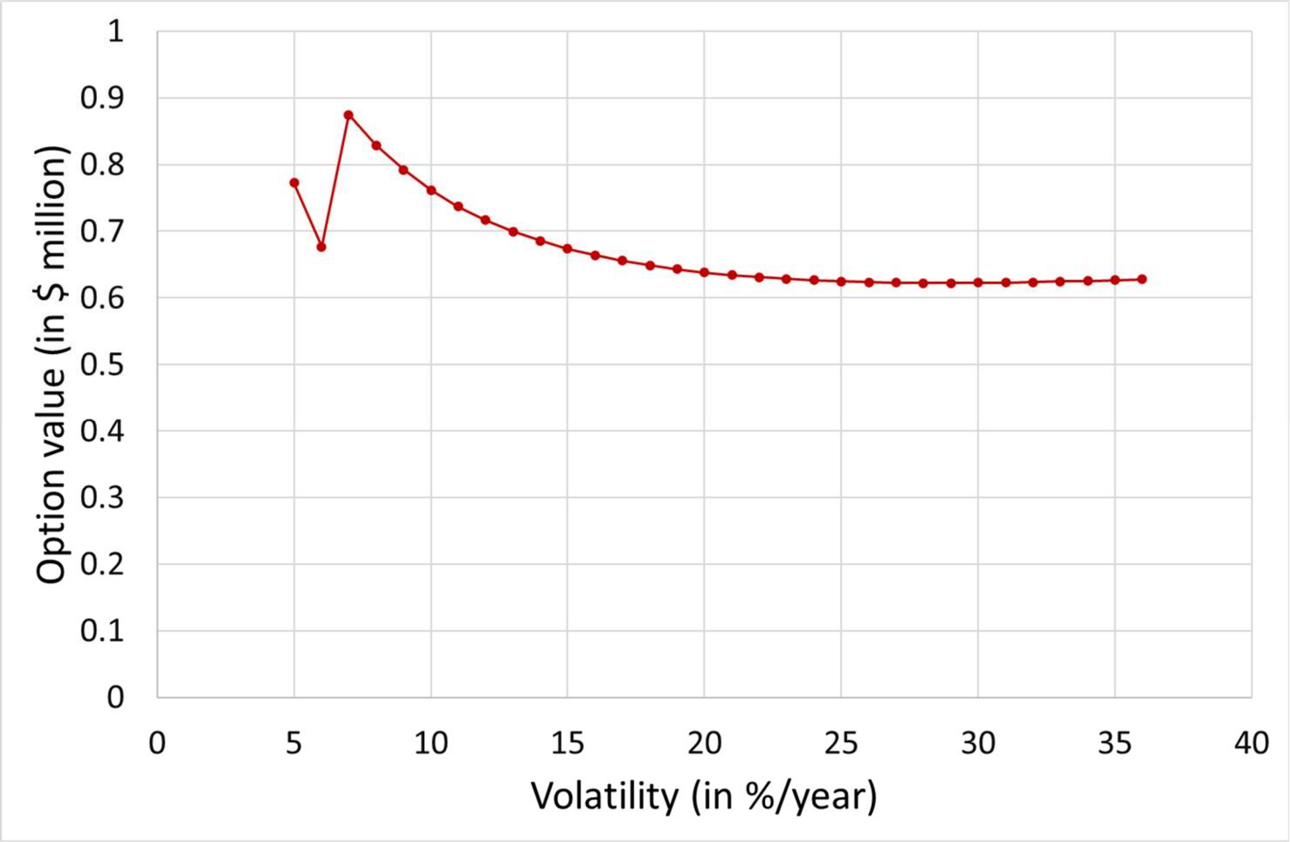
Sensitivity with installation price



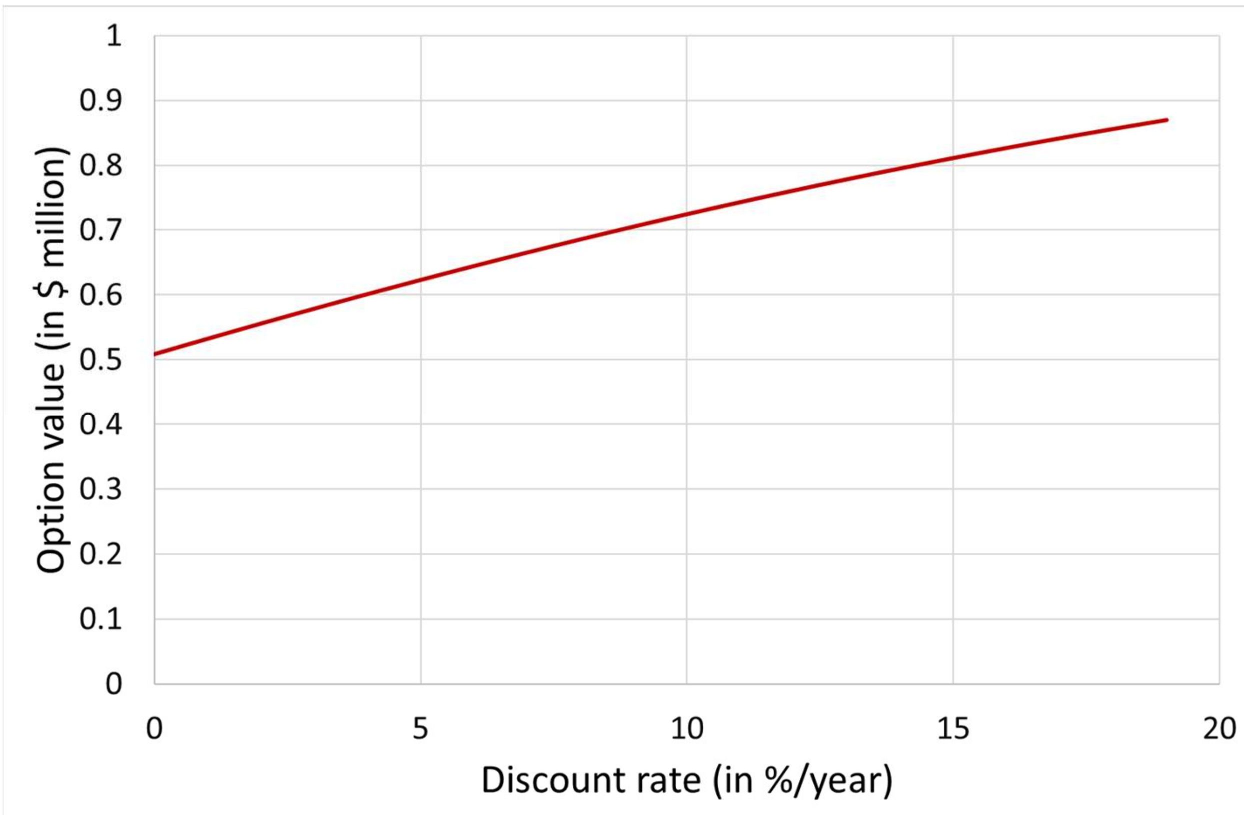
Sensitivity with modelling horizon



Sensitivity with volatility



Sensitivity with discount rate



Extension of option value model

Option value model assumes that cost uncertainty can be hedged

- Purchase futures on price of energy
- Future price = LMP

Loss to initial position

\+

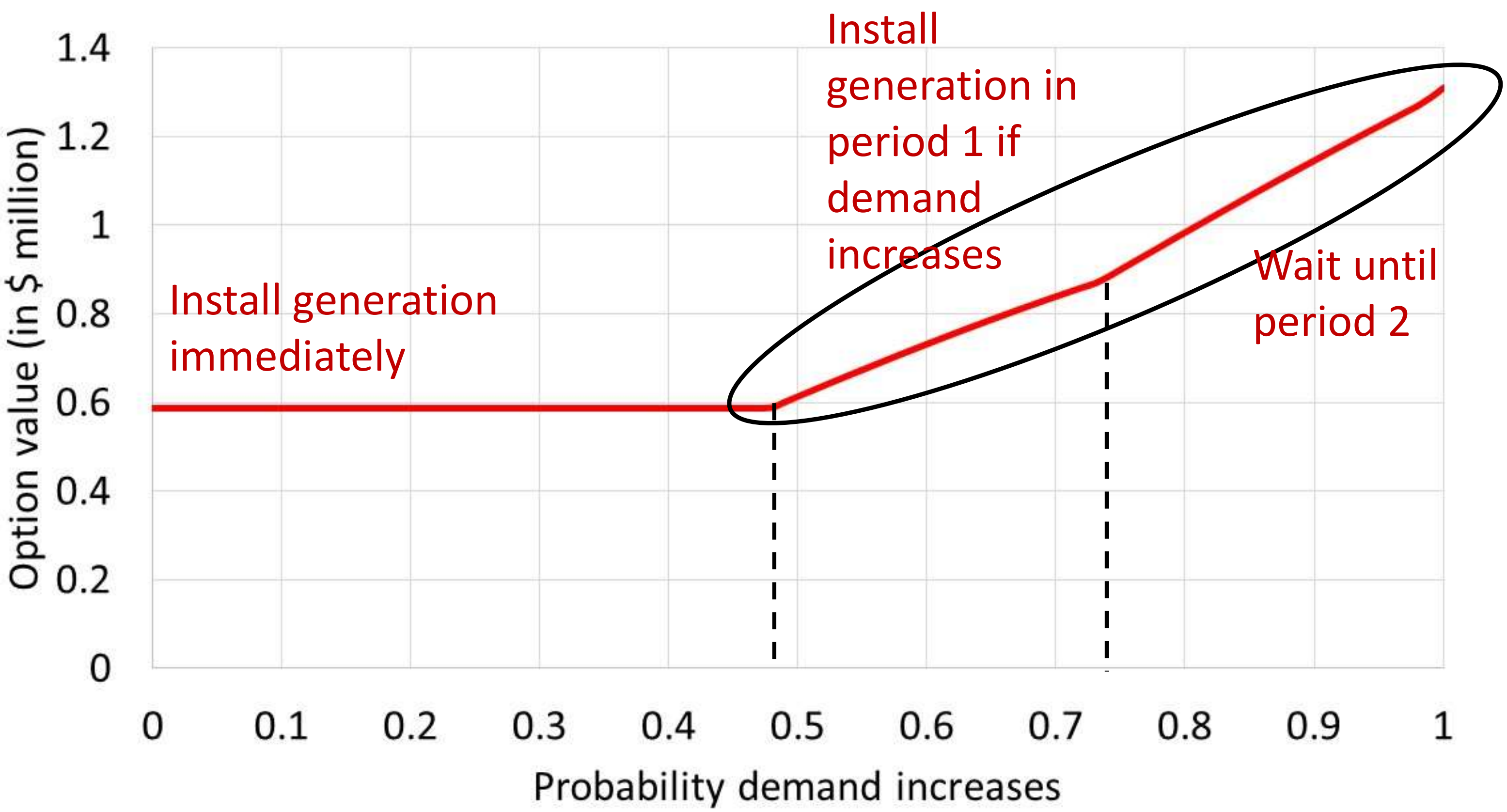
Gain to hedge

=

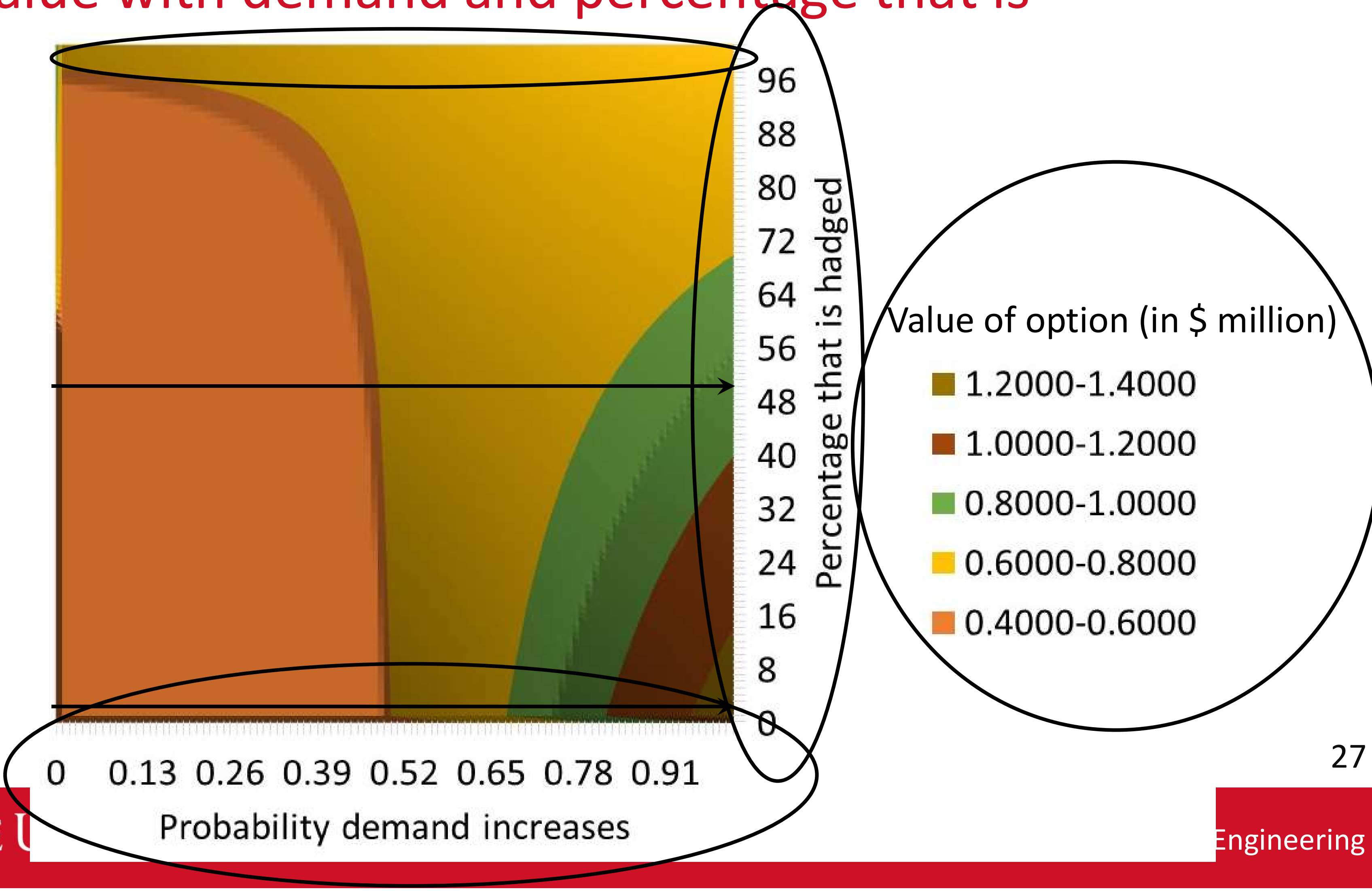
Neutral exposure or reduced risk

What if cost uncertainty cannot be hedged or only partially hedged?

Value of option without hedging

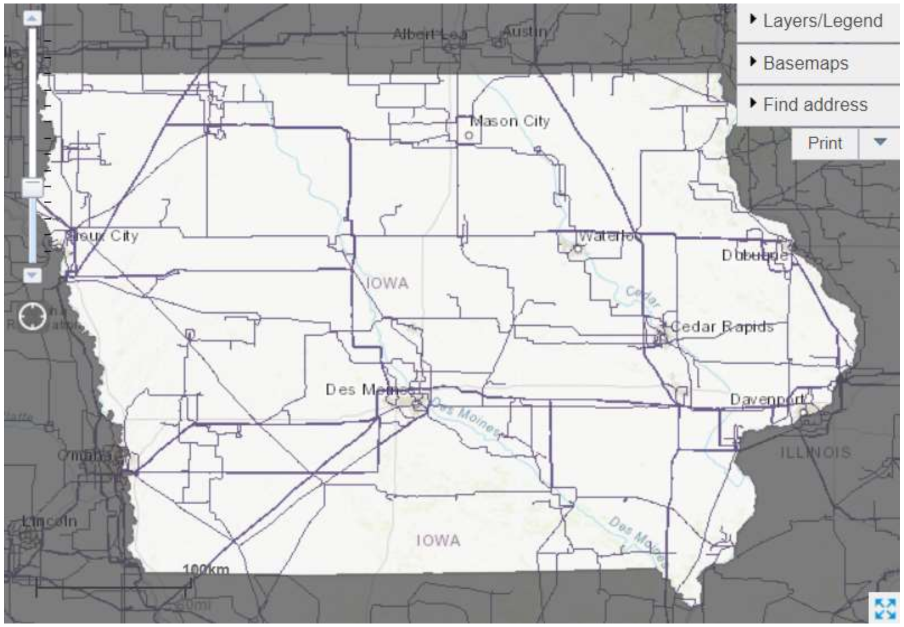


Option value with demand and percentage that is hedged



Economic value of transmission capacity

- How much is additional transmission capacity worth to state? A community? A municipal utility?
  - Where should existing transmission lines be improved?
  - Where should additional transmission lines be added?
- Challenges to answering these questions
  - Physics of electric power
  - Long-range planning
  - Uncertainty in demand planning
  - Uncertainty in weather events



Source: Iowa Energy Profile, U.S. Energy Information Administration

Economic decision making for farmers leasing land for wind turbines

- Under what circumstances should farmers lease land for developers to install wind turbines?
- Different payment types
  - Fixed payment
  - Royalty payments based on revenue
- End of lease considerations
- Farmers’ loss of control

Flexible electric generation portfolio in Iowa

- How should Iowa's electric profile change in the next 10-20 years?
- Uncertainties
  - Demand
  - Costs (investment, fuel)
  - Requirements for using renewable sources
  - Future carbon emission limits
- Dynamic decision making
- Requires long-term planning

Iowa Electric Profile (2020 - Including Non-Utility Generation)

ELECTRIC GENERATION IN IOWA BY PRIMARY ENERGY SOURCE	2020 NAMEPLATE CAPACITY (MW)[1]	PERCENT OF NAMEPLATE CAPACITY	2020 GENERATION (MWH)[2]	PERCENT OF GENERATION
Coal	5,754.7	25.61%	14,146,835	23.72%
Wind	11,406.9	50.76%	34,182,302	57.32%
Nuclear	0.0	0.0%	2,904,863	4.87%
Natural Gas	4,215.0	18.76%	7,036,824	11.80%
Hydro	129.2	0.58%	1,025,215	1.72%

Source: Iowa's Electric Profile, Iowa Utilities Board

Conclusions

- Optimal power flow enables LMP calculations
- Option value: value of installing new generation capability
  - Estimates project's financial worth
  - Determine when to install generation
  - Relation of different parameters (installation price, volatility, discount rate) to option value
- Extension to partial or no hedging
- Development of Excel tool: https://imse.iastate.edu/sweeet
- Applicable to renewable generation sources
- Day-long workshop at Iowa State University in summer 2022

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