# Application Portfolio: East Coast Offshore Wind Farm Development

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# Agenda

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  - NPV Analysis
  - Sources of Uncertainty
  - Fixed Base Case and Potential Flexibilities
- Decision Analysis
  - Decision Tree
  - Evaluation Criteria
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  - Lattice Analysis
  - Evaluation Criteria
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# 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 |
| *Turbine construction costs* | | | | | | | | |
| 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 |
| | | | | | | | | |
| *Revenue generated* | | | | | | | | |
| 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 |
| | | | | | | | | |
| *Maintenance costs* | | | | | | | | |
| 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 |
|---|---|---|---|---|---|
| *Turbine construction costs* | | | | | |
| 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 |
| | | | | | |
| *Revenue generated* | | | | | |
| 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 |
| | | | | | |
| *Maintenance costs* | | | | | |
| 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)** | | |

**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

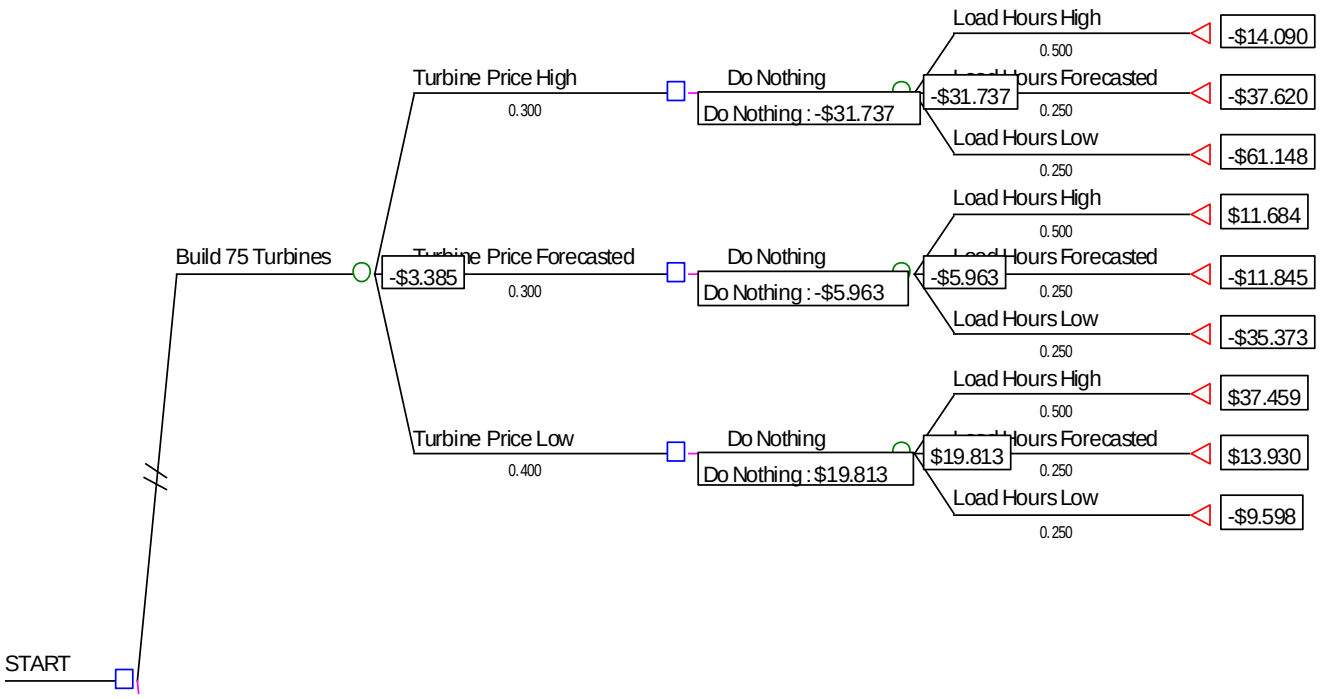
- Fixed base case is 75-turbine wind farm
  - Constructed in year 0
  - Usable total lifetime of 20 years
  - Downpayment is required in year 0 to finance loan
  - 20-year loan at borrowing rate of 9%
- Flexibility 1: Phased construction
  - Used in decision analysis
  - Build 40 turbines in year 0, 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<br>Full load hours of a turbine | Price of electricity |
| **Uncertainties assumed as fixed** | Price of electricity | Cost of a turbine<br>Full load hours of a turbine |
| **Flexibility exercised** | Phased construction flexibility | Shutdown flexibility |

# Decision Analysis

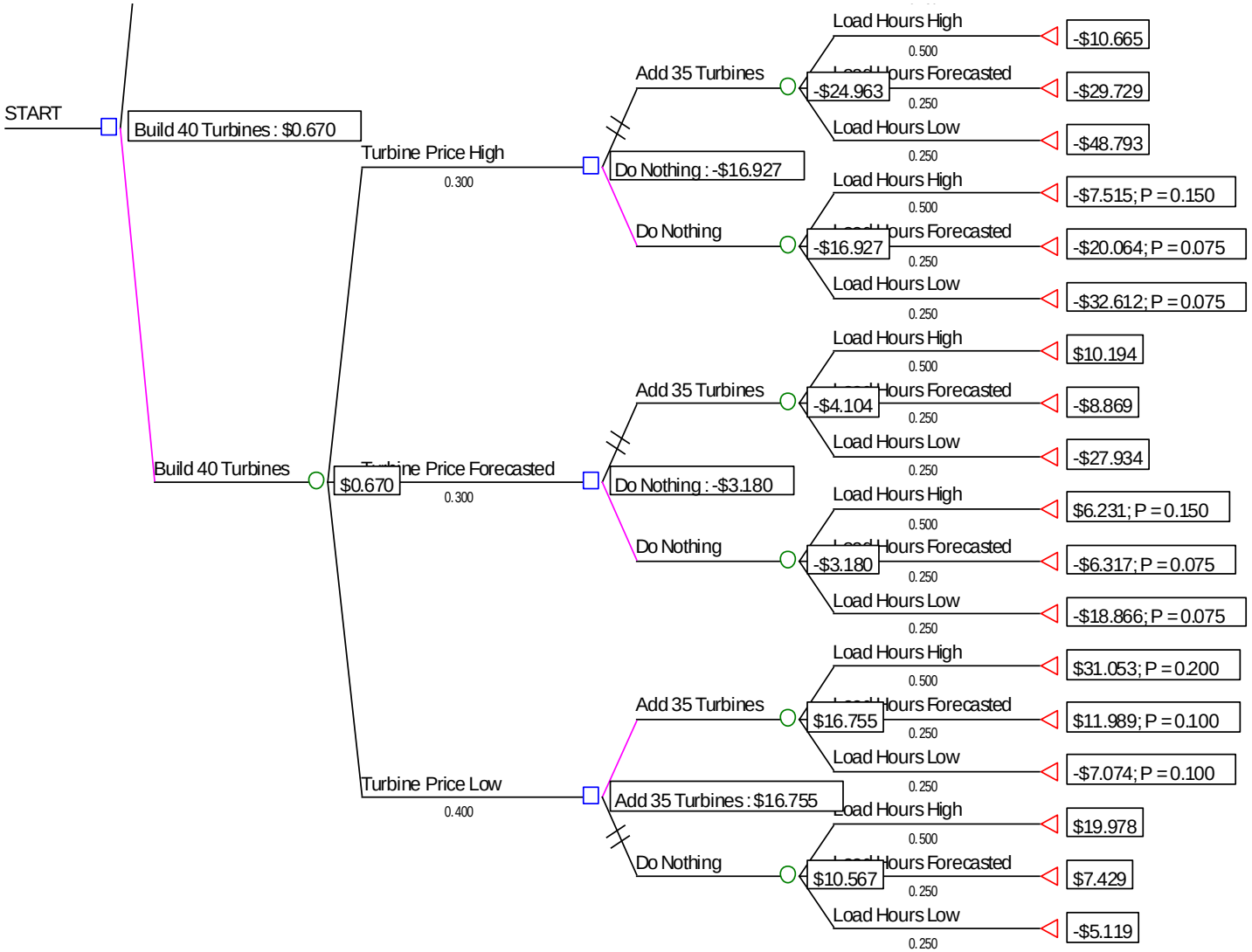
- Two-stage decision analysis
  - First decision: build 75-turbine plant now versus build 40-turbine plant now
  - First chance outcome: the cost of the installation of one turbine including materials, transportation, and labor could be at high, forecasted, or low levels
  - Second decision: wait 5 years, 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)



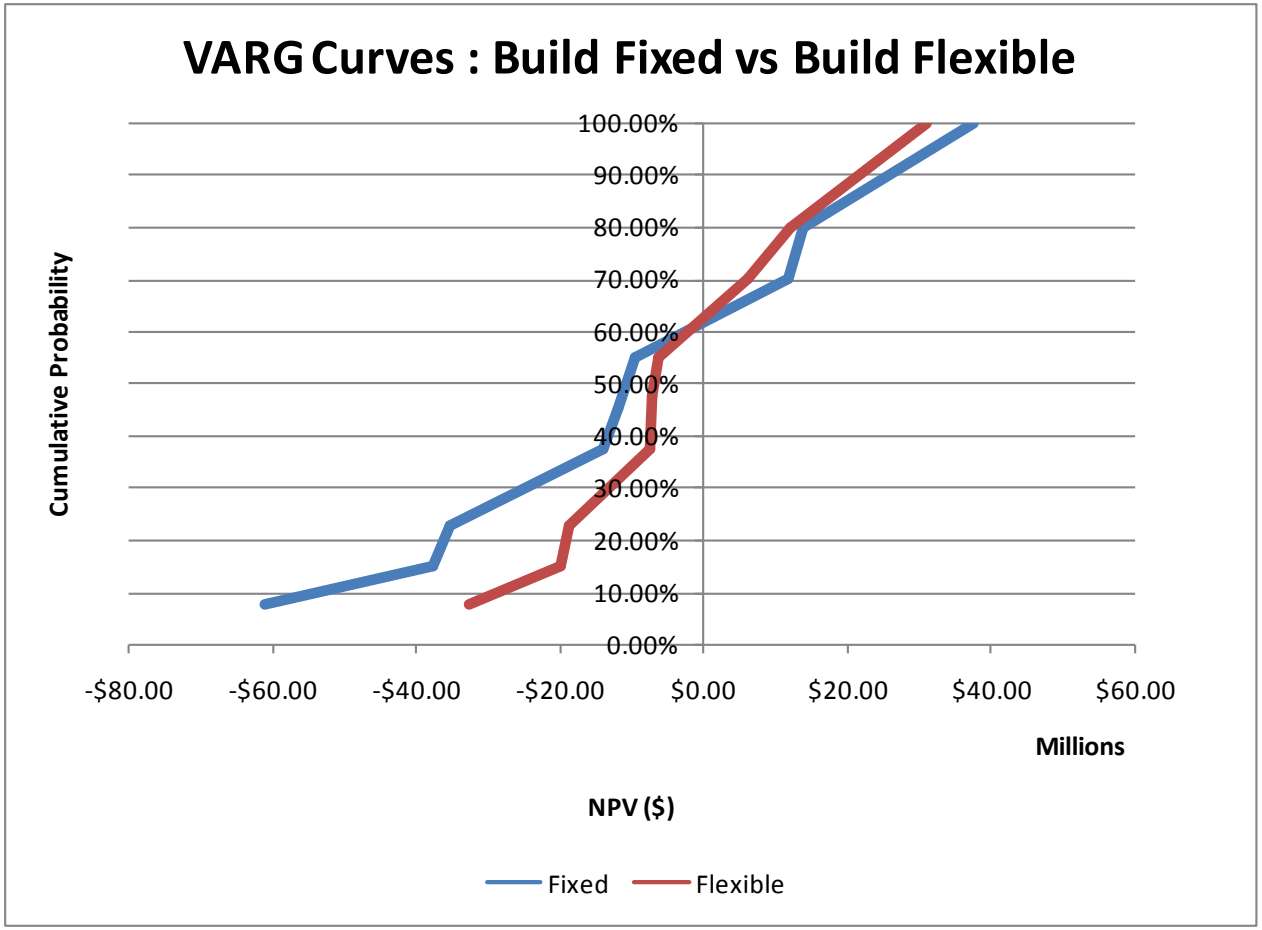

- Fixed implementation: -$3.39m NPV

# 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**

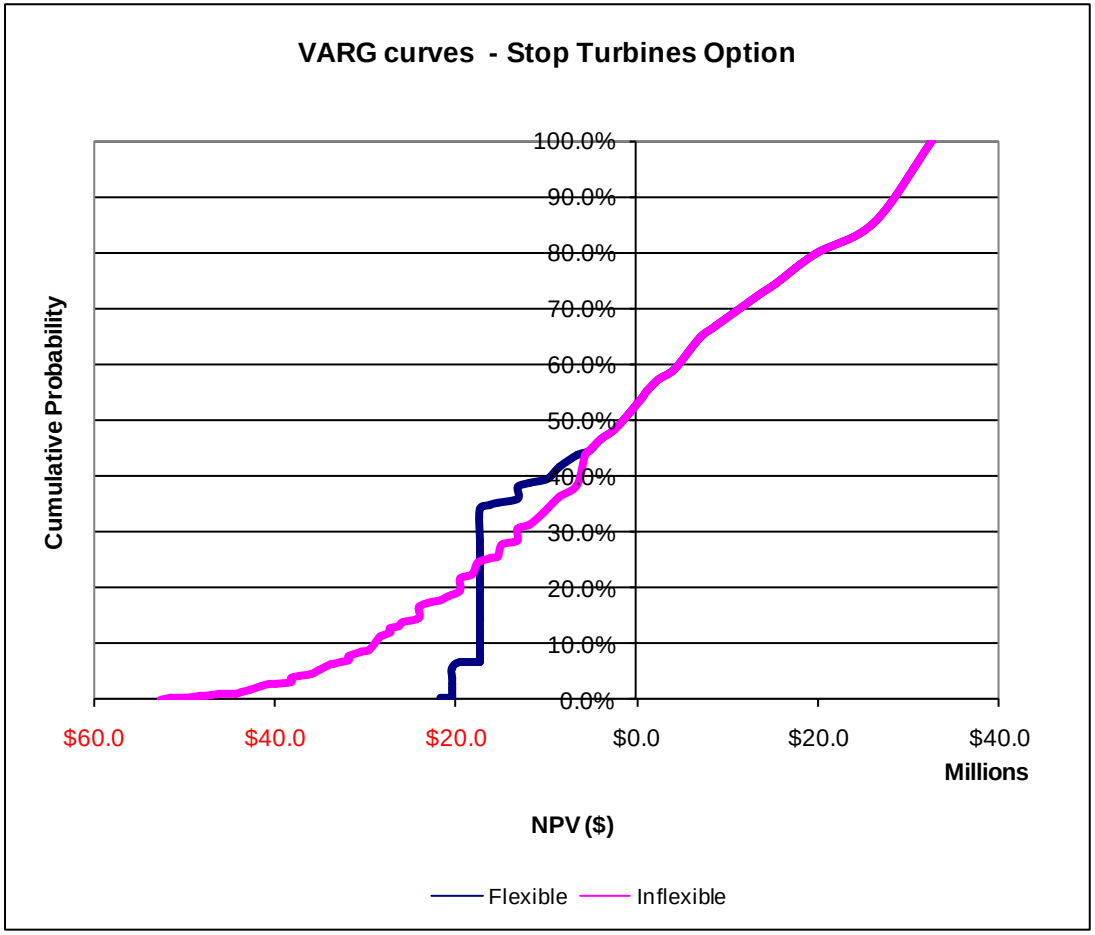
| | | | | | | | Step | (u/d)exp[step] | 0utcome/lowest |
|---|---|---|---|---|---|---|---|---|---|
| 100.00 | 112.25 | 125.99 | 141.42 | 158.74 | 178.18 | 200.00 | 6 | 8.00 | 8.00 |
| | 79.37 | 89.09 | 100.00 | 112.25 | 125.99 | 141.42 | 5 | 5.66 | 5.66 |
| | | 63.00 | 70.71 | 79.37 | 89.09 | 100.00 | 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 | | | 47,256,633 | 34,517,003 | 22,676,853 | 12,378,786 | 4,459,748 |
| approach | | | | 50,521,900 | 36,685,557 | 23,283,939 | 10,830,175 |
| (check next year) | | | | | 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 | | | 32,996,721 | 31,318,790 | 22,676,853 | 12,378,786 | 4,459,748 |
| approach | | | | 35,823,362 | 34,491,587 | 23,283,939 | 10,830,175 |
| (check next year) | | | | | 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 | | | YES | YES | **NO** | **NO** | |
| approach | | | | YES | YES | **NO** | |
| (check next year) | | | | | 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