

A large offshore wind turbine stands in the middle of a greenish-blue sea under a bright blue sky with scattered white clouds. The turbine has a white tower with a yellow section at the base, and three white blades extending from the top. The text 'Application Portfolio: East Coast Offshore Wind Farm Development' is overlaid in a black-bordered box across the middle of the image.

Application Portfolio: East Coast Offshore Wind Farm Development

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Agenda



- System Description
 - System Overview
 - NPV Analysis
 - Sources of Uncertainty
 - Fixed Base Case and Potential Flexibilities
- Decision Analysis
 - Decision Tree
 - Evaluation Criteria
- Lattice Analysis
 - Lattice Analysis
 - Evaluation Criteria
- Conclusions

System Overview



- Project: development of a 75-turbine wind farm off the East Coast of the United States
- Assumed project lifetime of 20 years, 12% discount rate



NPV Analysis



Year		0	1	2
<i>Turbine construction costs</i>				
Actual cost per turbine (\$)	\$	2,520,000.00		
Turbines installed in year		75		
Down payment	\$	11,025,000.00		
Loan amount per year	\$	19,496,533.89		
Loan costs for the year	\$	(11,025,000.00)	\$ (19,496,533.89)	\$ (19,496,533.89)
Total turbines built so far		75	75	75
<i>Revenue generated</i>				
Full load hours (MWh)		2500		
Electricity generated in year (MWh)			187500	187500
Price per MWh (\$)		120		
Revenue from wind generation (\$)	\$		22,500,000.00	22,500,000.00
<i>Maintenance costs</i>				
Maintenance cost (\$/MWh)		15		
Total maintenance cost	\$		(2,812,500.00)	(2,812,500.00)
Total profit (revenue - cost)	\$	(11,025,000.00)	\$ 190,966.11	\$ 190,966.11
discount rate		12%		
loan rate		9%		
PV	\$	(11,025,000.00)	\$ 170,505.46	\$ 152,237.01
NPV	\$	(9,598,589.40)		

NPV model constructed with three cash flows:

1. Turbine construction: cost of construction, installation, and financing of turbines
2. Electricity revenue: revenue from wind-generated electricity
3. Maintenance costs: cost of overhead and maintenance of operating turbines

Sources of Uncertainty



Year		0	1	2
<i>Turbine construction costs</i>				
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**Cost per turbine
(incl. installation)**

- Low: \$2.52m
- Forecast: \$2.94m
- High: \$3.36m

**Full load hours per
turbine (MWh/year)**

- Low: 2500
- Forecast: 2700
- High: 2900

**Electricity Price
(\$ per MWh)**

- Low: \$25
- Forecast: \$120
- High: \$200
(over 6 years)

Fixed Base Case and Flexibilities



- Fixed base case is 75-turbine wind farm
 - Constructed in year 0
 - Usable total lifetime of 20 years
 - Downpayment is required in year 0 to finance loan
 - 20-year loan at borrowing rate of 9%
- Flexibility 1: Phased construction
 - Used in decision analysis
 - Build 40 turbines in year 0, build 35 more turbines in year 5 if conditions favorable
- Flexibility 2: Shutdown flexibility
 - Used in lattice analysis
 - Shutdown turbines to save on operations cost when electricity price is low

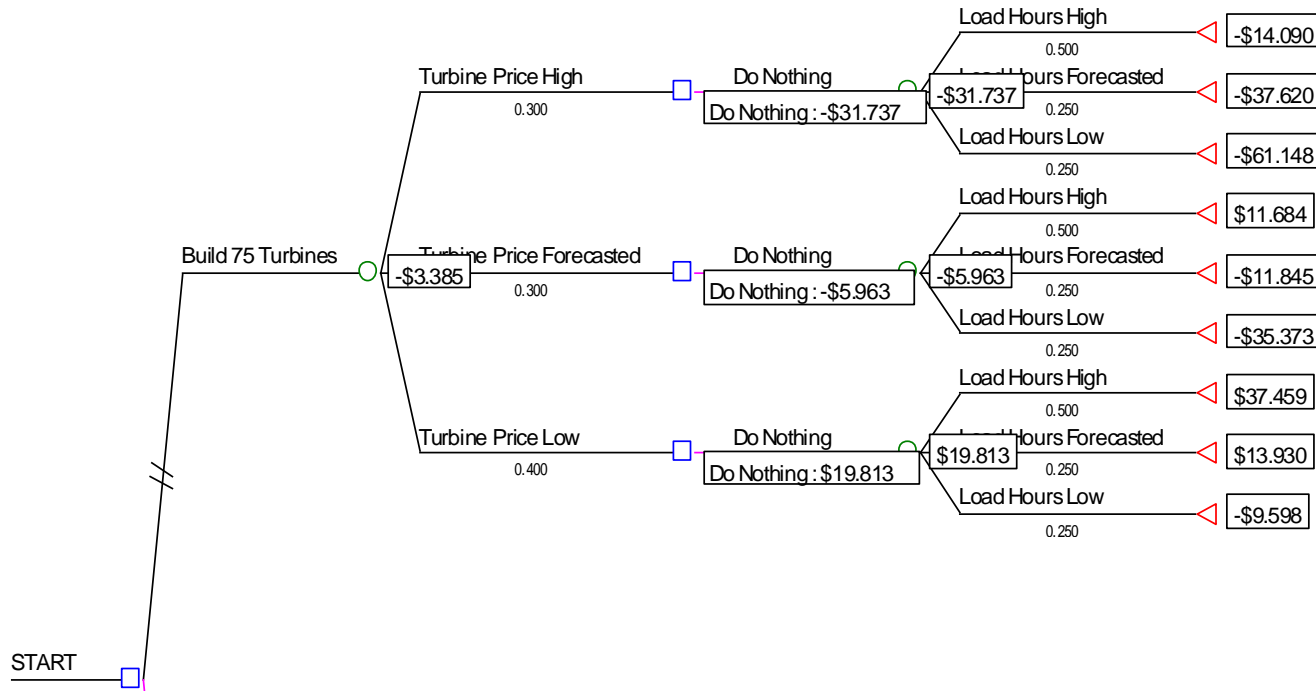
	Decision Analysis	Lattice Analysis
Uncertainties	Cost of a turbine Full load hours of a turbine	Price of electricity
Uncertainties assumed as fixed	Price of electricity	Cost of a turbine Full load hours of a turbine
Flexibility exercised	Phased construction flexibility	Shutdown flexibility

Decision Analysis



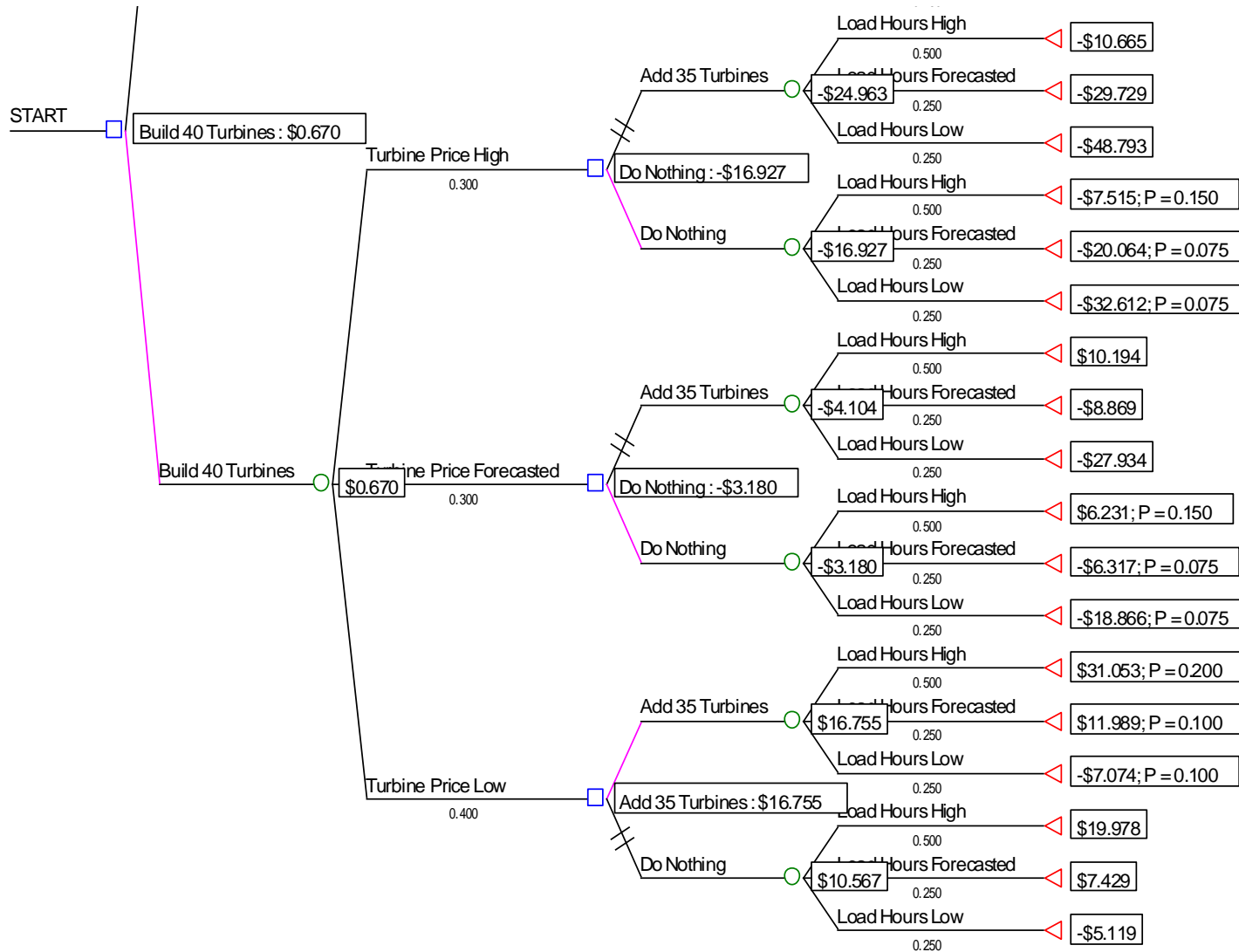
- Two-stage decision analysis
 - First decision: build 75-turbine plant now versus build 40-turbine plant now
 - First chance outcome: the cost of the installation of one turbine including materials, transportation, and labor could be at high, forecasted, or low levels
 - Second decision: wait 5 years, then build 35 additional turbines (if not at 75 already) if conditions are favorable.
 - Second chance outcome: the number of full load hours per turbine could be at high, forecasted, or low levels

Decision Analysis (Fixed Branch)



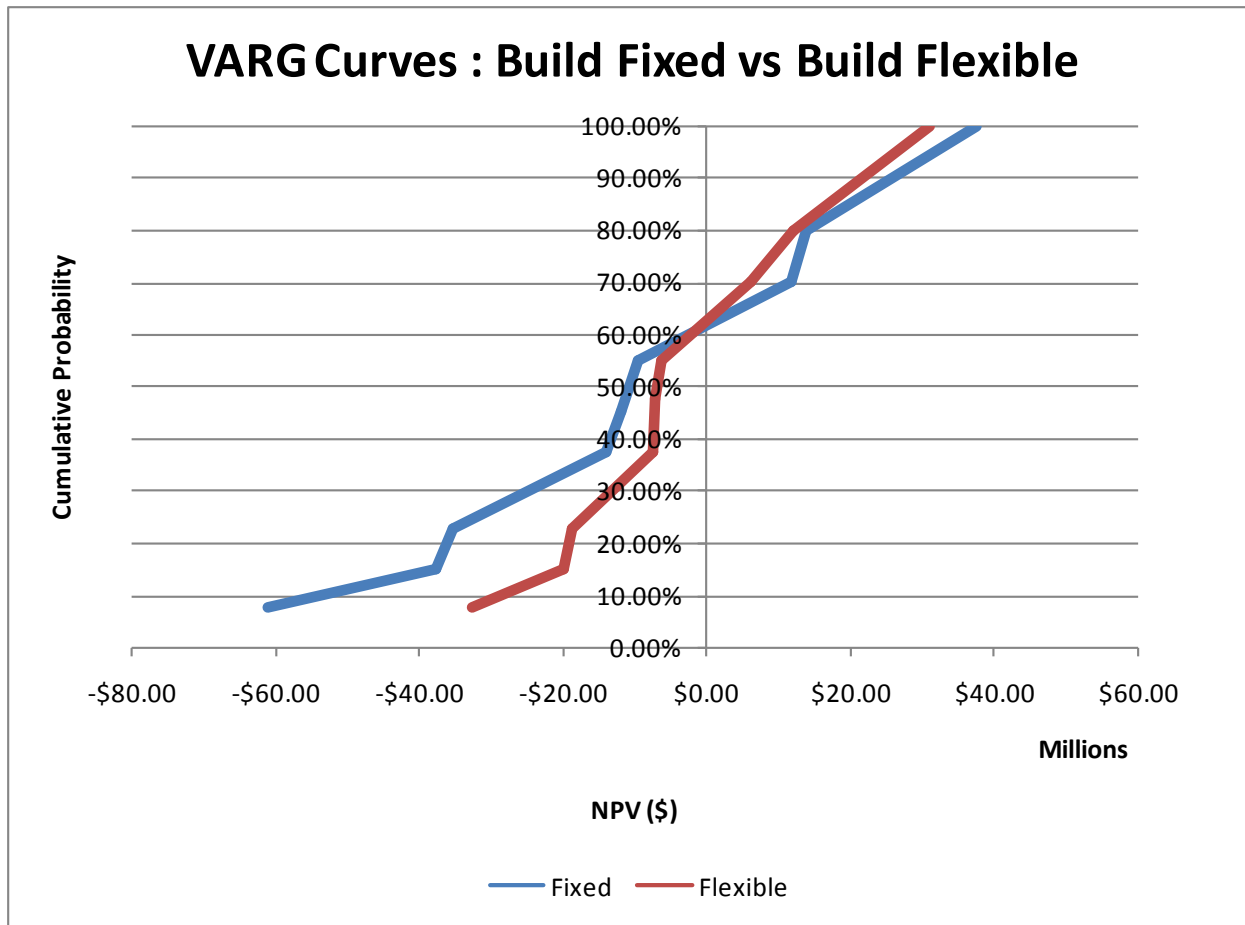
- Fixed implementation: -\$3.39m NPV

Decision Analysis (Flexible Branch)



- Flexible implementation: \$0.67m NPV

VARG Curve



- VARG curve shows building in flexible manner decreases downside risk while achieving almost equal upside potential

Multiple Criteria



Criterion	Fixed Design	Flexible Design	Comparison
Expected NPV	-\$3.39m	\$0.67m	Flexible design better
Maximum NPV	\$37.5m	\$31.0m	Fixed design better
Minimum NPV	-\$61.1m	-\$32.6m	Flexible design better
P10 Value	approx. -\$50m	approx. -\$30m	Flexible design better
P90 Value	approx. \$30m	approx. \$25m	Fixed design better
Initial CAPEX	\$11.0m	\$5.88m	Flexible design better
ENPV/CAPEX	-0.31	0.11	Flexible design better

- Flexible design is better in all criteria except P90 value and maximum NPV
- Flexible implementation is preferred design

Lattice Analysis



- Base case: 75-turbine wind farm constructed in year 0
- Flexibility: after year 1, option to shut down turbines to prevent maintenance cost, if electricity price low
- Uncertainty: Price of electricity varying over 6 years, with a low value of \$25 per MWh, a forecasted value of \$120 per MWh, and a high value of \$200 per MWh

OUTCOME LATTICE

							Step	(u/d)exp[step]	Outcome/lowest
100.00	112.25	125.99	141.42	158.74	178.18	200.00	6	8.00	8.00
	79.37	89.09	100.00	112.25	125.99	141.42	5	5.66	5.66
		63.00	70.71	79.37	89.09	100.00	4	4.00	4.00
			50.00	56.12	63.00	70.71	3	2.83	2.83
				39.69	44.54	50.00	2	2.00	2.00
					31.50	35.36	1	1.41	1.41
						25.00	0	1.00	1.00

ENPV: Flexible vs. Inflexible Design



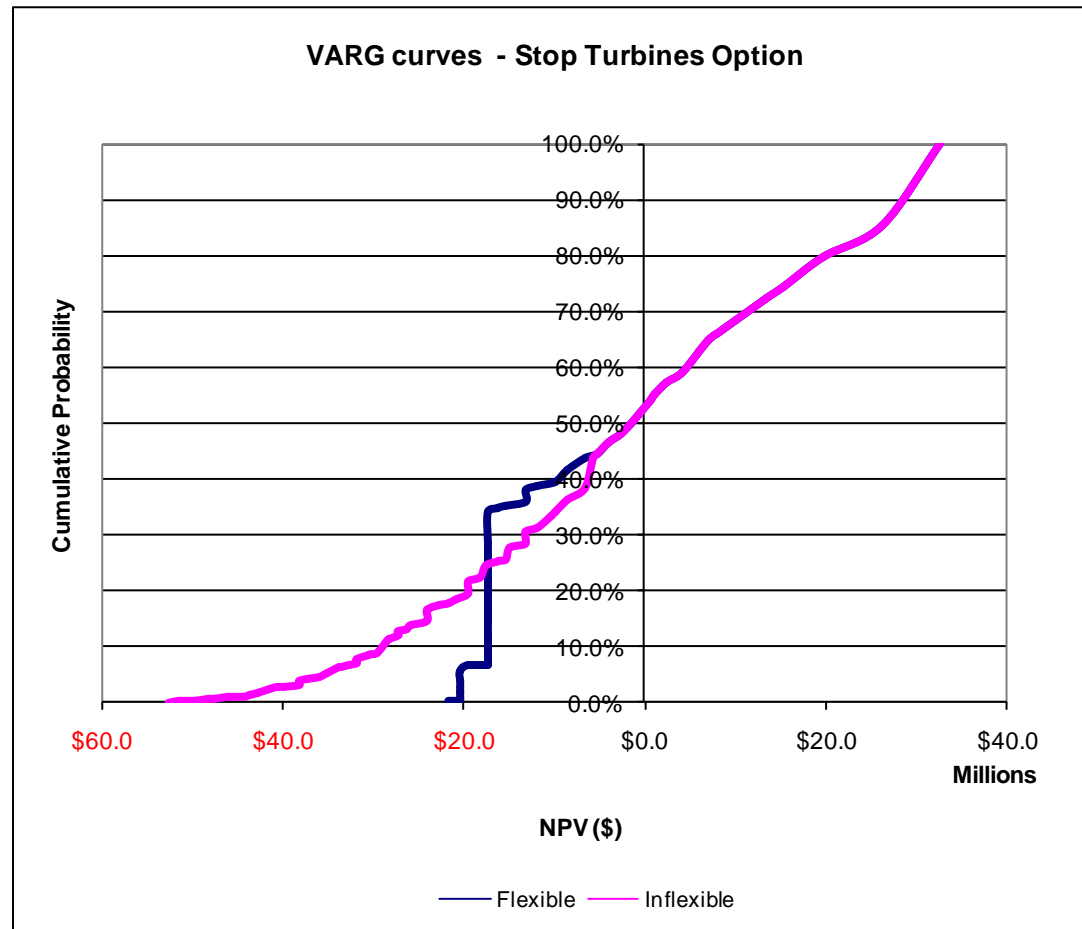
ENPV (Cash Flow)	192,276	125,723	11,304,642	20,127,134	25,151,852	24,853,737	17,290,252
NO FLEXIBILITY		35,438,189	22,999,758	11,882,660	2,865,555	3,043,430	4,549,397
Dynamic programming approach			47,256,633	34,517,003	22,676,853	12,378,786	4,459,748
(check next year)				50,521,900	36,685,557	23,283,939	10,830,175
					46,591,206	30,995,047	15,334,748
						36,447,624	18,519,962
							20,772,248

ENPV(Cash Flow)	1,790,993	67,090	11,304,642	20,127,134	25,151,852	24,853,737	17,290,252
WITH STOP OPTION		29,435,376	22,214,483	11,882,660	2,865,555	3,043,430	4,549,397
Dynamic programming approach			32,996,721	31,318,790	22,676,853	12,378,786	4,459,748
(check next year)				35,823,362	34,491,587	23,283,939	10,830,175
					38,066,869	30,995,047	15,334,748
						36,447,624	18,519,962
							20,772,248

Stop Turbines?	NO	NO	NO	NO	NO	NO
WITH STOP OPTION		YES	NO	NO	NO	NO
Dynamic programming approach			YES	YES	NO	NO
(check next year)				YES	YES	NO
					YES	NO
						NO

- ENPV of inflexible design: \$0.192m
- ENPV of flexible design: \$1.79m

VARG Curve



- VARG curve shows shutdown flexibility decreases downside risk while achieving equal upside potential

Multiple Criteria



Criterion	Inflexible Design	Flexible Design	Comparison
Expected NPV	\$0.192m	\$1.79m	Flexible design better
Maximum NPV	\$32.7m	\$32.7m	Same
Minimum NPV	-\$52.6m	-\$21.8m	Flexible design better
P10 Value	-\$29.0m	-\$17.3m	Flexible design better
P90 Value	\$28.0m	\$28.0m	Same
Initial CAPEX	\$11.0m	\$11.0m	Same
ENPV/CAPEX	0.02	0.15	Flexible design better

- Flexible design is the same or better for all criteria
- Flexible design is preferred implementation

Conclusions



- Development of a 75-turbine offshore wind farm can be designed with flexibility
 - Limits downside risk (i.e. ENPV)
 - Achieves almost equal gain (i.e. ENPV)
- Decision analysis shows benefits of deploying the wind farm in two stages
 - Stage 1: 40 turbines in year 0
 - Stage 2: 35 turbines in year 5, if conditions favorable
- Lattice analysis shows benefits of the option to shutdown turbines
 - When price of electricity low, shutting down turbines saves money compared to continued operation