Capacity Investments and Operational Uncertainty in a CCS value chain

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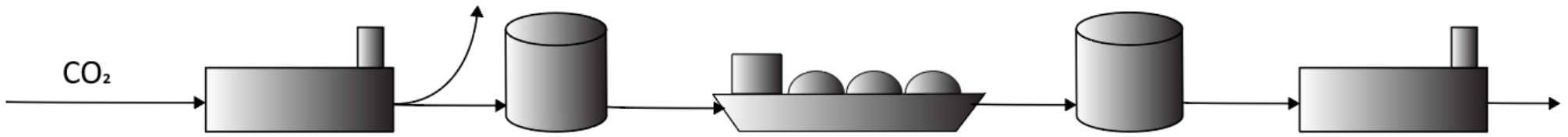
Motivation

- Over the past decade, the interest for CO_2 shipping has been growing due to its
  - "Cost-efficiency" for capacities and for long distances
  - Limited investements
  - Flexibility
- Ship-based transport is a very attractive option for the Norwegian full-scale, as well as to kick-start CCS from European emissions
- Ship-based transport can be significantly impacted by weather conditions
  - The impact of weather conditions on the design of ship-based transport and the CCS value chain is however not a research focus

How are optimal investments affected by the weather conditions?

- Two-stage investment model
- Data from Metrologisk Institutt
- Gain insights:
  - Optimal investments and operations for a minimum required capture rate
  - The cost of seasonal variations in emission
  - The cost of neglecting delays on ship transport
  - The cost of wrongly forecasting wrong fuel cost

Ship-based CCS value chain

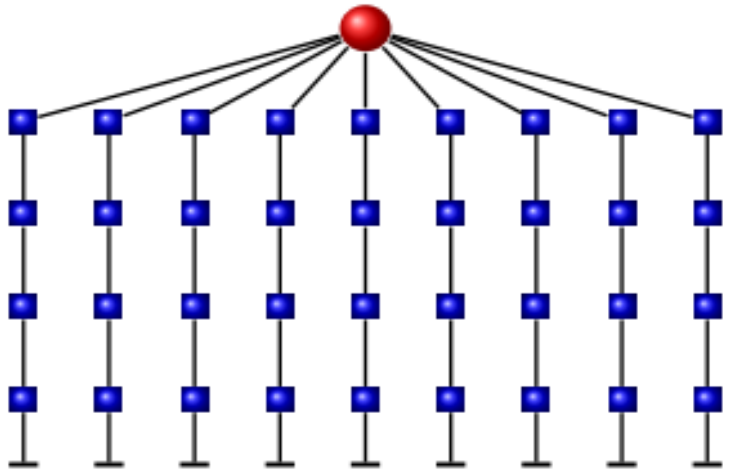
Value chain:	Conditioning	Buffer storage	Vessel	Buffer storage	Reconditioning
	CO_2				
Investments:	Operational capacity	Buffer capacity	-	Buffer capacity	Operational capacity
Operational:	Capturing Liquefaction Emission	Inventory level Loading of vessel	Sailing speed	Inventory level Unloading of vessel	Regasification Permanent storage

The structure of the problem

- The first-stage decisions determine the boundaries of the second-stage problem

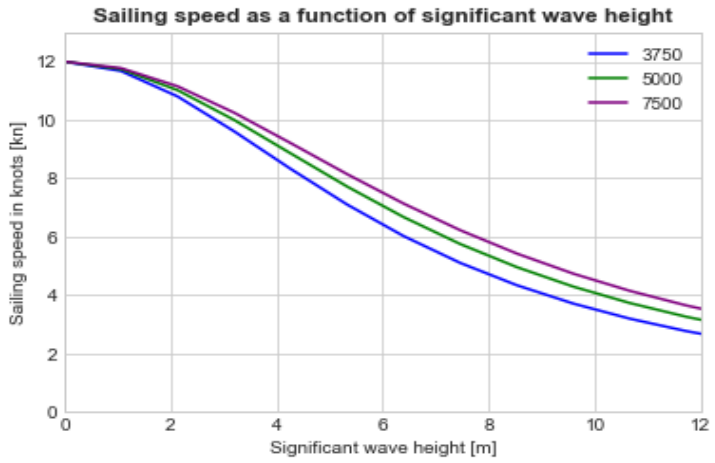
- Investments are made initially
  - Planning for 25 years

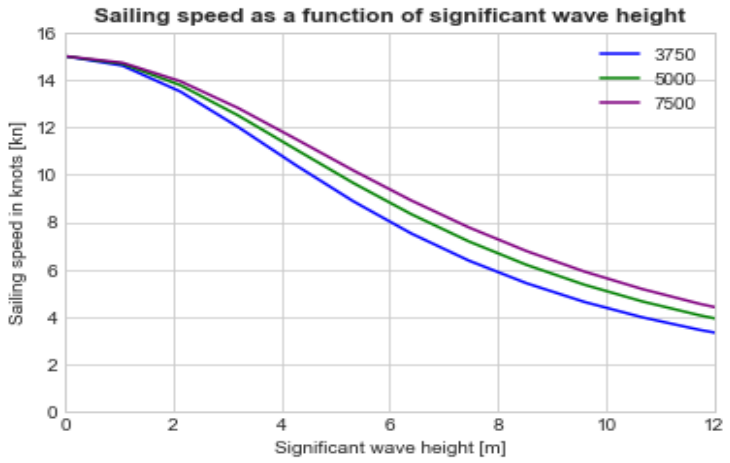
- Scenarios:
  - 136 operational time steps
  - Each operational time step is 3 hours
  - One season is 17 days of operation



The STAwave-1 method

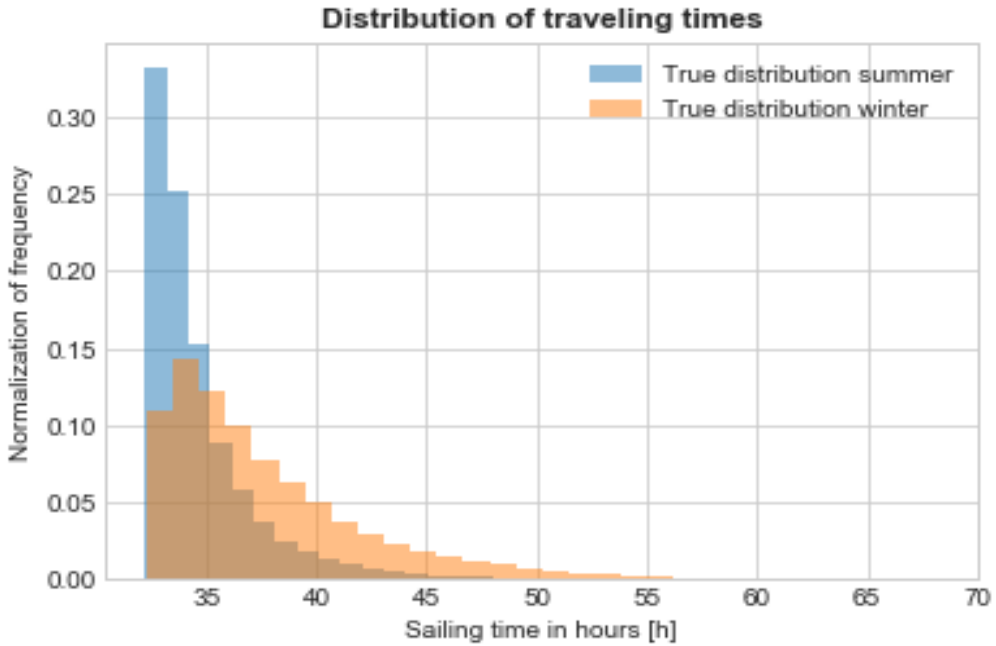
- $V(H_s) = \dfrac{P}{R_f + \frac{1}{16}\rho g H_s B \sqrt{\frac{B}{L_{BWL}}}}$
- Varable power drive





Simulating traveling times

- Data from 1987 to 2016
- 87 000 simulated route times
  - Brevik - Kollsnes



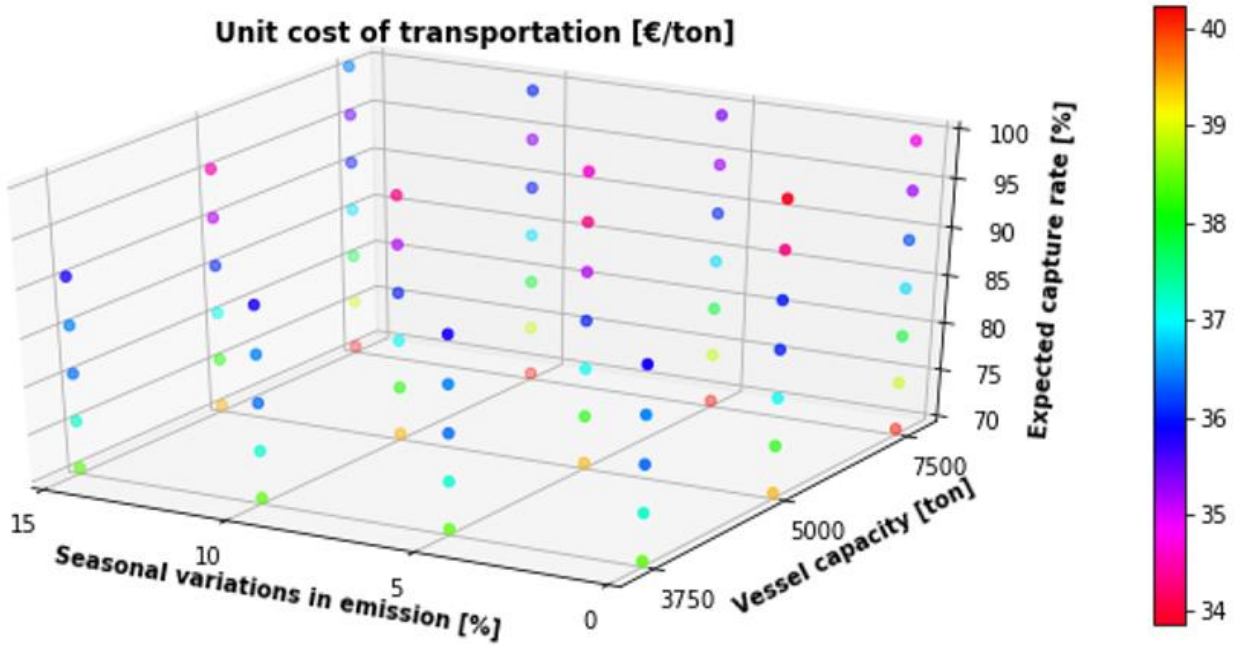
	Summer	Winter
Mean	34.68	37.69
Std	2.61	4.63

Case study

- Single source single sink value chain
- Emissions: 400 000 ton/a
- Transport route: 715 km, Brevik – Kollsnes
- Vessel transport capacity:
  - 3750 ton
  - 5000 ton
  - 7500 ton

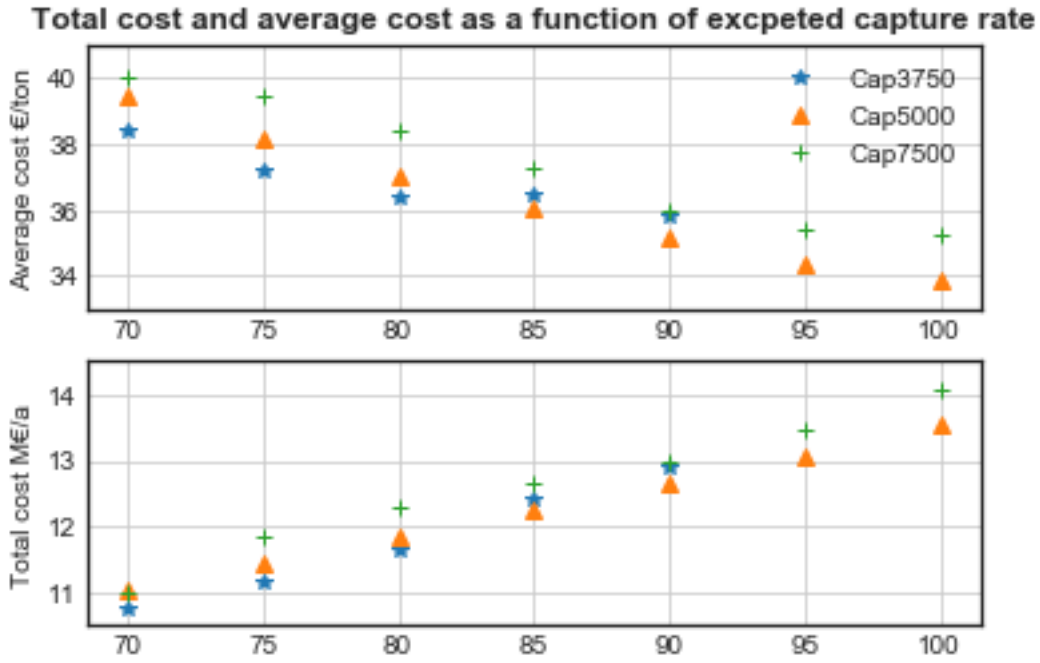
Results

- Ran above 84 instance of the problem
- Dimensions
  - Required capture rate
  - Seasonal variations on emission
  - Initial investment in ship capacity
- 33.8 – 40.7 €/ton of CO_2 transported
- Neglectable cost of seasonal variations up 15 %



Decreasing unit costs

- 5000-ton capacity is optimal
- 95 % Operation rate:
  - Total cost: 13.04 M€/a
  - Unit cost: 34.3 €/ton
  - CAPEX/OPEX 59 % / 41 %
  - 4 days and 6 hours buffer capacity
- Varying sailing speed strategies



Optimal investments and stochastic delays

- Constant delays gives low investments in buffer storage
- When the delays become stochastic, the only solution is to increase the speed
- Cost of above 0.19 M€/a

The cost of wrong forecast of fuel prices

- Increased fuel prices make buffer storage relativly cheap
- Up to 5 days storage capacity
- Under estimating fuel cost: 0.51 M€/a
- Over estimating: 0.071 M€/a

Summary

- Operational rates above 95 % gives the lowest unit prices
- Value in the flexibility of varying speed and buffer capacity
  - Higher value for buffer when operational rates increase
- Planning for stochastic delays and increased fuel prices make the buffer capacity storage more valuable

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