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Performance assessment of geothermal systems: quantifying key performance indicators in exploration and resource potential estimation

› Jan-Diederik van Wees

Erice september 28 2012

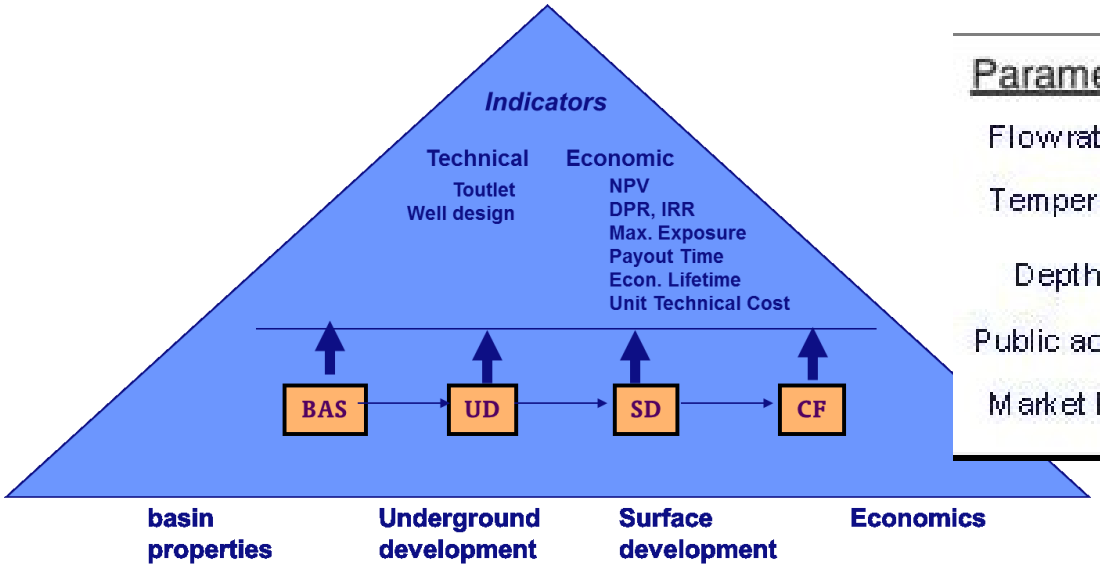
Performance assessment of geothermal systems: assisting in exploration strategies

- We all know that
  - uncertainties in geothermal exploration can be significant
  - Crucial to incorporate them in decision making properly
  - Crucial to communicate them transparently to all stakeholders

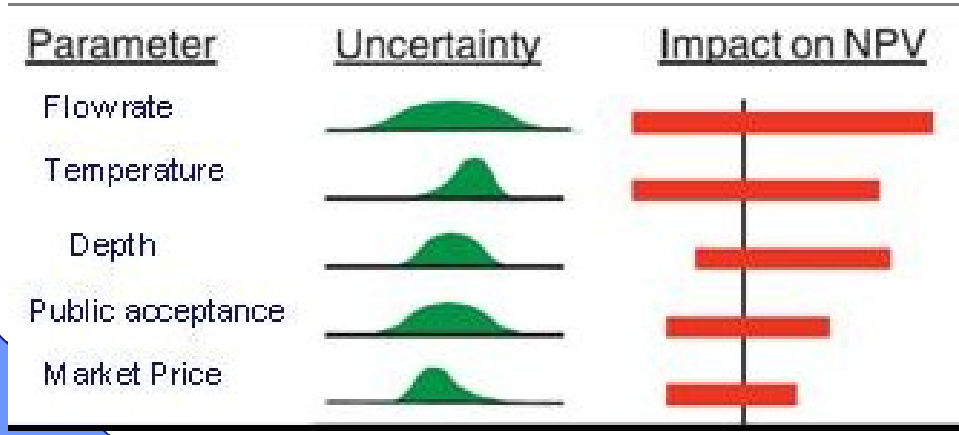
- Quantitative performance tools are key

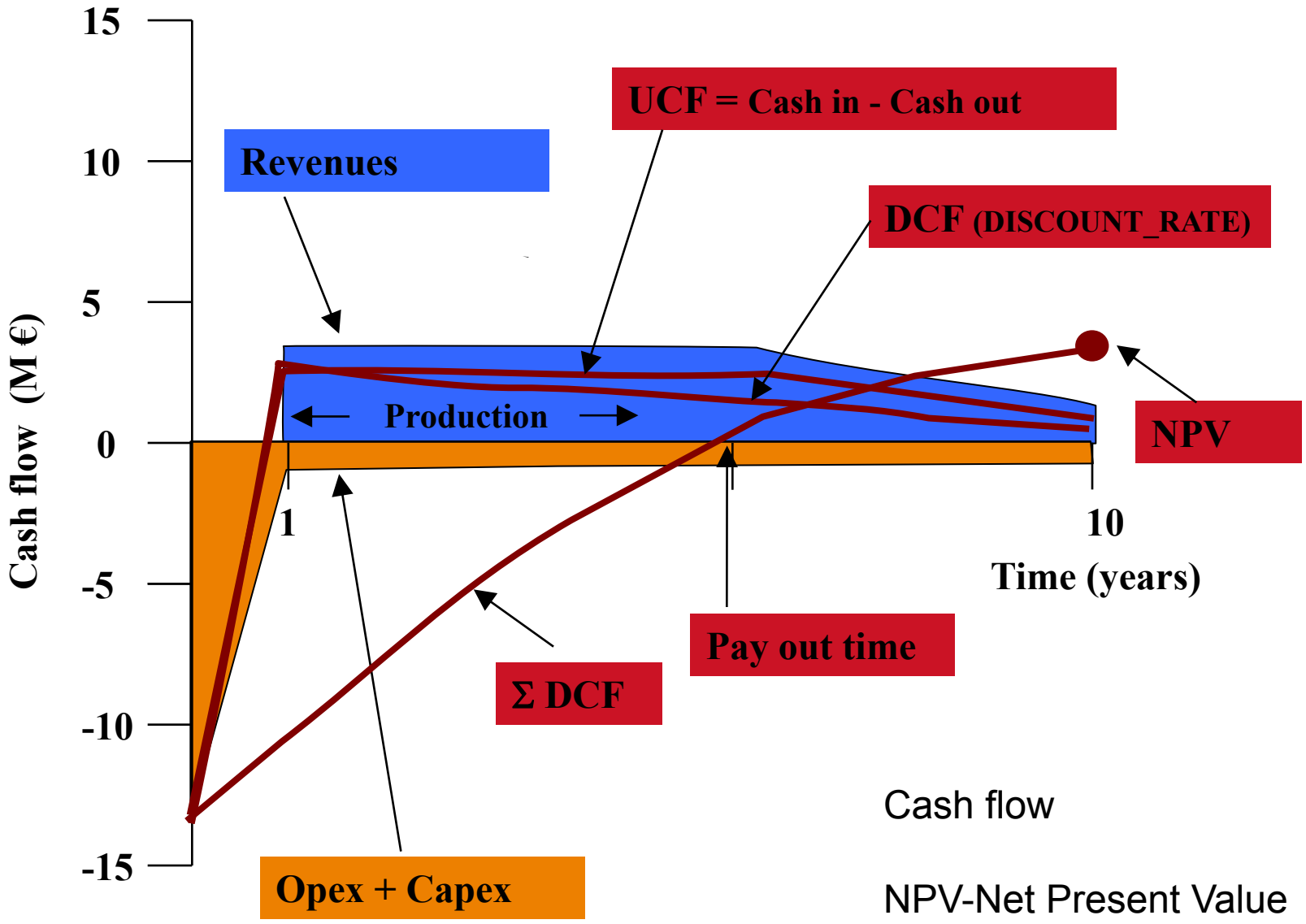
How to achieve transparant framework

- Evaluate transparant Key Performance Indicators
  - Net Present Value, Levelized Cost of Energy
  - Evaluate with fastmodels for techno-economic performance
  - Use MC sampling evaluate risk and upside in reward



driving philosophy is to trade-off accuracy for completeness





Cash flow

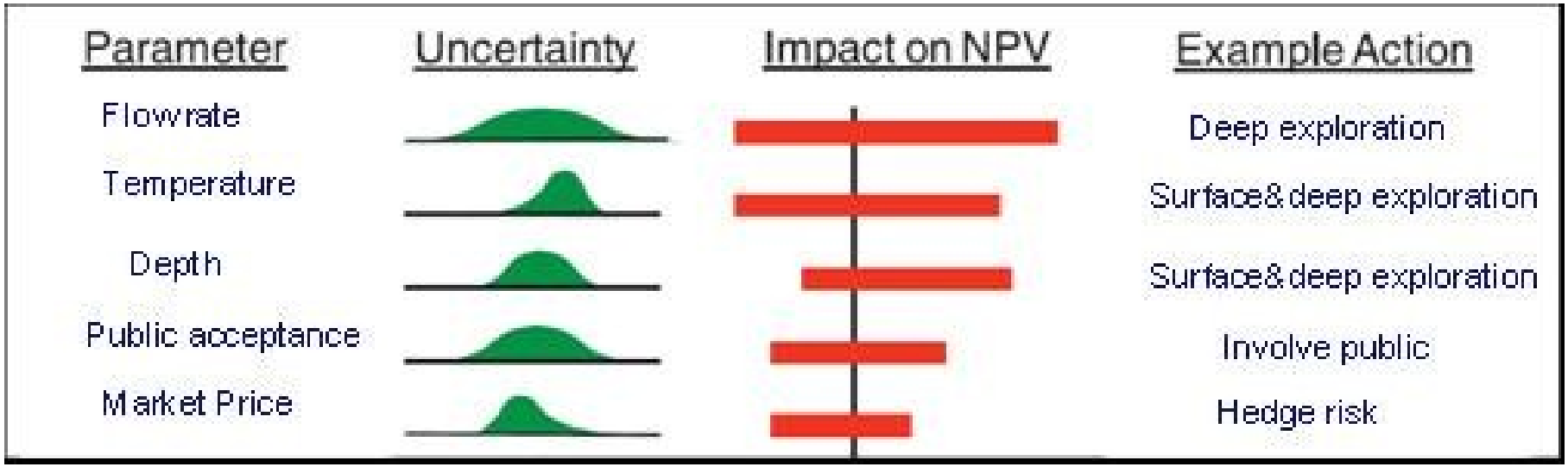
NPV-Net Present Value

Levelized Cost of Energy

- Discounted energy produced [MWh, GJ]
- Discounted cash out [EUR]

- LCOE = discouted cash-out / discounted energy produced

Usage for resource potential project risk



Potential estimates
→ NL aquifers

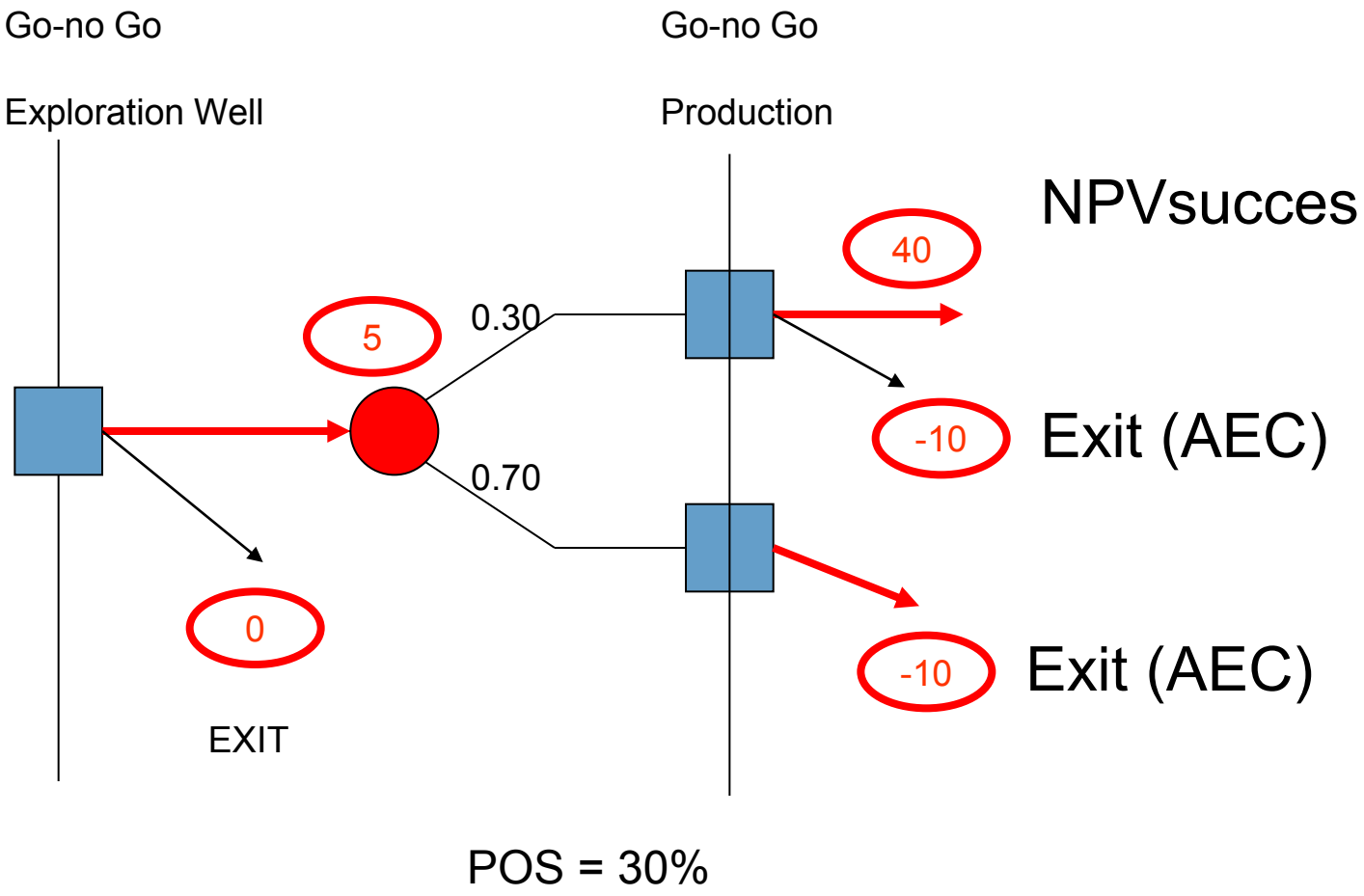
Staged project workflow → Mitigation and awareness of risk

Batini and Van Wees (2010)

The investors perspective

- Definition of risk
  - Risk = probability of something * impact
  - Risk (project) = expected negative income
  - NPV = POS NPVsucces + (1-POS) AEC
  - Risk = (1-POS) AEC
  - Reward = NPV = POS NPVsucces + (1-POS) AEC

Putting things together Default workflow

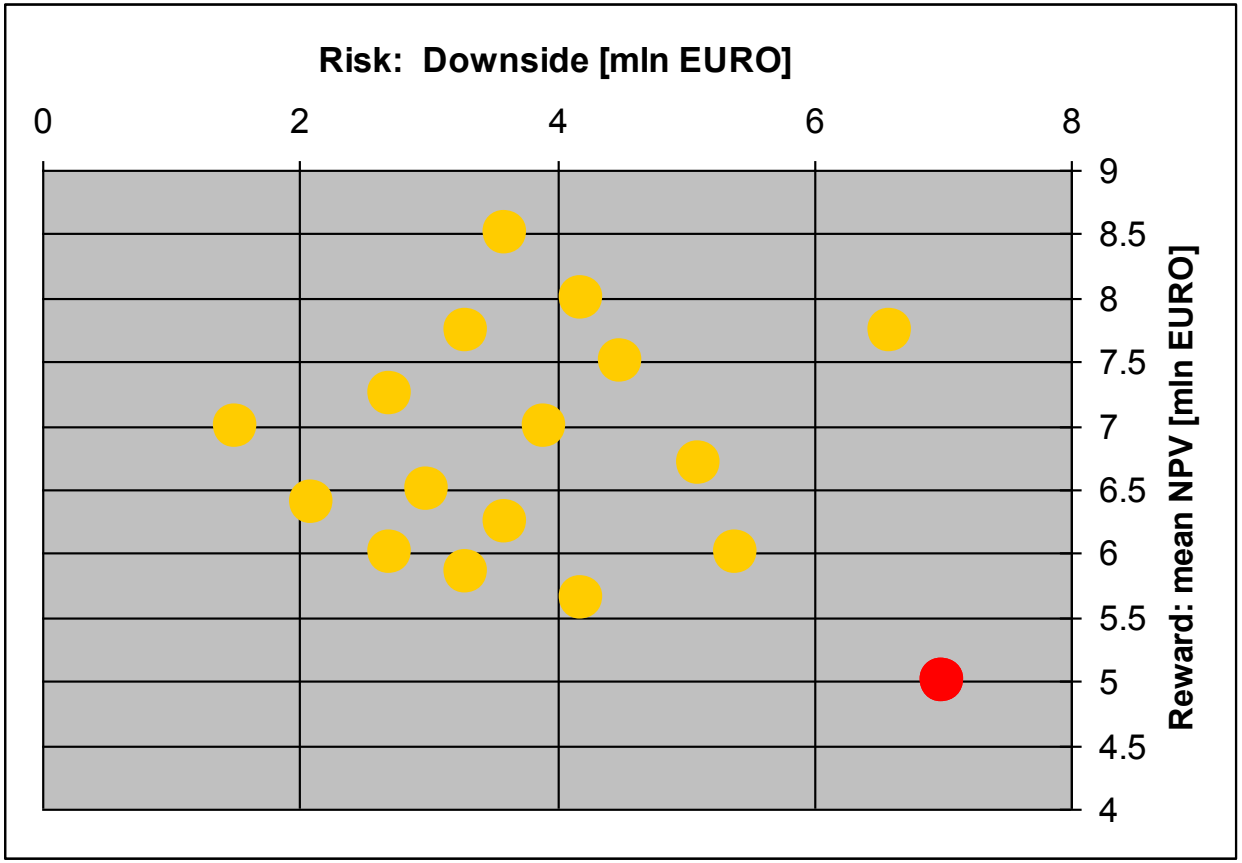


POS = 30%

Imaginary prospect (red) with exploration costs 10 mln, POS 30%, NPVsucces 40 mln

Expectation NPV of Prospect

- Risk = 0.7*10 = 7
- Reward = 5

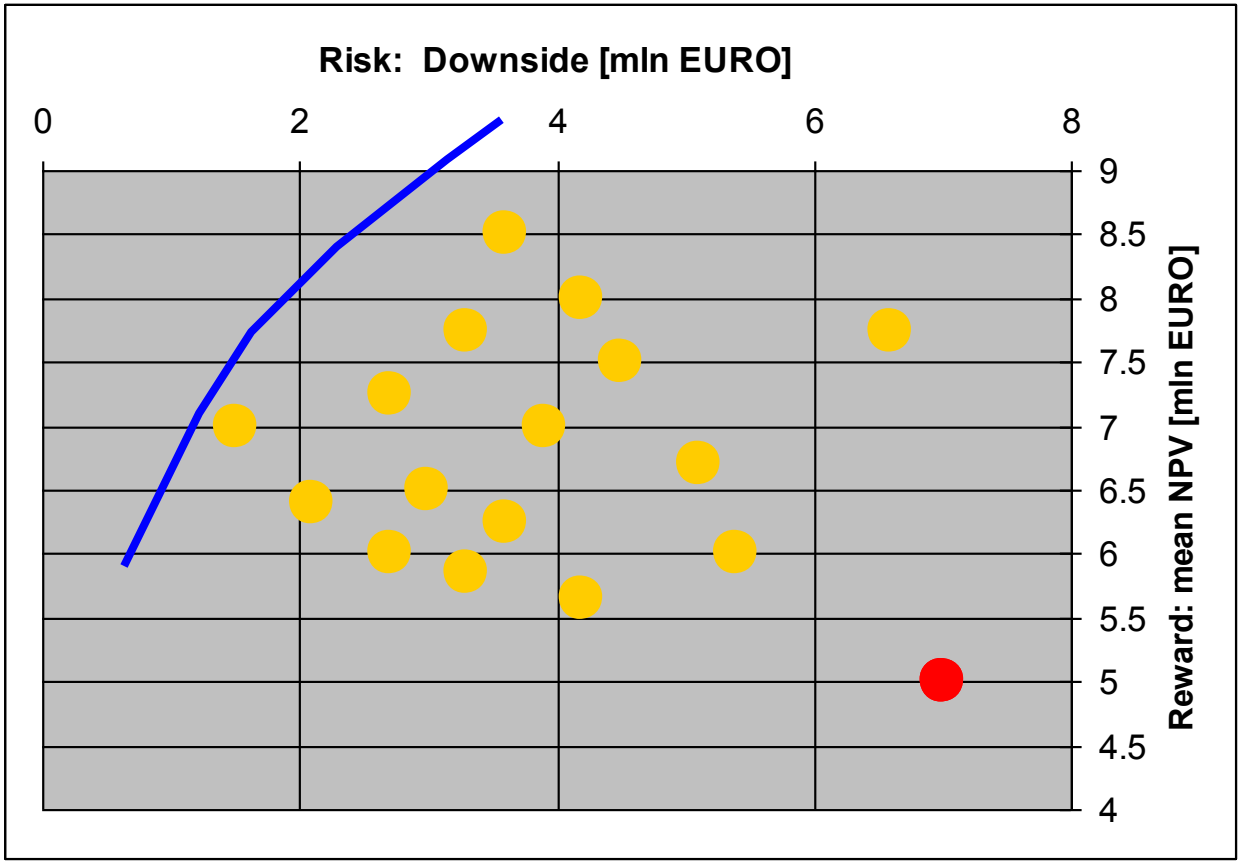


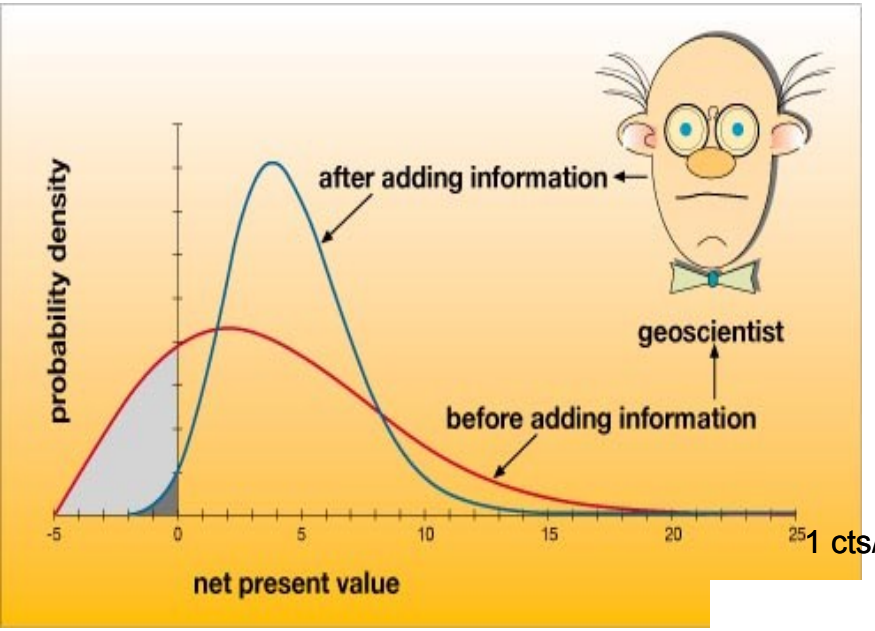
Deterministic volume prospect

Expectation NPV of Prospect

- Risk = 0.7*10 = 7
- Reward = 5

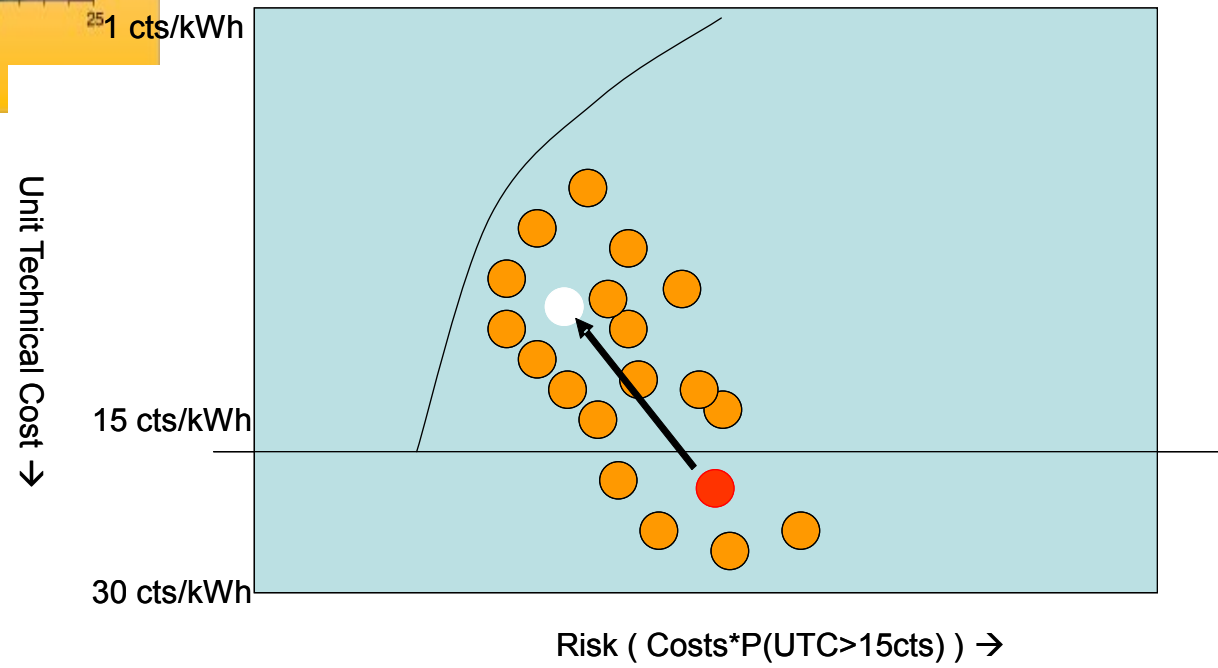
Efficient frontier





Risk and reward are dynamic

what is optimum project strategy?



FAST ANALYTICAL MODEL for EGS, EXCEL

http://engine.brgm.fr/DecisionSupportSystem.asp

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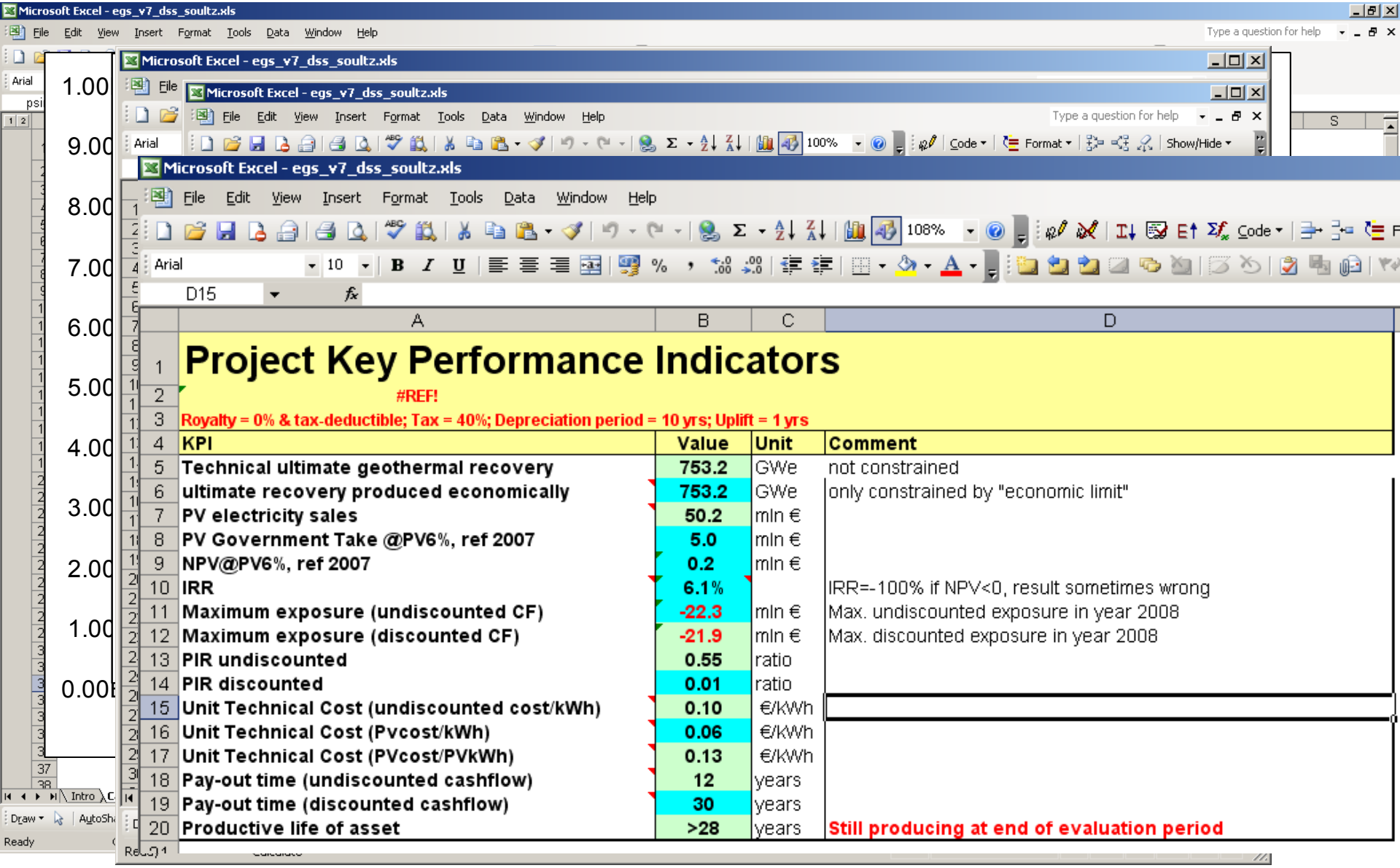

Microsoft Excel - egs_v7_dss_soultz.xls

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D15

Project Key Performance Indicators

#REF!

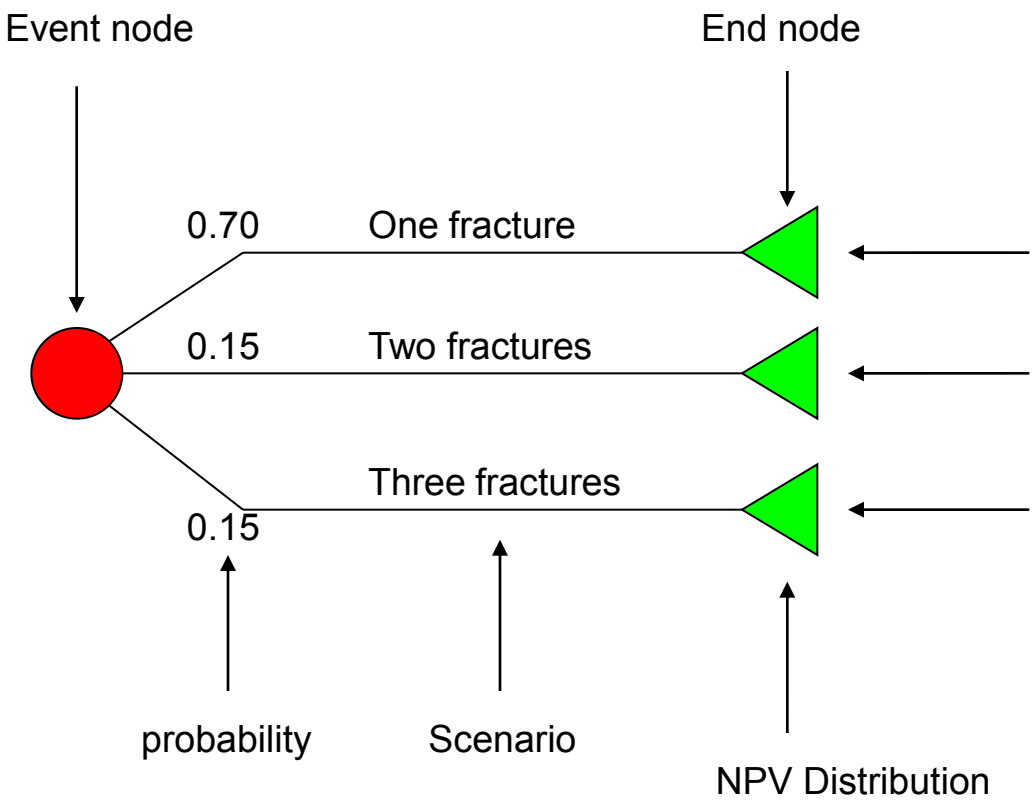
Royalty = 0% & tax-deductible; Tax = 40%; Depreciation period = 10 yrs; Uplift = 1 yrs

KPI	Value	Unit	Comment
Technical ultimate geothermal recovery	753.2	GWe	not constrained
ultimate recovery produced economically	753.2	GWe	only constrained by "economic limit"
PV electricity sales	50.2	mln €	
PV Government Take @PV6%, ref 2007	5.0	mln €	
NPV@PV6%, ref 2007	0.2	mln €	
IRR	6.1%		IRR=-100% if NPV<0, result sometimes wrong
Maximum exposure (undiscounted CF)	-22.3	mln €	Max. undiscounted exposure in year 2008
Maximum exposure (discounted CF)	-21.9	mln €	Max. discounted exposure in year 2008
PIR undiscounted	0.55	ratio	
PIR discounted	0.01	ratio	
Unit Technical Cost (undiscounted cost/kWh)	0.10	€/kWh	
Unit Technical Cost (Pvcost/kWh)	0.06	€/kWh	
Unit Technical Cost (PVcost/PVkWh)	0.13	€/kWh	
Pay-out time (undiscounted cashflow)	12	years	
Pay-out time (discounted cashflow)	30	years	
Productive life of asset	>28	years	Still producing at end of evaluation period

A synthetic case with exploration risk for EGS

Parameter	Uncertainty	Impact on NPV/UTC	Action
Sustainable flowrate	80-120 l/s	?	Assess rock physics, Adapt fraccing technology
Thermal shortcut (#fractures)	1,2 or 3	?	Analyse natural fractures, cross well seismic
% inflow from connected fracture	30-50%	?	Tracer tests
Temperature	205-210C	?	Temperature models, MT

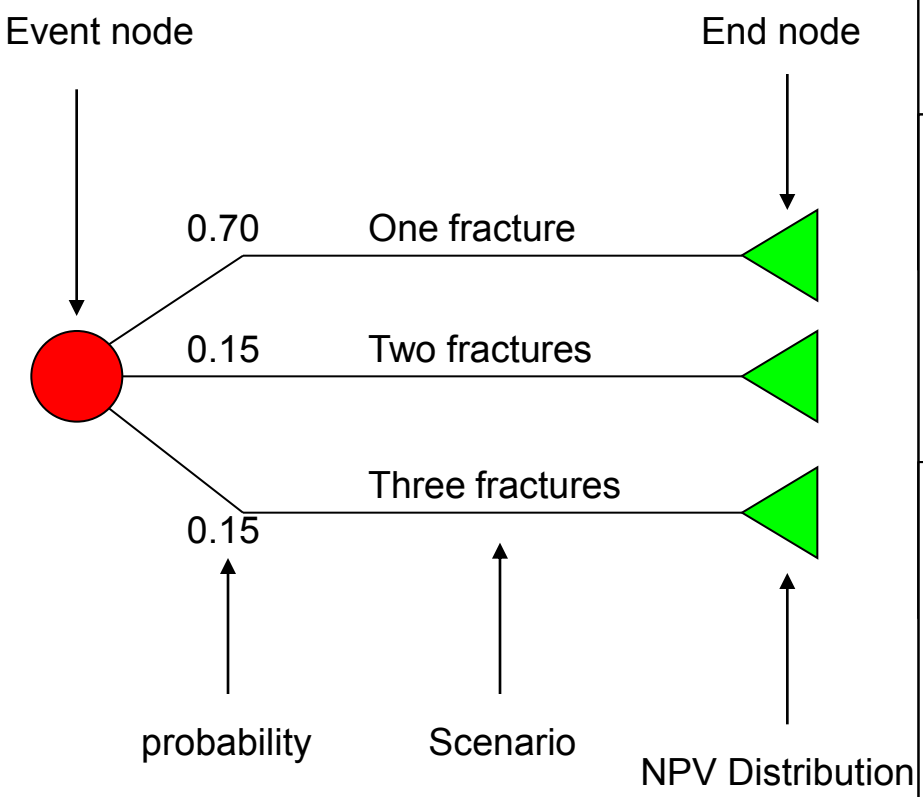
Scenario Tree, mixing discrete and continuous uncertainties

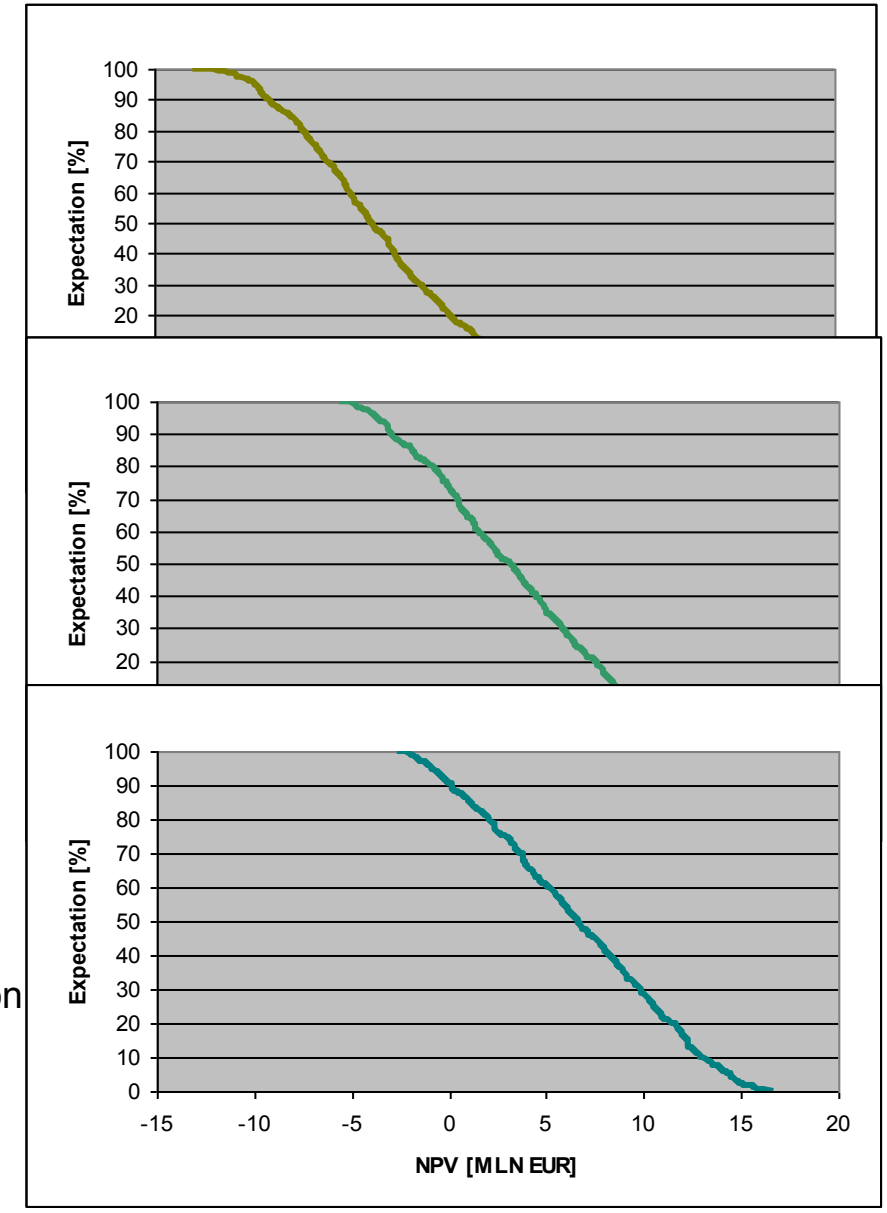


Monte Carlo Simulation

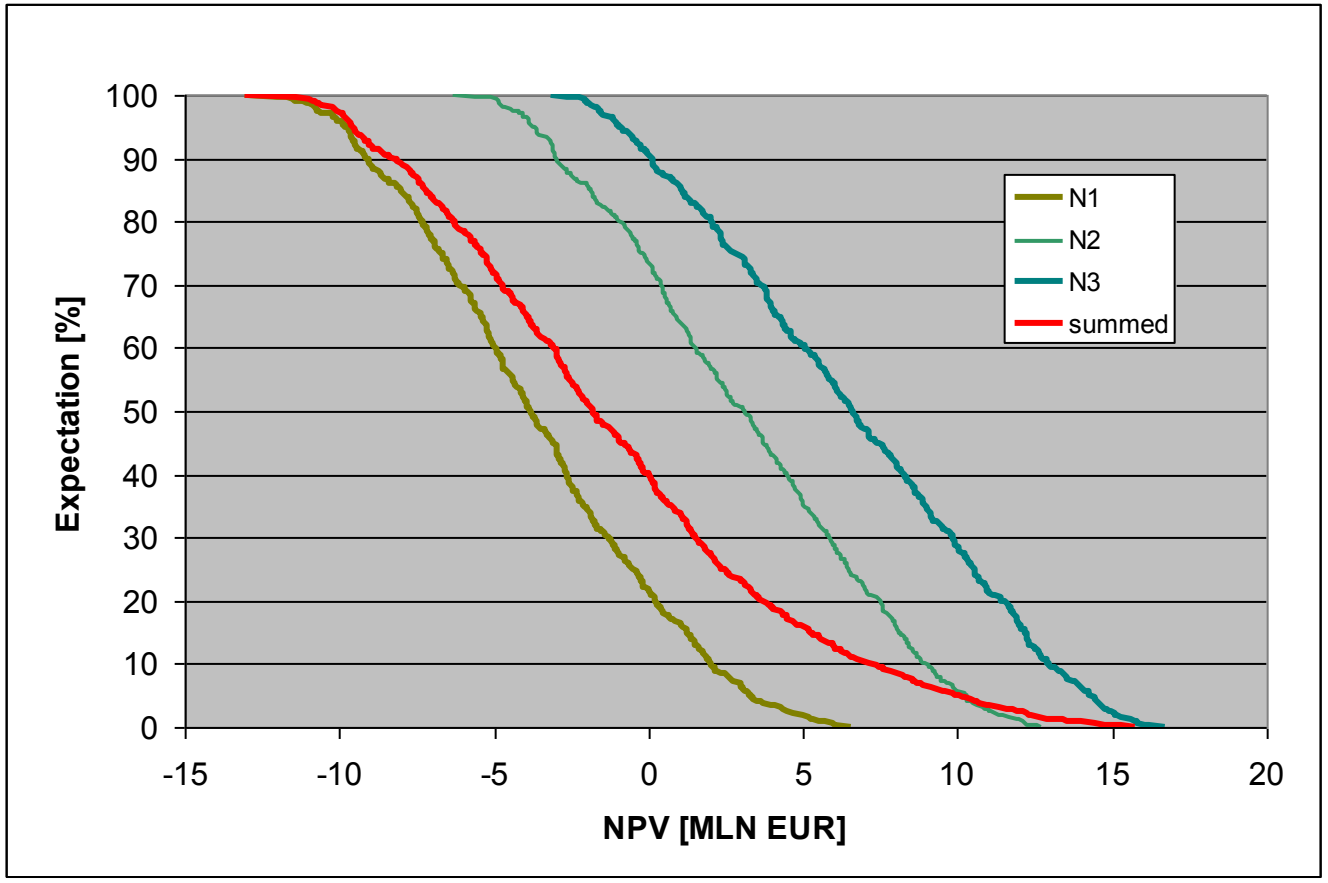
Parameter	Uncertainty
Sustainable flowrate	80-120 l/s
% inflow from connected fracture	30-50%
Temperature	205-210C

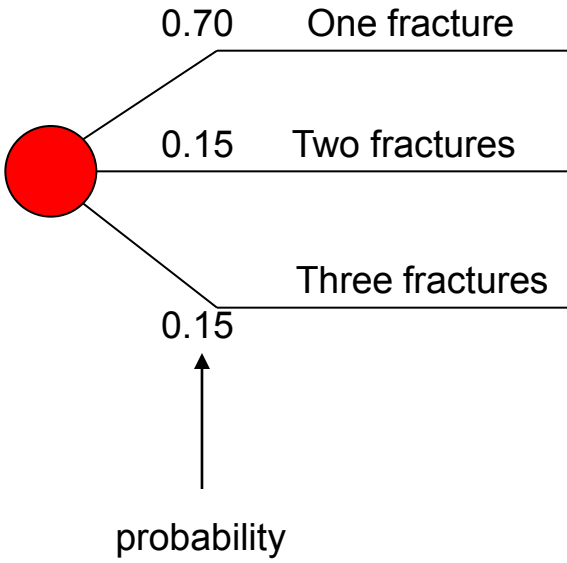
Scenario Tree, mixing discrete and continuous uncertainties





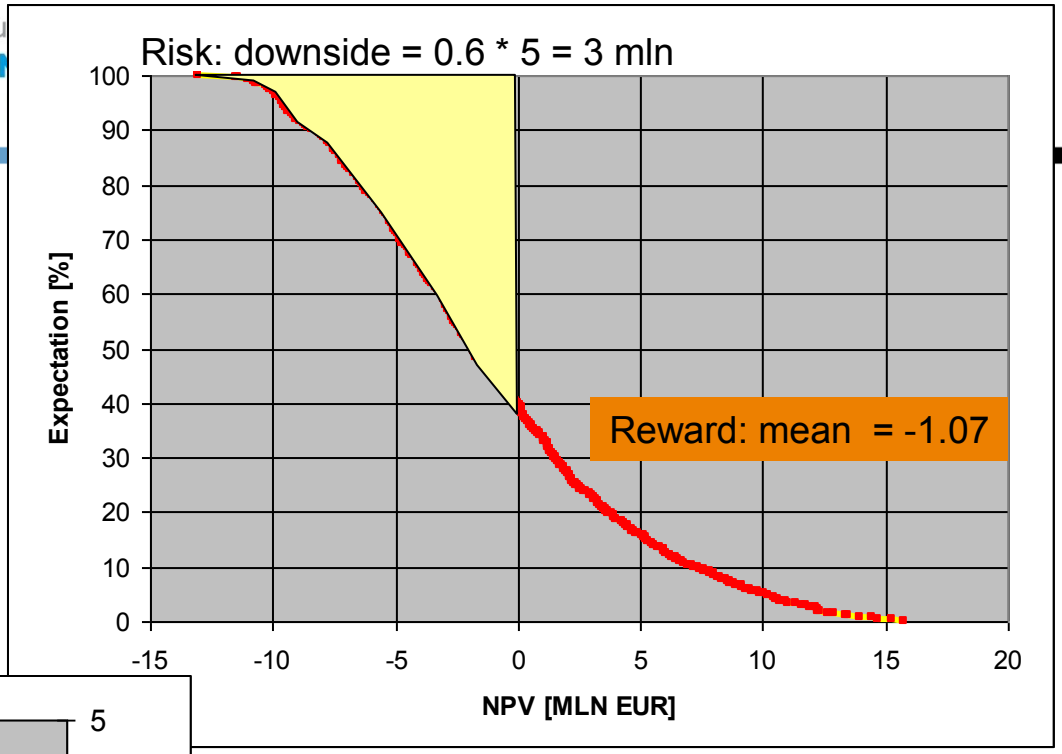
Scenario Tree, mixing discrete and continuous uncertainties

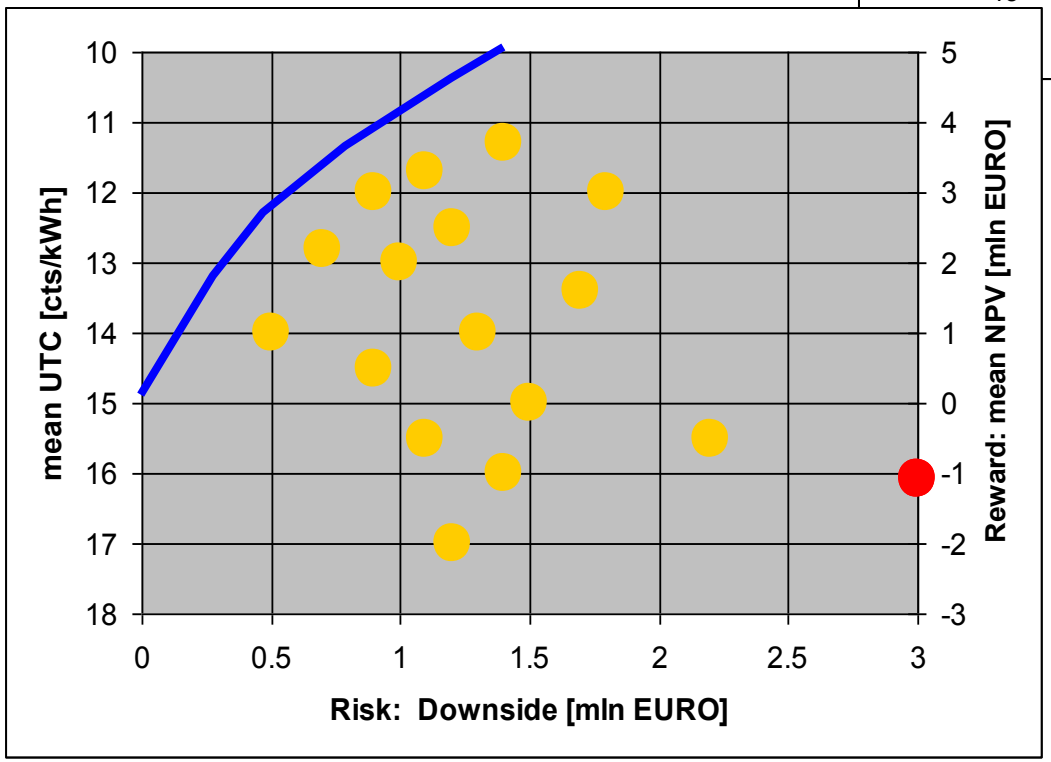




Expectation NPV of Prospect

- Risk
- Reward

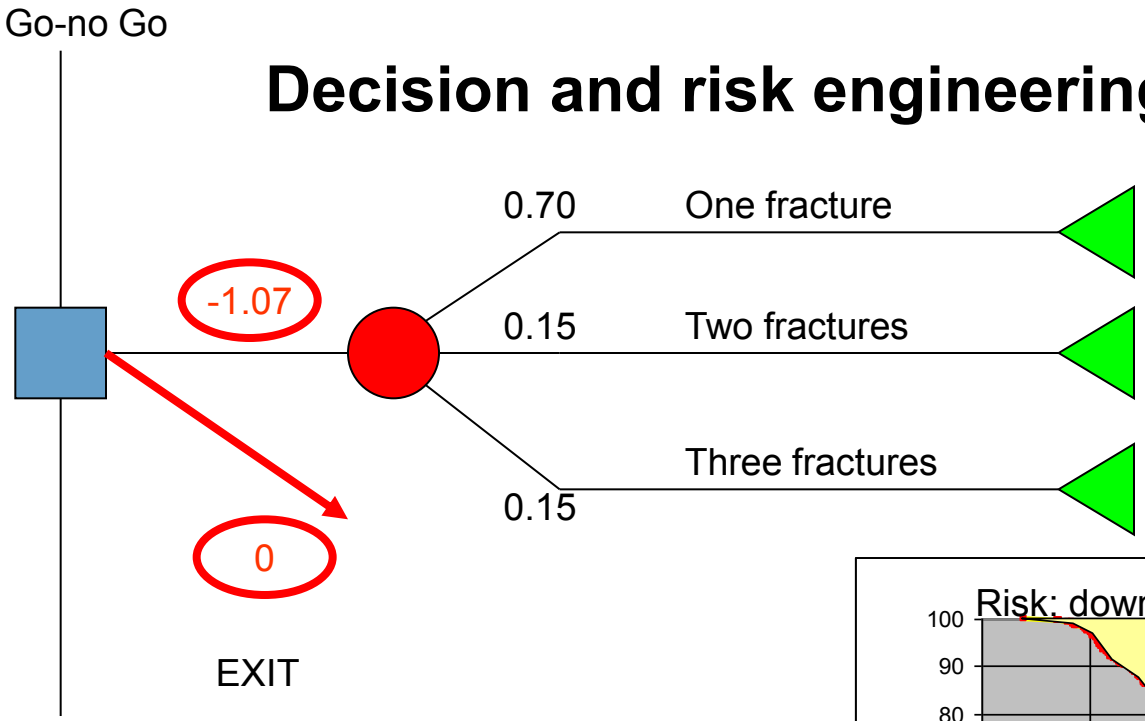


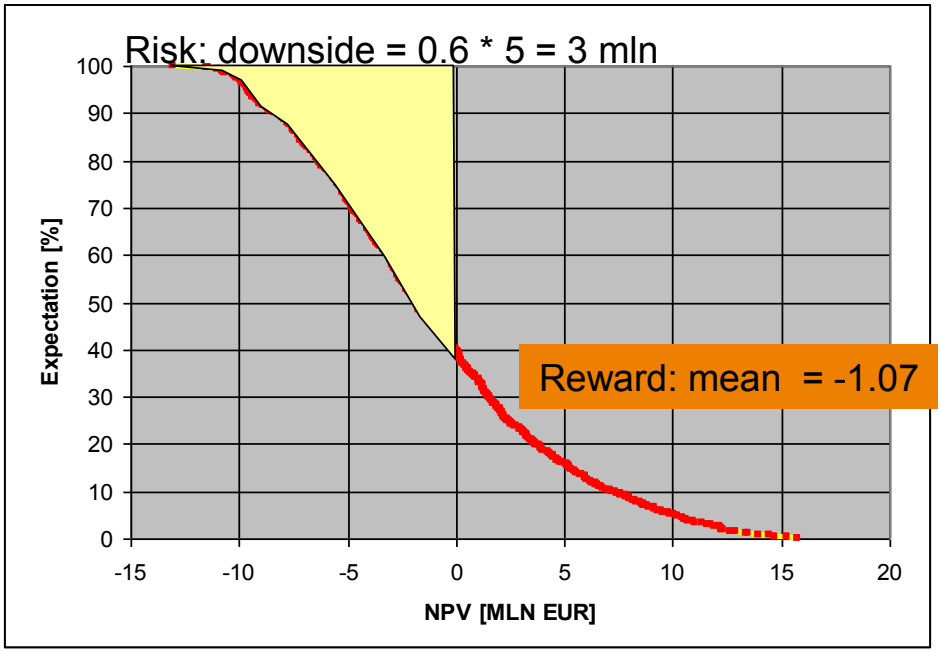


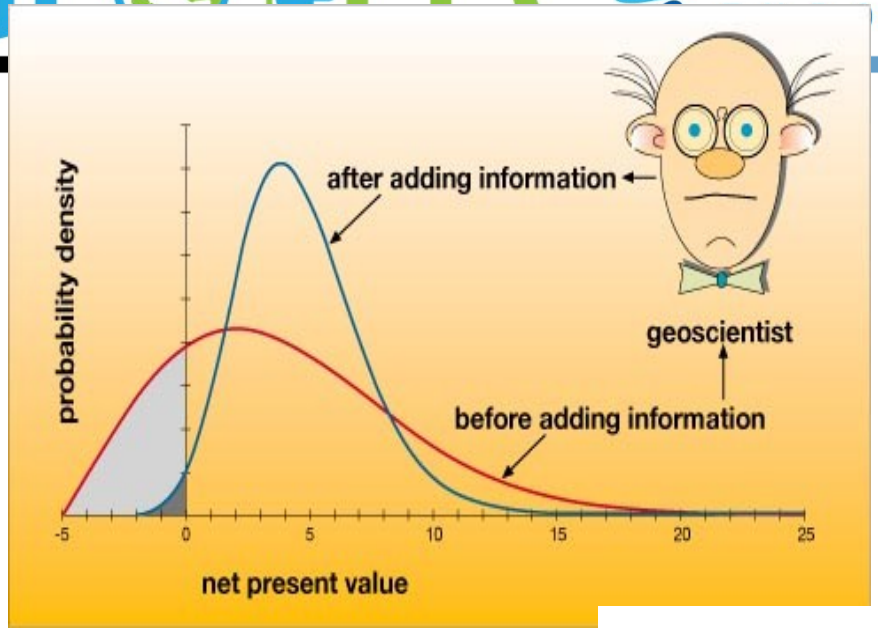
Portfolio plot

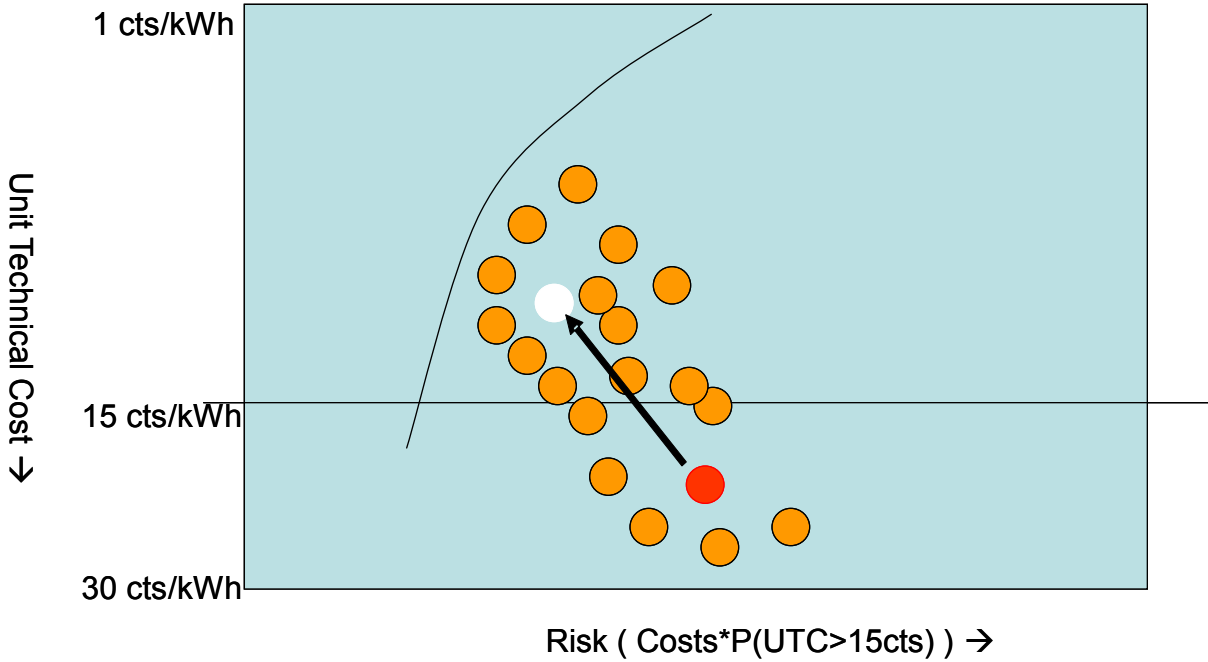
- How to get Prospect (red) to the Efficient Frontier (blue line)

Decision and risk engineering, starting point



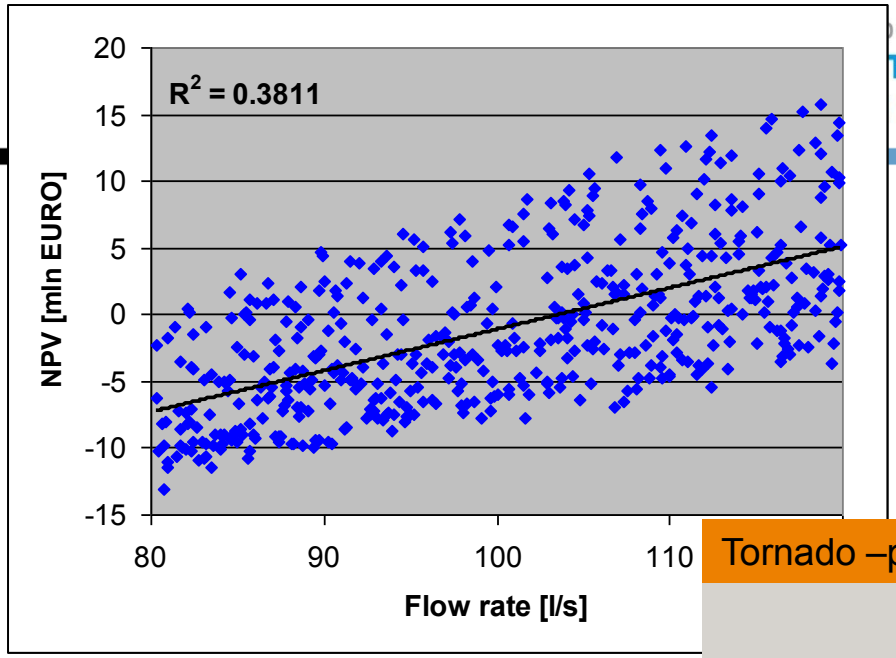


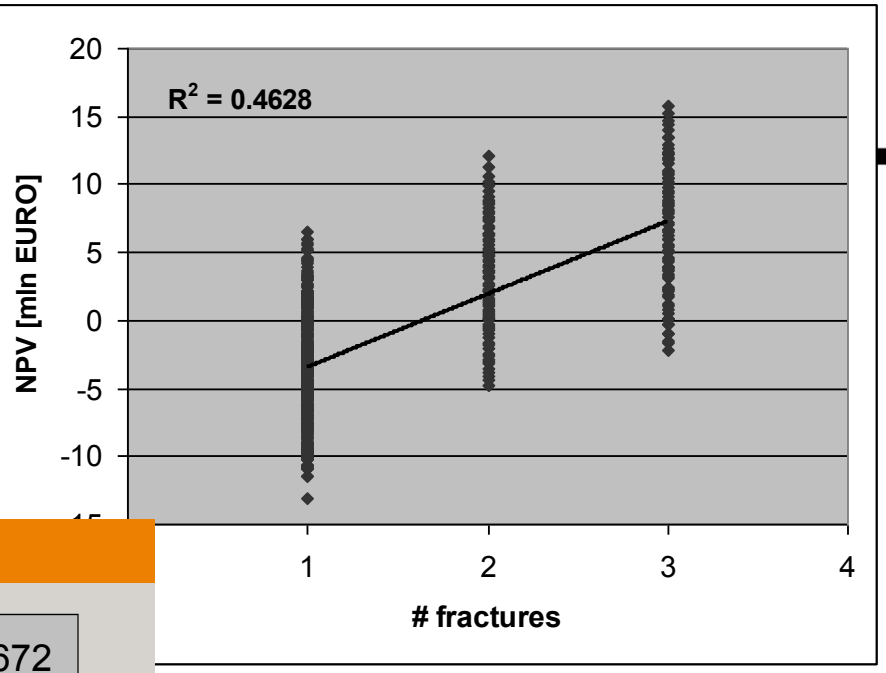

probability density
after adding information
geoscientist
before adding information
-5
0
5
10
15
20
25
net present value

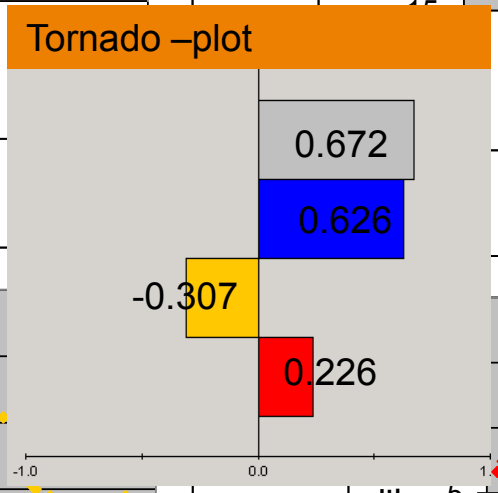

1 cts/kWh
15 cts/kWh
30 cts/kWh
Unit Technical Cost →
Risk (Costs*P(UTC>15cts)) →

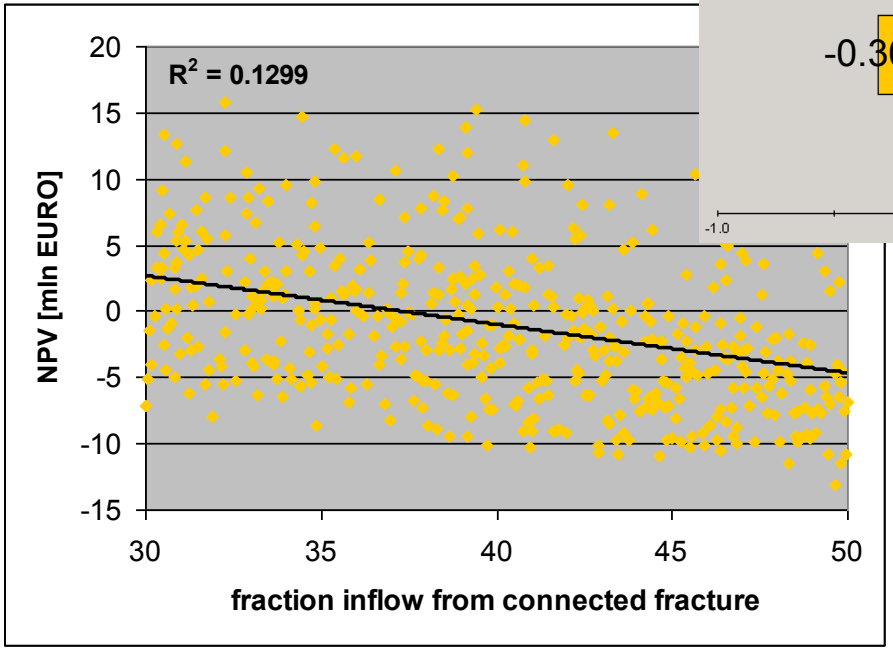
First Step, understand effect of uncertainties

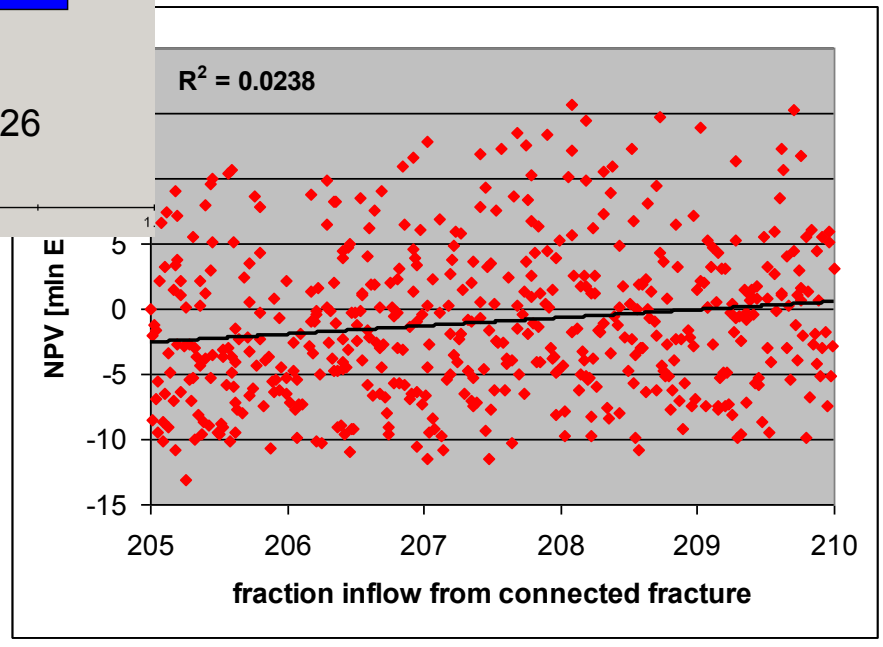
Parameter	Uncertainty	Impact on NPV/UTC	Action
Sustainable flowrate	80-120 l/s	?	Assess rock physics, Adapt fraccing technology
Thermal shortcut (#fractures)	1,2 or 3	?	Analyse natural fractures, cross well seismic
% inflow from connected fracture	30-50%	?	Tracer tests
Temperature	205-210C	?	Temperature models, MT


R^2 = 0.3811
NPV [mln EURO]
Flow rate [l/s]

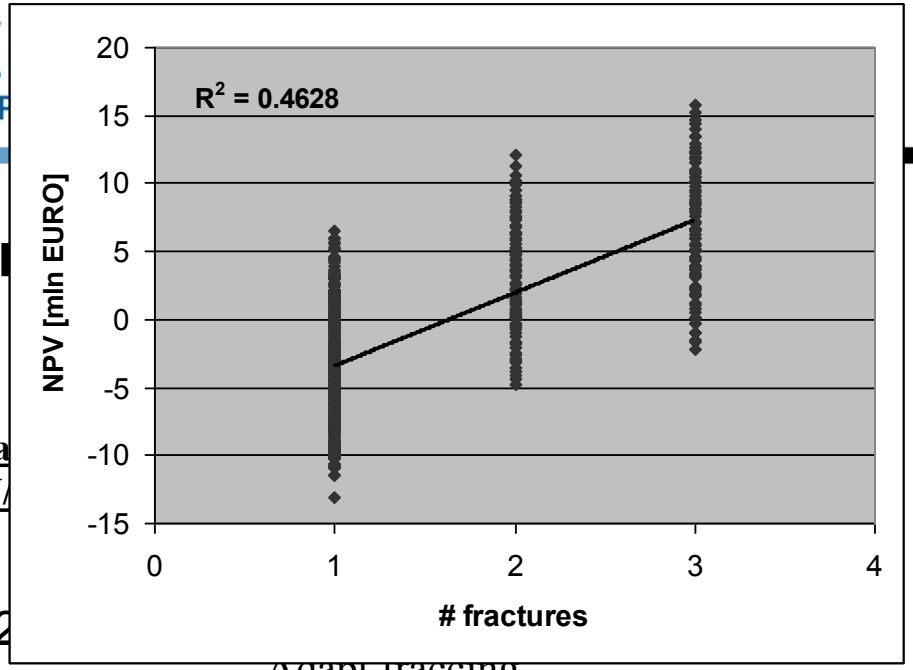

R^2 = 0.4628
NPV [mln EURO]
fractures


Tornado –plot
0.672
0.626
-0.307
0.226


R^2 = 0.1299
NPV [mln EURO]
fraction inflow from connected fracture

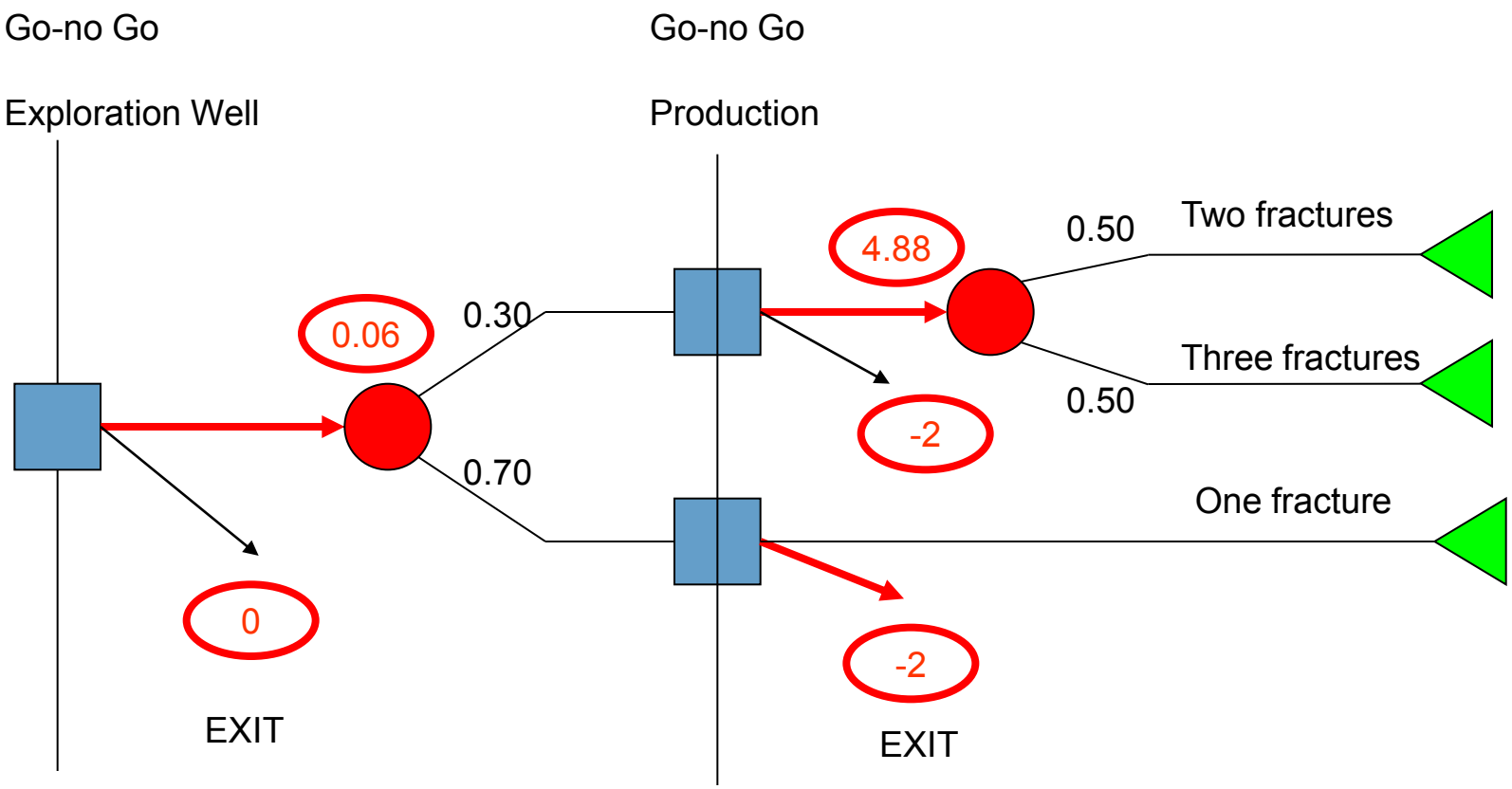

R^2 = 0.0238
NPV [mln E
fraction inflow from connected fracture

First Step, understand effect of u

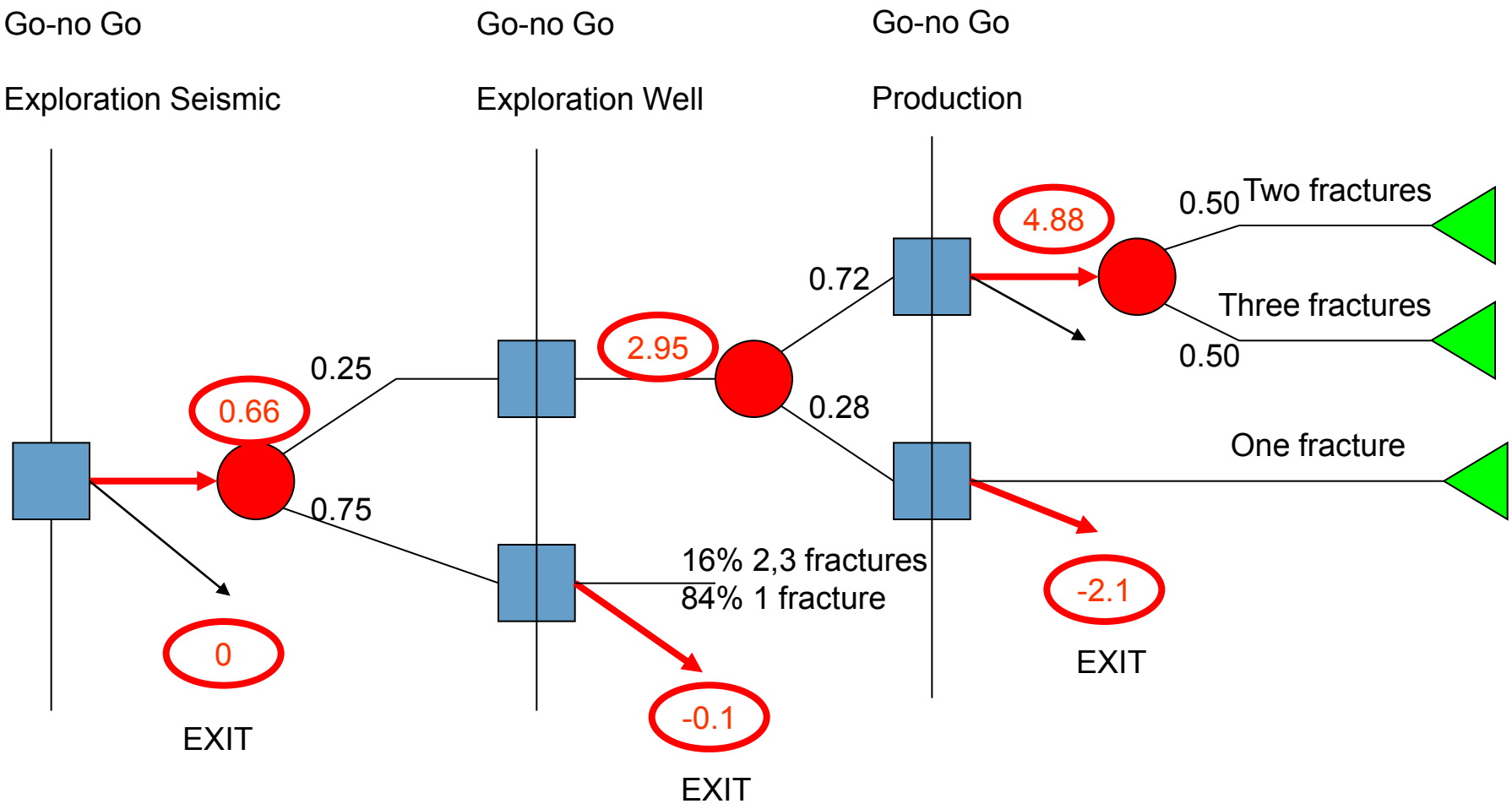


Parameter	Uncertainty	Impa NPV/	
Sustainable flowrate	80-120 l/s	0.62	Adapt fracing technology
Thermal shortcut (#fractures)	1,2 or 3	0.672	Analyse natural fractures, cross well seismic
% inflow from connected fracture	30-50%	-0.307	Tracer tests
Temperature	205-210C	0.226	Temperature models, MT

Exploration Well at reduced cost – 2 mln

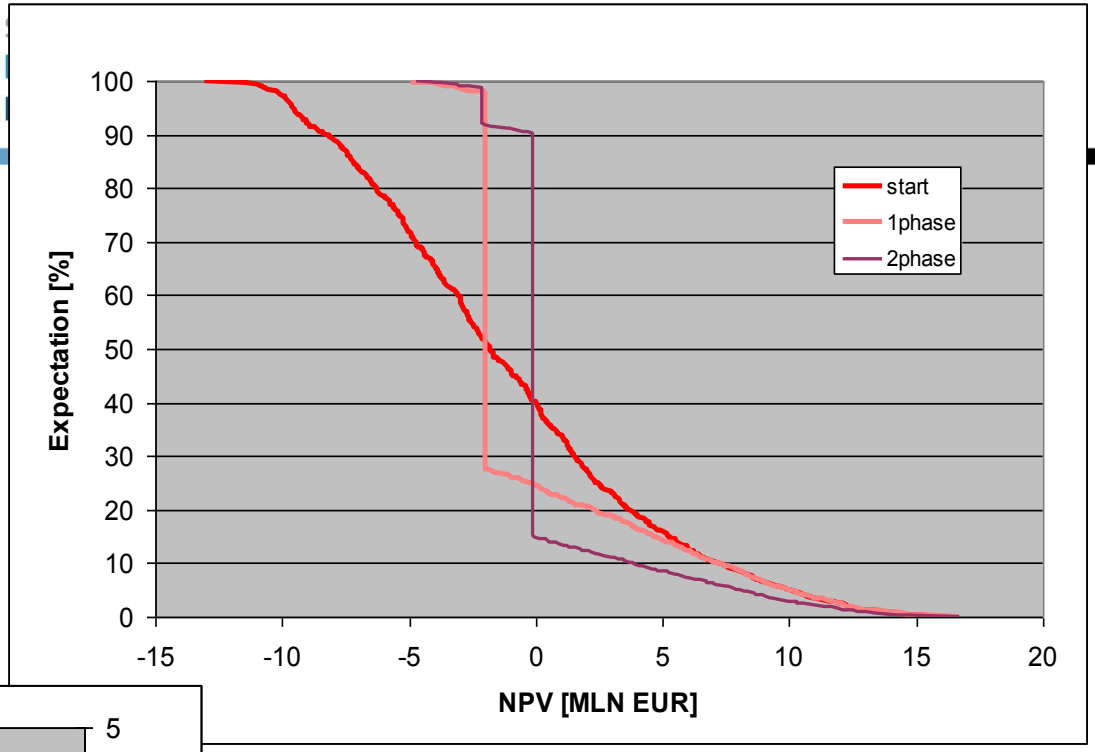


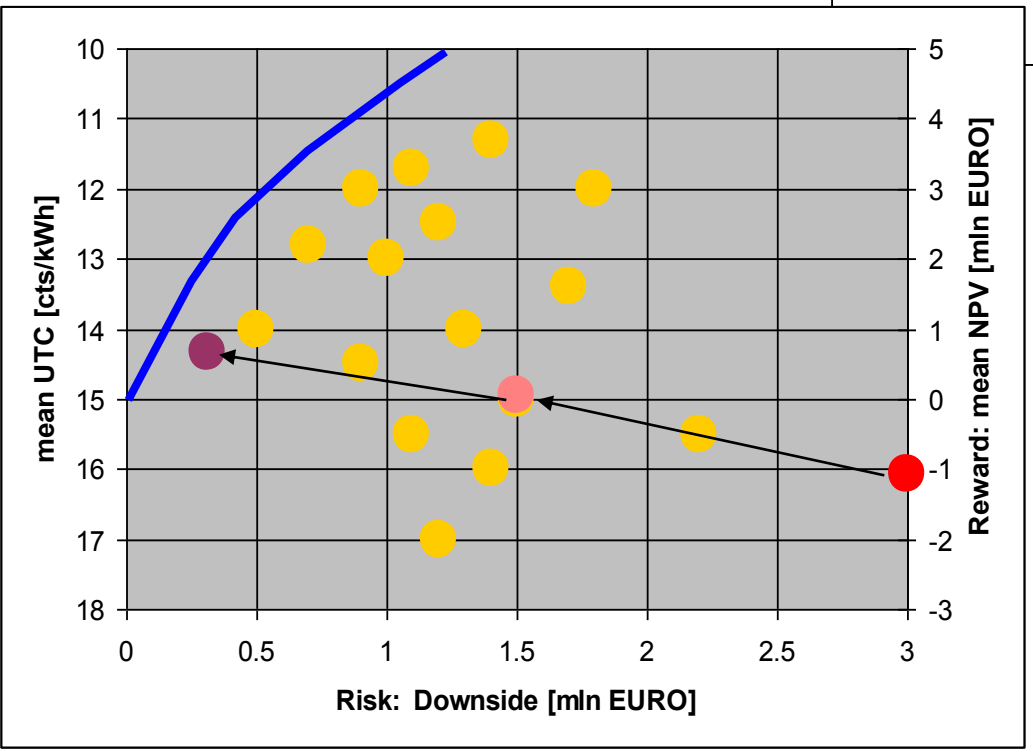
Exploration VSP in existing well
0.1 mln EURO



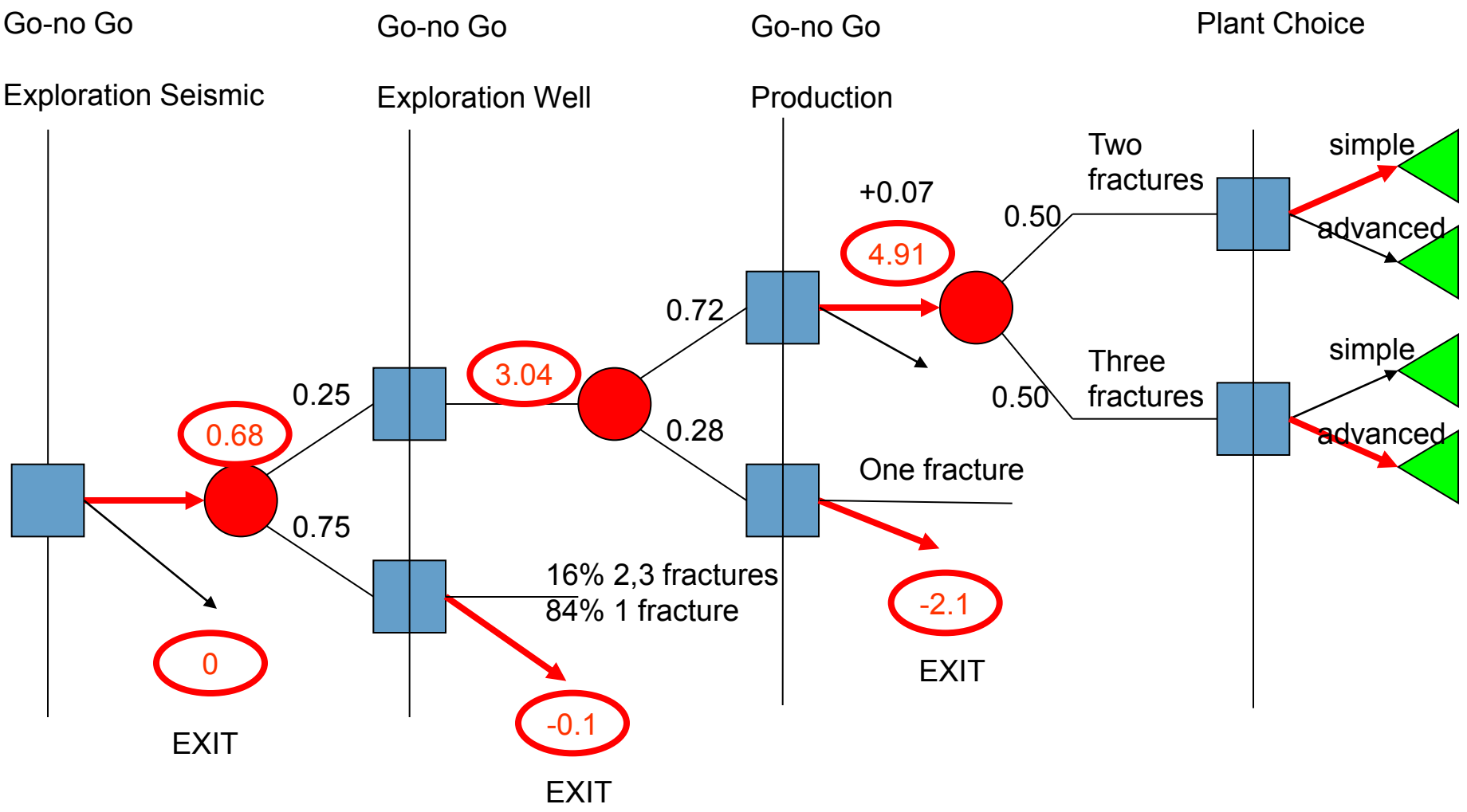
Portfolio plot

- How to get Prospect (red) to the Efficient Frontier (blue line)

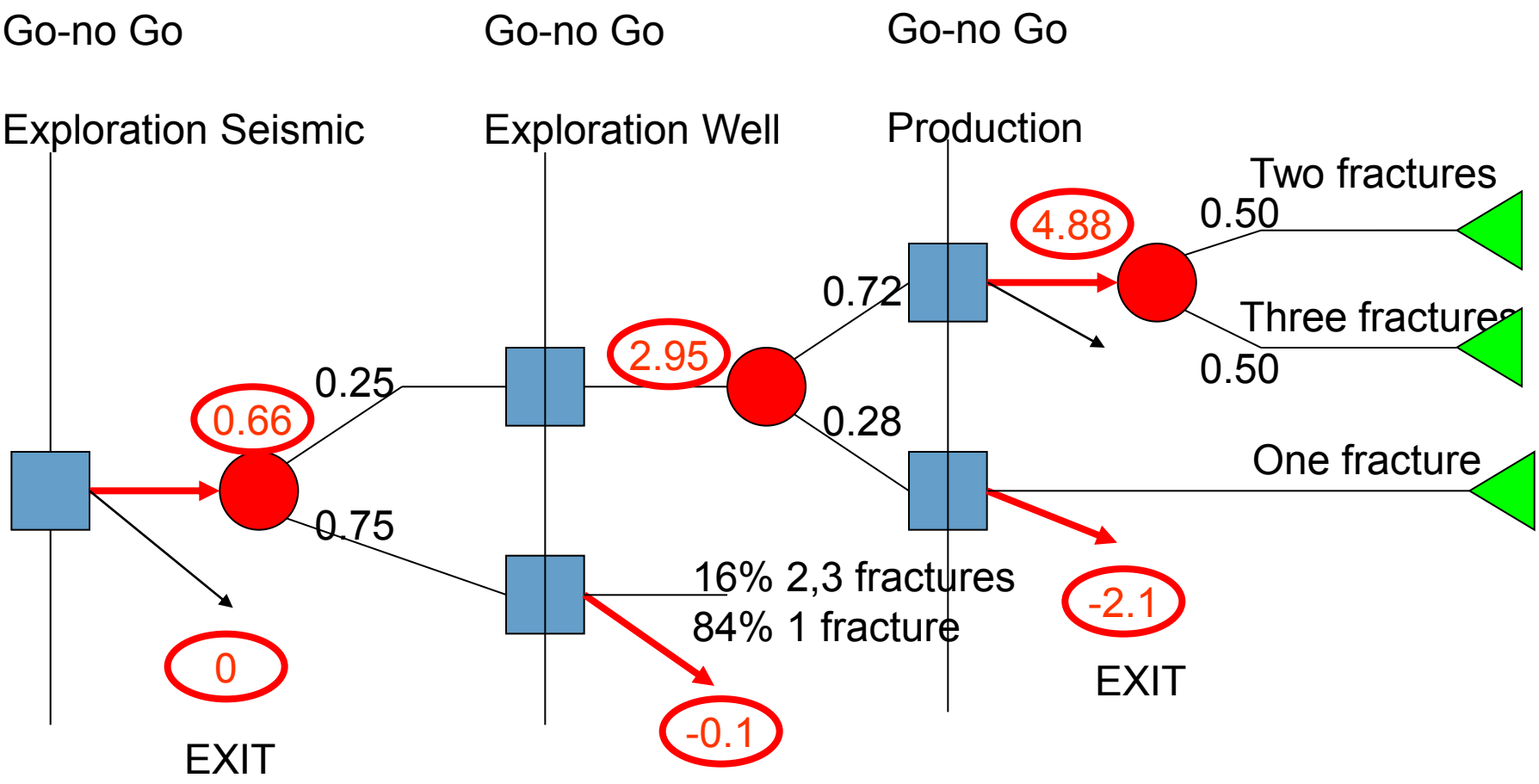




Value of Flexibility – Adaptation of power plant at higher efficiency-higher cost



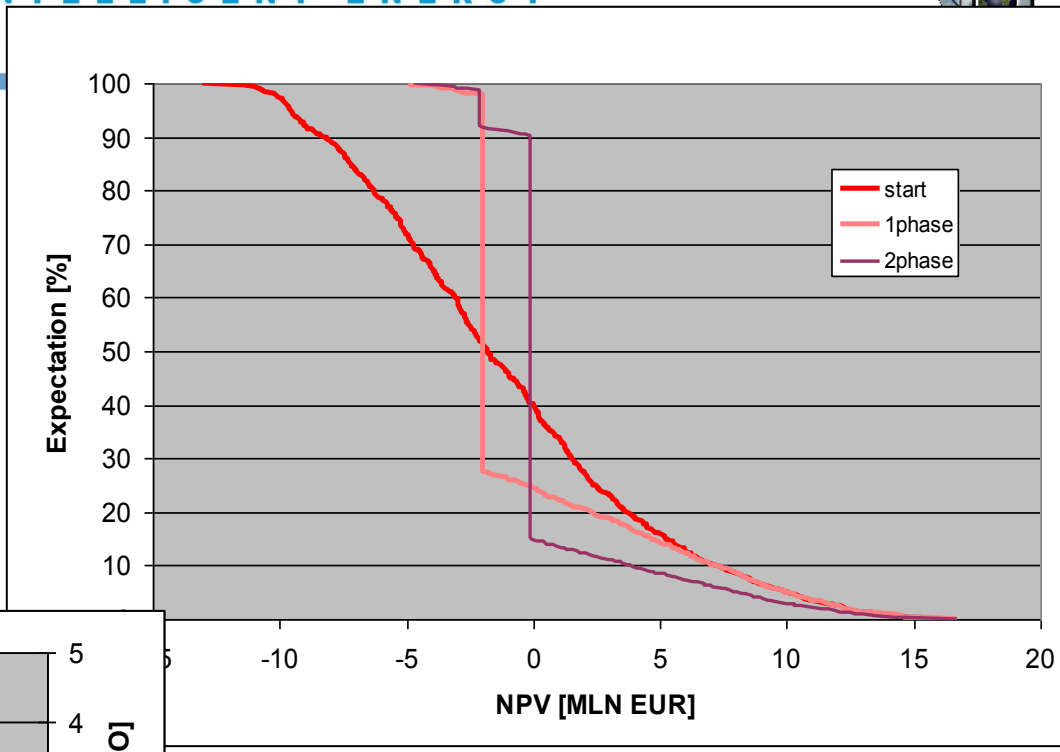
Staged approach for EGS

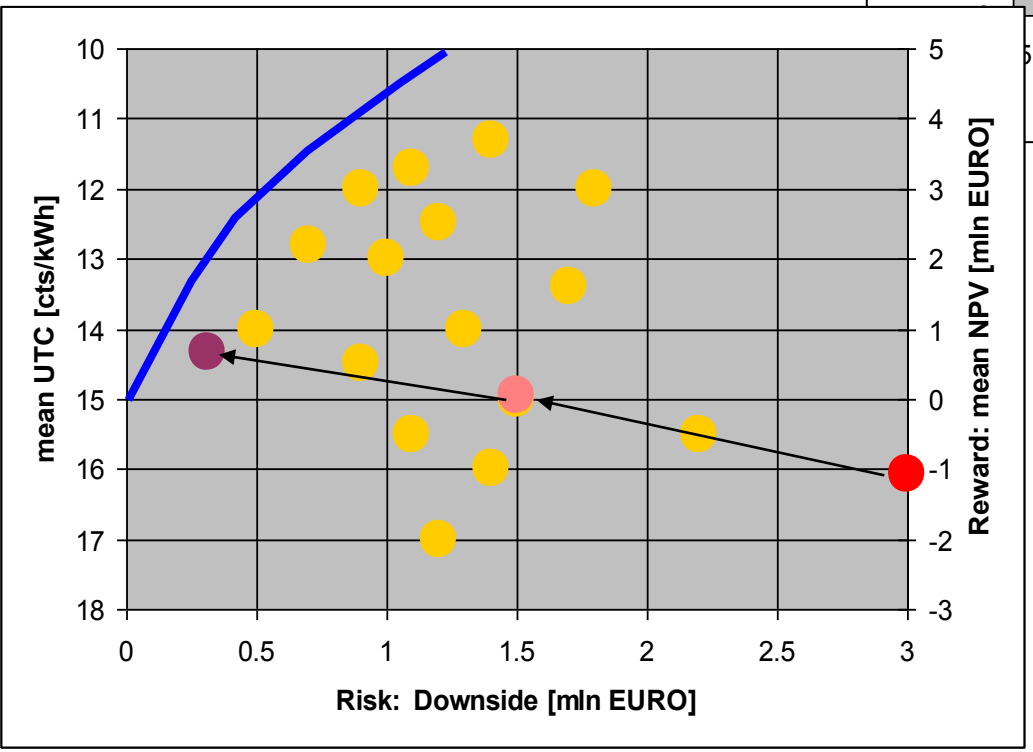


Van Wees et al., 2010
Frick et al., 2010

Portfolio plot

- Staged project flow moves prospect (red) to the Efficient Frontier (blue line)





Mitigating project risk – include acceptance issues and be aware of there high impact

		reconaissance		surface exploration		deep exploration	
category	parameter	uncertainty	NPVdistribution	uncertainty	NPVdistribution	uncertainty	NPVdistribution
resource characteristic	temperature	medium	high	low	medium	low	low
	flow rate	high	high	high	high	low	medium
	depth	medium	high	low	medium	low	low
	volume	medium	high	low	medium	low	low
	recovery factor	medium	medium	medium	medium	low	low
	chemistry	medium	high	medium	high	low	low
technology	energy-conversion costs	medium	medium	medium	medium	low	low
	drilling costs	medium	high	medium	medium	low	low
	plant costs	medium	medium	medium	medium	low	low
	operational costs	medium	low	medium	low	low	low
logistic	grid connection costs	low	low	low	low	low	low
	access roads and supplies	low	low	low	low	low	low
environmental&social	reserved areas	medium	high	medium	high	medium	high
	acceptance of exploration	high	high	high	high	low	medium
	acceptance of production	high	high	high	high	medium	medium
market	energy prices	medium	high	medium	high	medium	high
	tax and regulations	low	medium	low	medium	low	medium

Multicriteria Score - Ri

Techno-economic NPV distribition

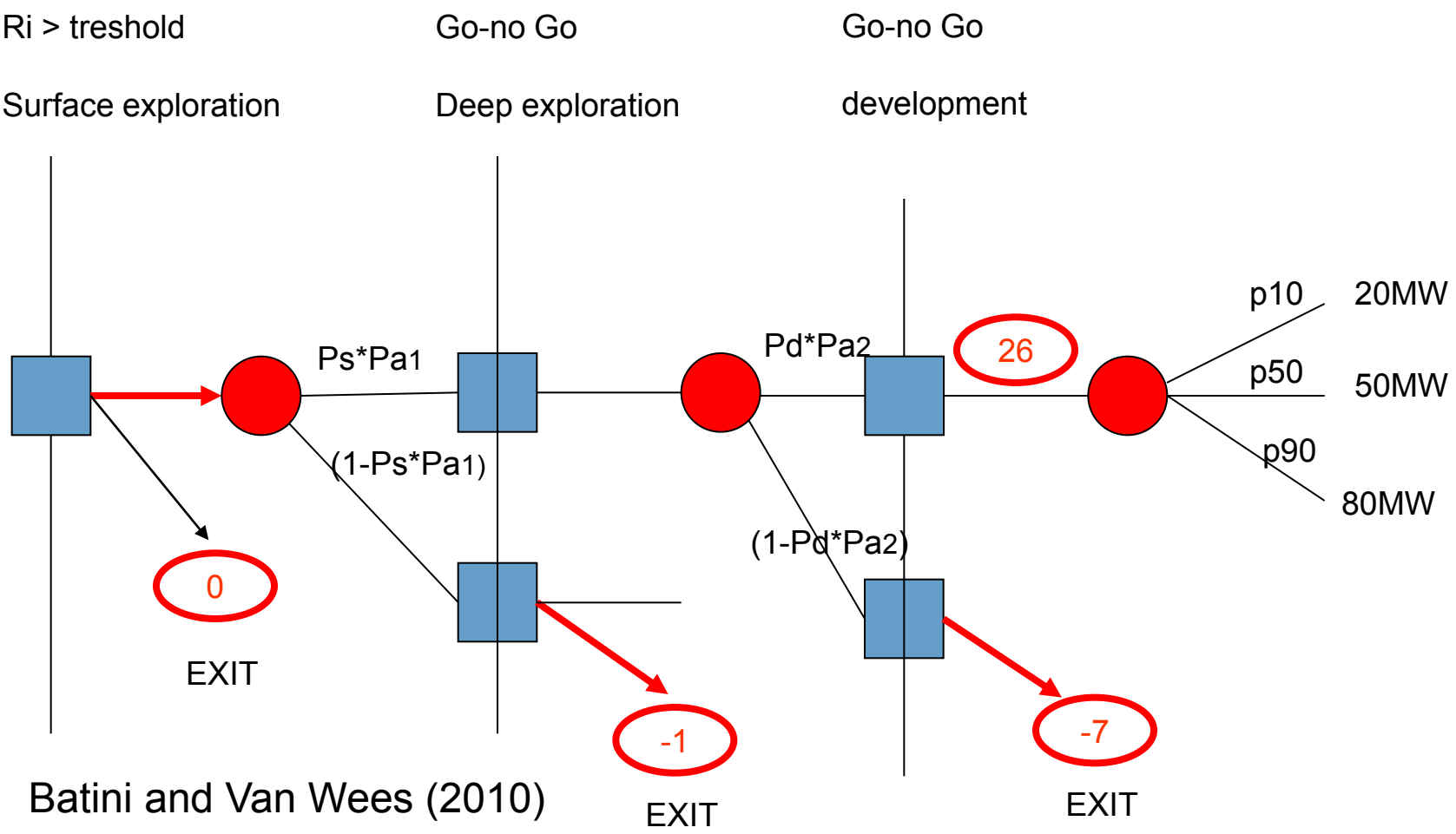
Techno-economic NPV distribition

Decision toll-gate Surface exploration

Decision toll-gate deep exploration

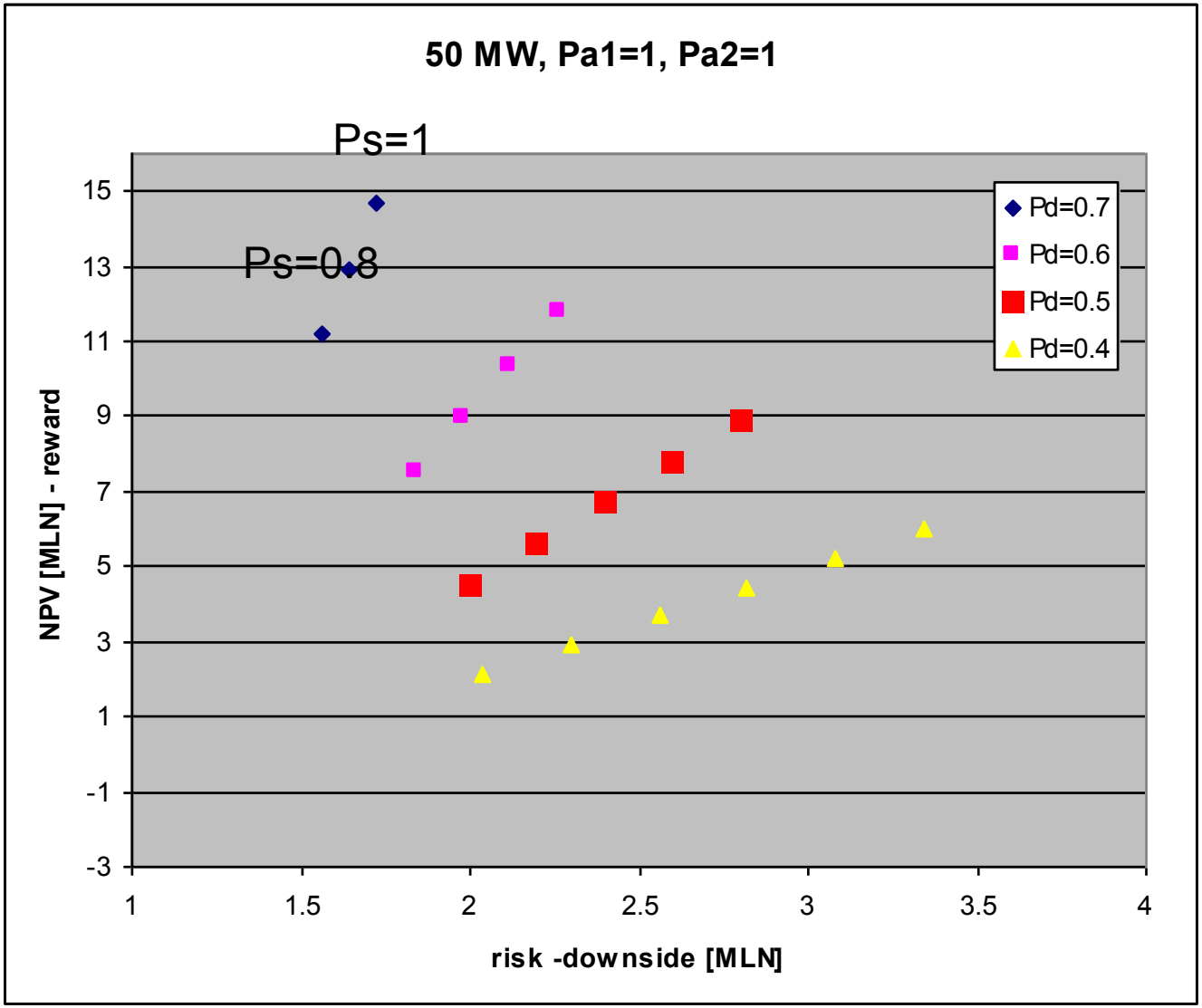
Batini and Van Wees (2010)

Decision tree - include public acceptance probabilities (Pa1,Pa2)

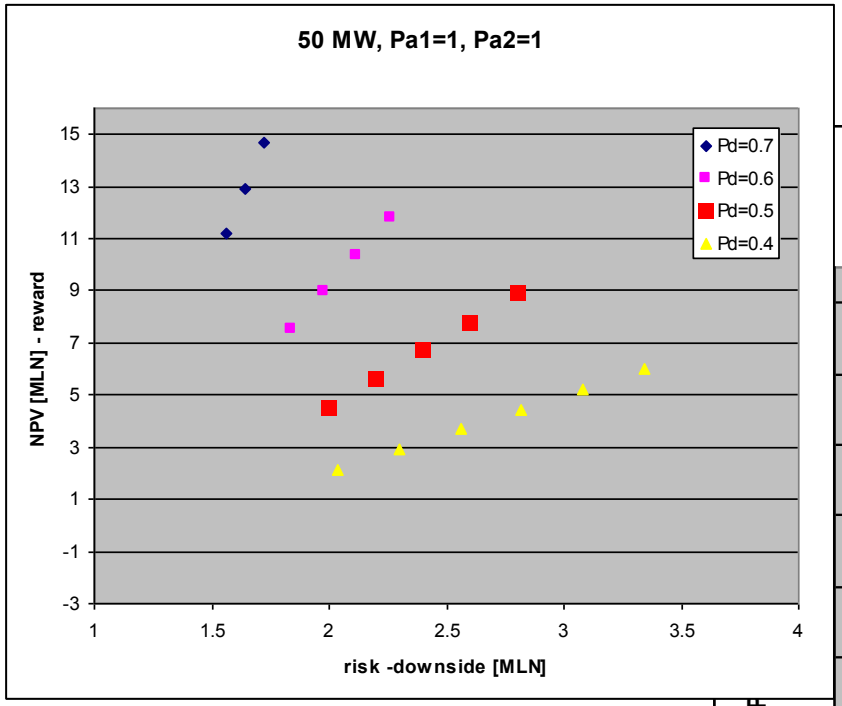


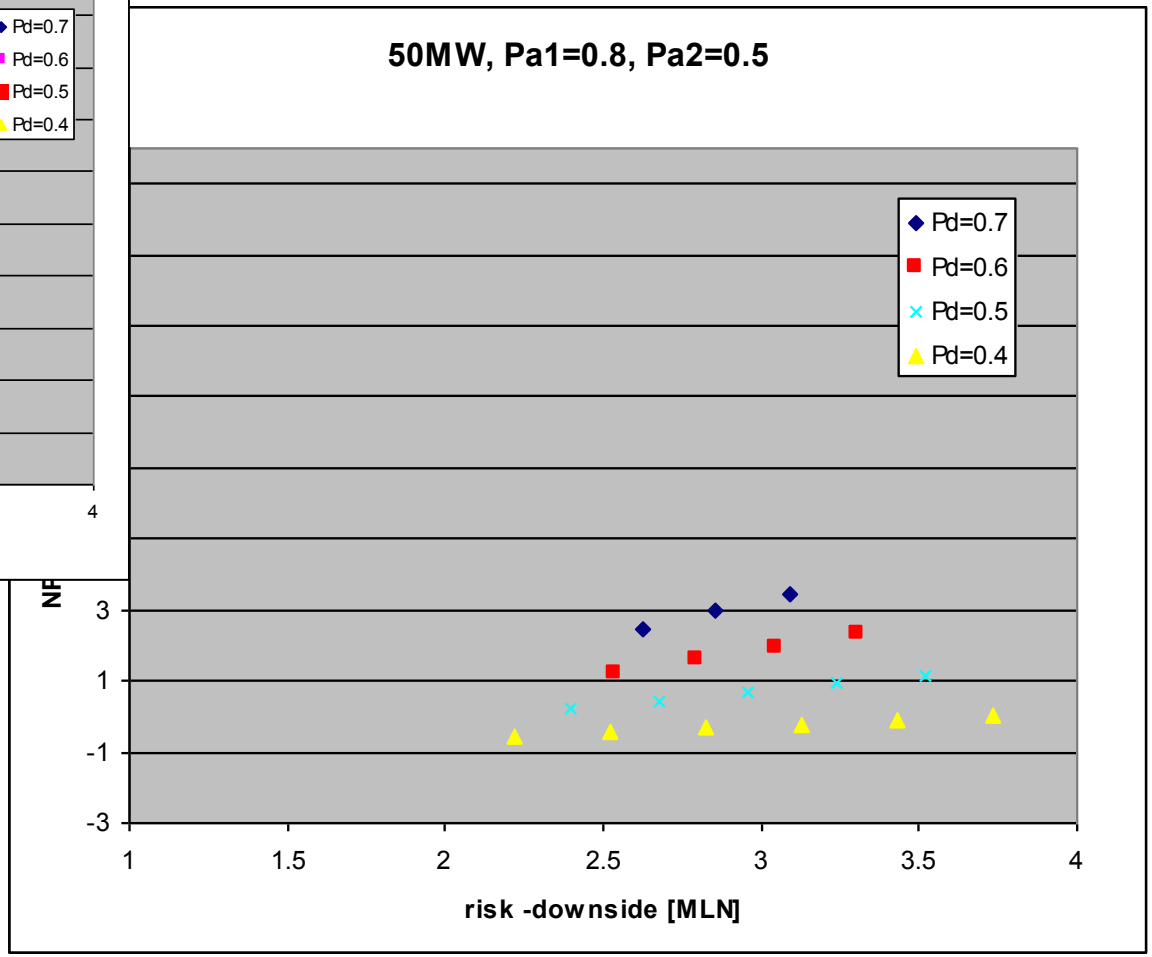
Batini and Van Wees (2010)

Risk-reward plot as function of Probability of succes of deep (Pd) and surface (Ps) exploration



Risk-reward plot demonstrates strong influence of Public acceptance probabilities





Monte Amiata- Italy

- Excellent geothermal potential (ca 200 MWe)

Move towards Zero emission and Low visual impact

Conclusions

Resource potential can be assessed on an economic basis.

- Access to subsurface data and understanding of critical parameters (T, expected Q) is key.
- Uncertainty has strong impact on potential estimates
- neglecting upside, results in underevalution of geothermal potential

Risk mitigation in iexploration requires a staged workflow, gradually reducing downside and increasing reward

- Move to the efficient frontier asking the right questions
- Public acceptance often neglected but, if quantified, clearly demonstrates significant impact

Thanks for your Attention

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