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Cost-Emission Relations for Maritime Logistics Support in Aquaculture

MTEC/ICMASS 2019
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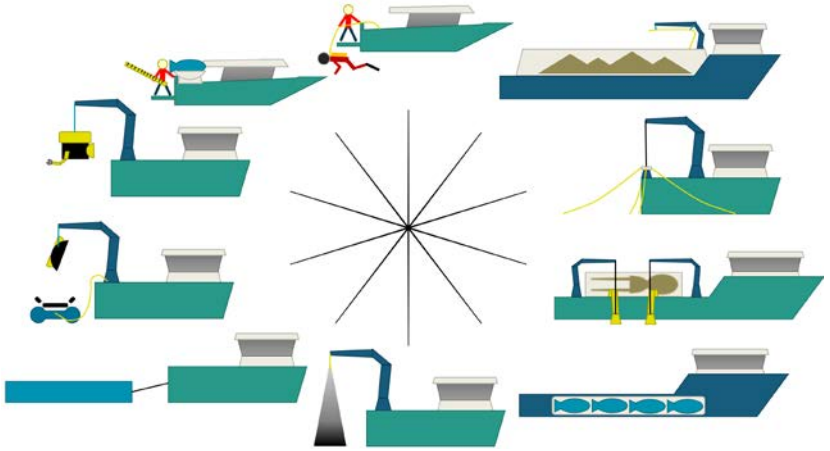
14.11.19 Trondheim

Background

- Support vessels in aquaculture come in many different shapes and sizes
- Together they form a fleet and perform tasks to support a set of fish farms
- Today, various fuel alternatives exist
  - In general, greener is more expensive



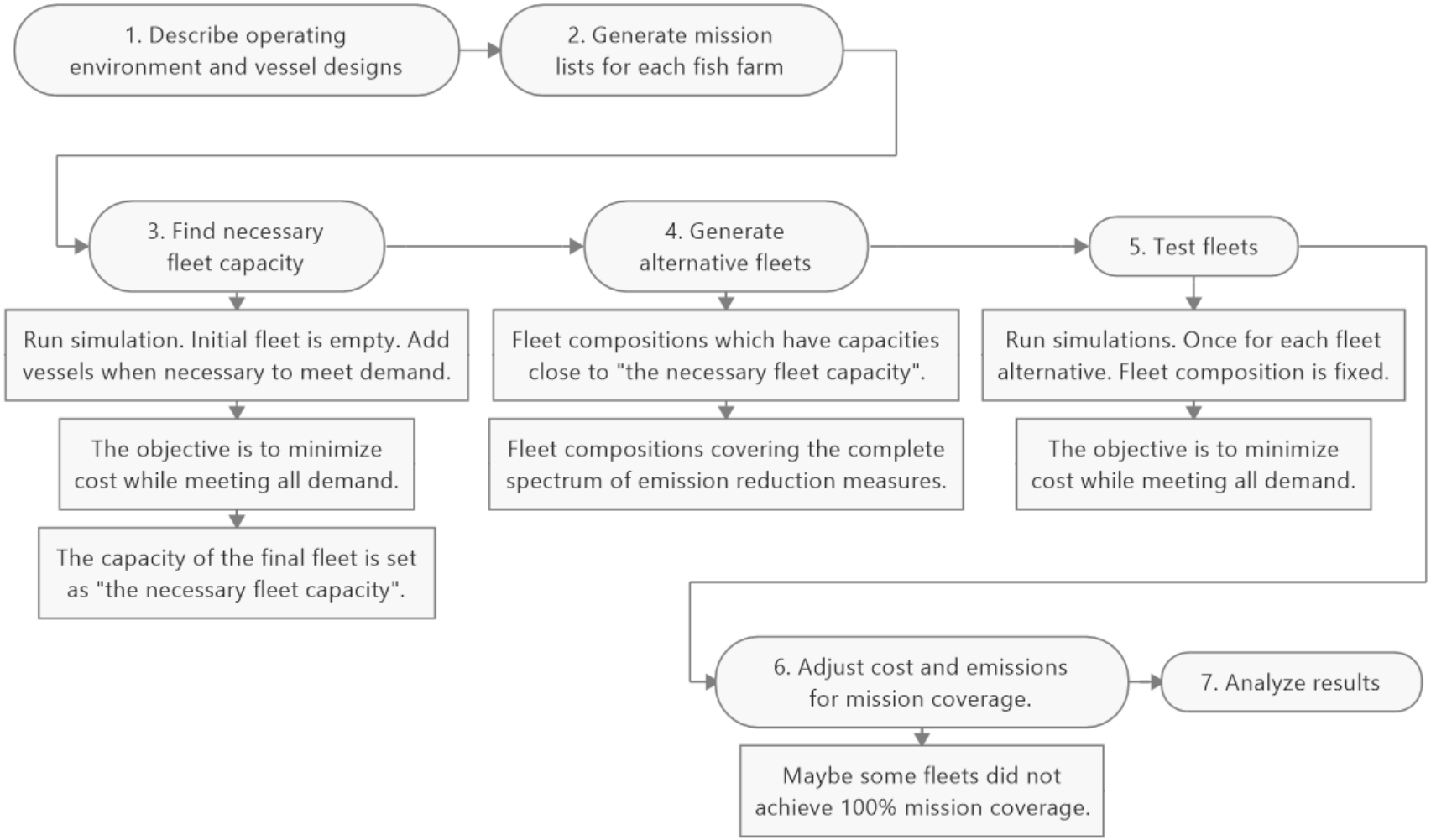
Background 2

- Purpose
  - Knowledge about the cost-emission relation for vessels in aquaculture, could be used as decision support when cost and emissions considerations are in conflict
- Objective
  - Proposing a method that can be used to establish cost-emission relations for vessel operations in aquaculture

Background 3

- The premise is that we only care about cost and emissions at the fleet level
  - Assuming that these metrics are more than a superposition of the single vessels
  - I.e. it is not trivial to predict the effect on the fleet cost and emissions based on the characteristics of the vessels

The method


1. Describe operating environment and vessel designs
2. Generate mission lists for each fish farm
3. Find necessary fleet capacity
4. Generate alternative fleets
5. Test fleets
Run simulation. Initial fleet is empty. Add vessels when necessary to meet demand.
The objective is to minimize cost while meeting all demand.
The capacity of the final fleet is set as "the necessary fleet capacity".
Fleet compositions which have capacities close to "the necessary fleet capacity".
Fleet compositions covering the complete spectrum of emission reduction measures.
Run simulations. Once for each fleet alternative. Fleet composition is fixed.
The objective is to minimize cost while meeting all demand.
6. Adjust cost and emissions for mission coverage.
7. Analyze results
Maybe some fleets did not achieve 100% mission coverage.

1.1 Describe operating environment

- 1000 days of operation
- Stochastic weather

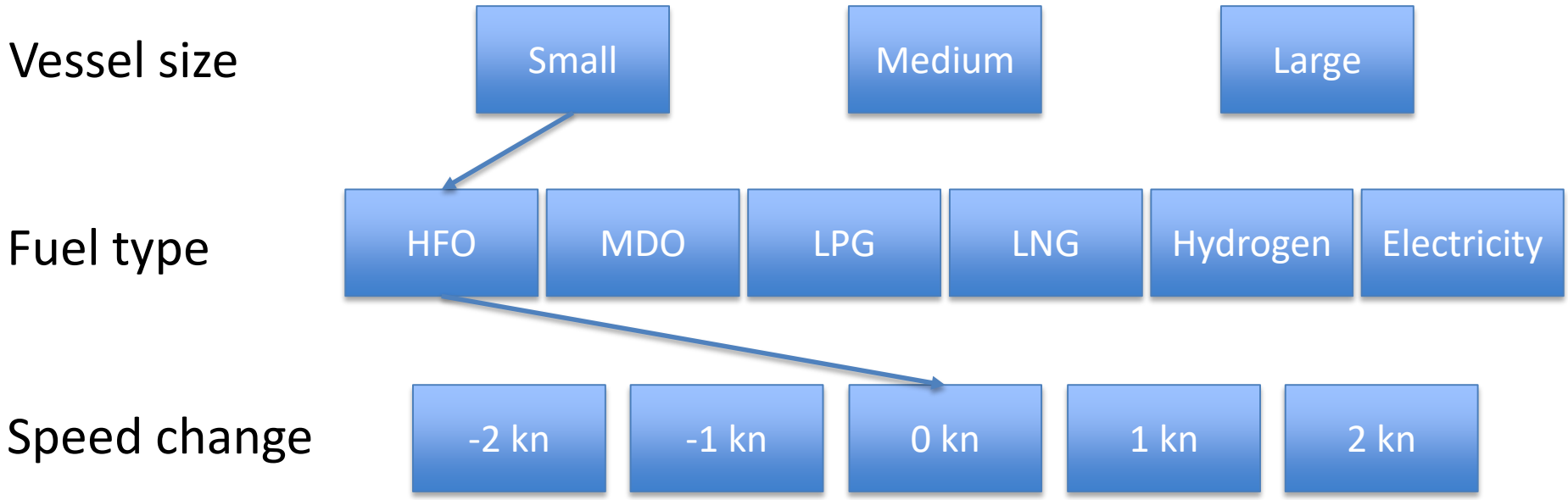
Fish farms	Hatcheries	Slaughterhouses	Ports	Area (km^2)
40	2	3	8	20 000 (100x200)

Fuel type	Efficiency (kWh_{output}/kWh_{fuel})	CO_2 (kg/kWh_{fuel})	Price ($/kWh)	ΔCAPEX (%)
HFO	40%	0.27	0.04	0
MDO	40%	0.25	0.055	0
LPG	40%	0.22	0.085	5
LNG	40%	0.18	0.01	10
Hydrogen	45%	0	0.285	15
Electricity	75%	0	0.20	20

1.2 Describe vessel designs

	Small Vessel		Medium Vessel		Large Vessel	
Mission types	Rate (t/h)	Limit	Rate (t/h)	Limit	Rate (t/h)	Limit
- **Transport smolt**	50	2	75	2	100	3
- **Delousing 1**	50	2	75	2	100	2
- **Delousing 2**	200	2	300	3	400	3
- **Sorting fish**	50	2	75	3	100	3
- **Transport slaughter**	100	2	150	2	200	3
Vessel characteristics						
- **Volume [m^3, tons]**	1000, 150		2000, 300		3000, 450	
- **CAPEX [USD/day]**	2877		4795		6712	
- **Speed [kn]**	10		11		12	
- **Power [kW]**	1000		1450		2100	

1.2 Describe vessel designs

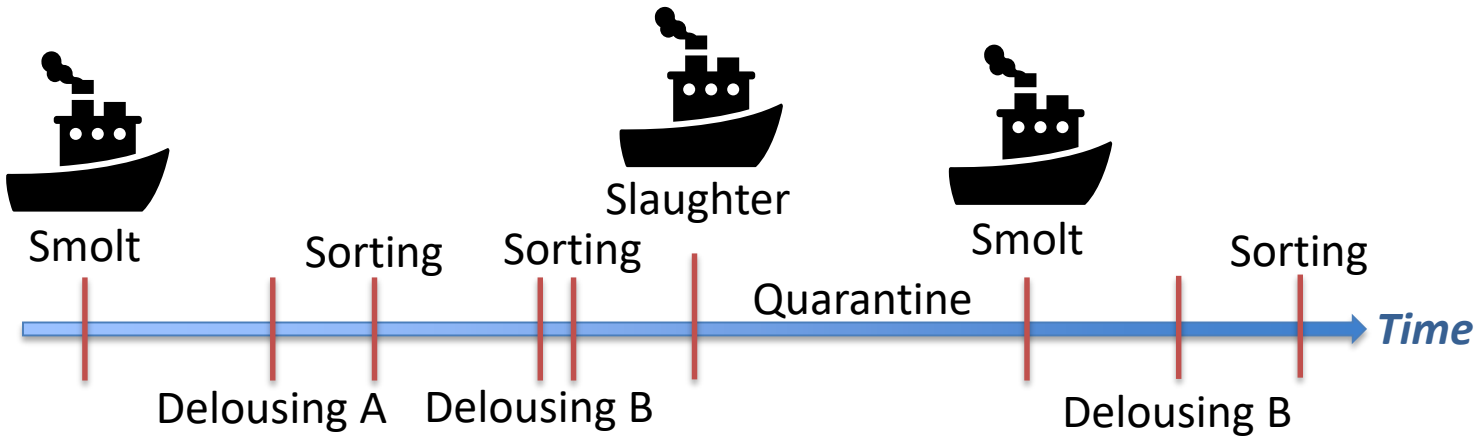


1.2 Describe vessel designs

- A sample of the 90 vessel types to choose from when composing a fleet

Size	Speed	Power	Fuel	CAPEX
150	8	940	1	2704,38
150	8	940	2	2704,38
150	8	940	3	2839,599
150	8	940	4	2974,818
150	8	940	5	3110,037
150	8	940	6	3245,256
150	9	960	1	2761,92
150	10	1000	1	2877
150	11	1060	1	3049,62
150	12	1140	1	3279,78
150	12	1140	6	3935,736
300	9	1363	1	4507,3
300	13	1653	6	6559,56
450	10	1974	1	6309,28
450	14	2394	6	9182,016

2. Generate mission list for each fish farm



- A list of missions “requested” by the fish farms that the logistics support, i.e. the vessels, have to perform

3. Find necessary fleet capacity

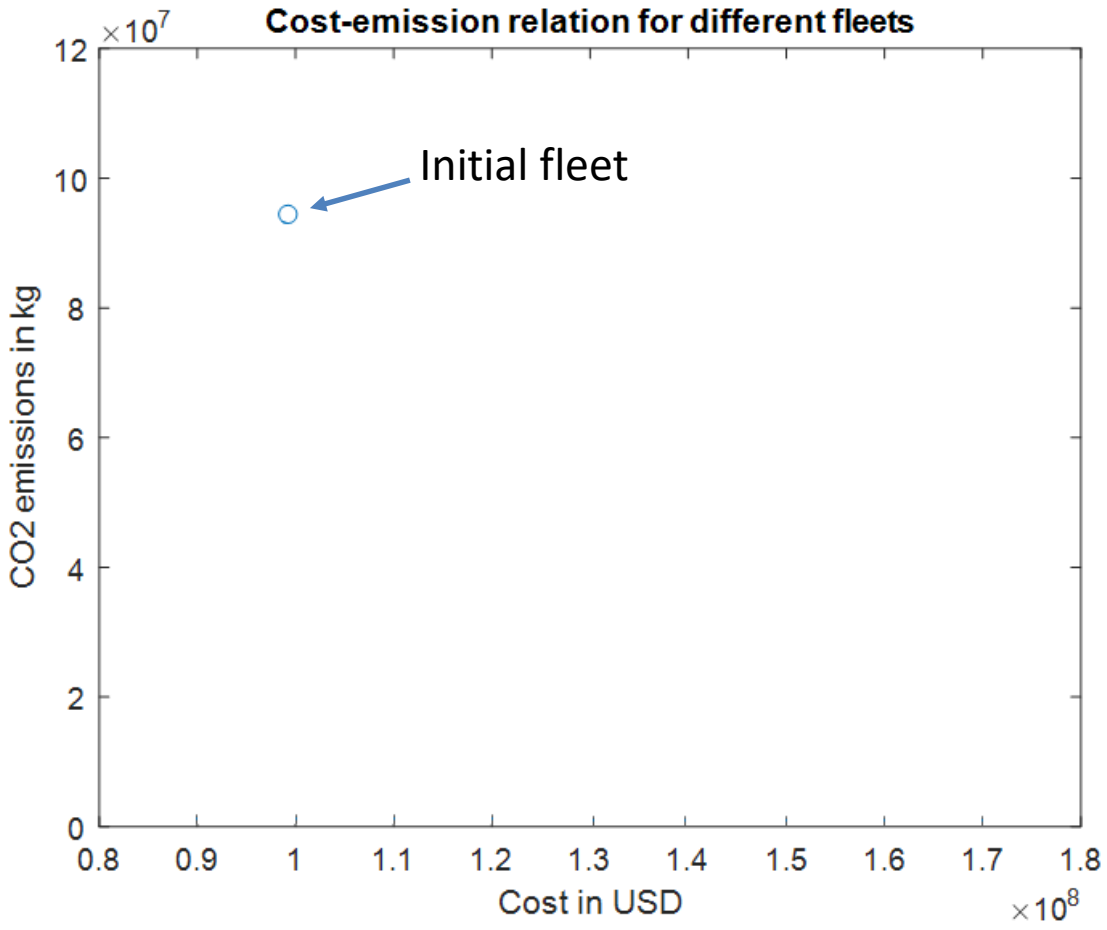
Day 1
Week 1
Mission A
Mission B
Mission C
Mission D
Week 2
Mission E
Mission F
Mission G

Day 8
Week 2
Mission E
Mission F
Mission G
Week 3
Mission H
Mission I
Mission J
Mission K
Mission L

3. Find necessary fleet capacity

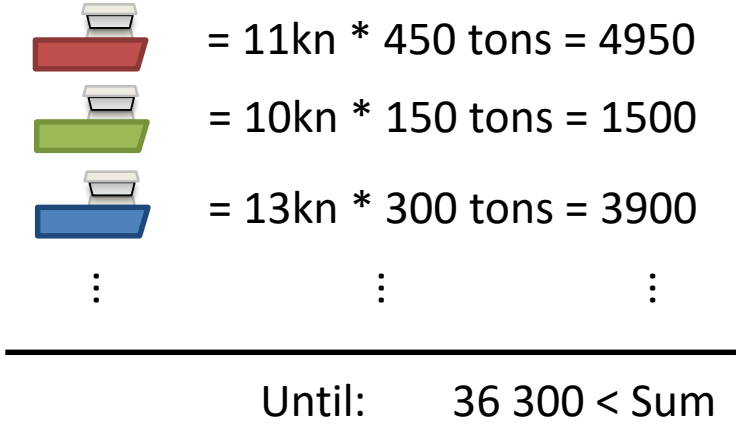
- Composition of initial fleet?
  - 11 vessels of various sizes, running on HFO
- Necessary fleet capacity (NFC)?
  - 36 300 ton*kn
- Fleet performance?
  - Cost: 99 218 813 USD = 99 200 USD/day
  - Emissions: 94 439 171 kg = 94 439 kg/day
  - Mission coverage = 100%

3. Find necessary fleet capacity



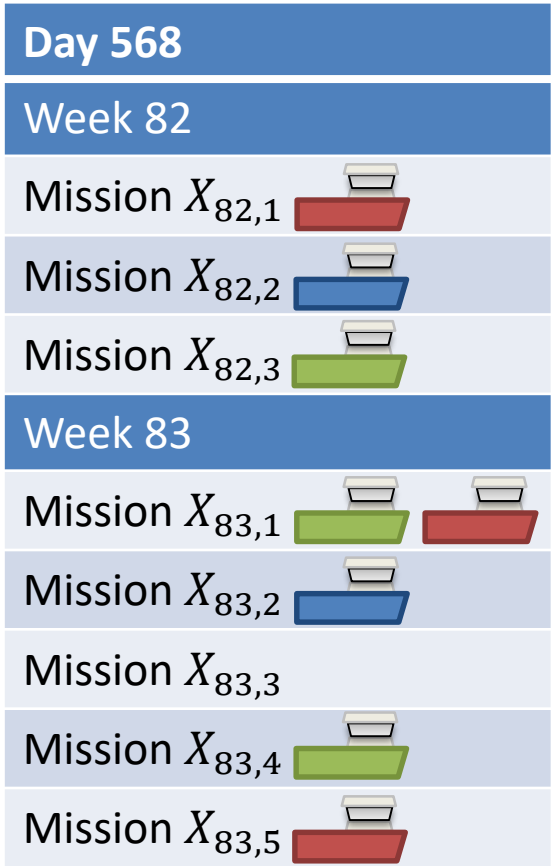
4. Generate alternative fleets

- How many fleets? 499 (Makes 500 in total)
- For each fleet, add vessels of random size and speed until NFC
- Fuel type is random
  - Based on fleet number
  - Fleet 1: [1 1]
  - Fleet 250: [1 6]
  - Fleet 499: [6 6]



5. Test fleets

- Now, let's say we have generated 499 new fleets
- Each fleet is tested in the same operating environment as the initial fleet
  - Now vessels cannot be added to the fleet during the simulation
  - The remaining decision is how to assign the vessels to the tasks

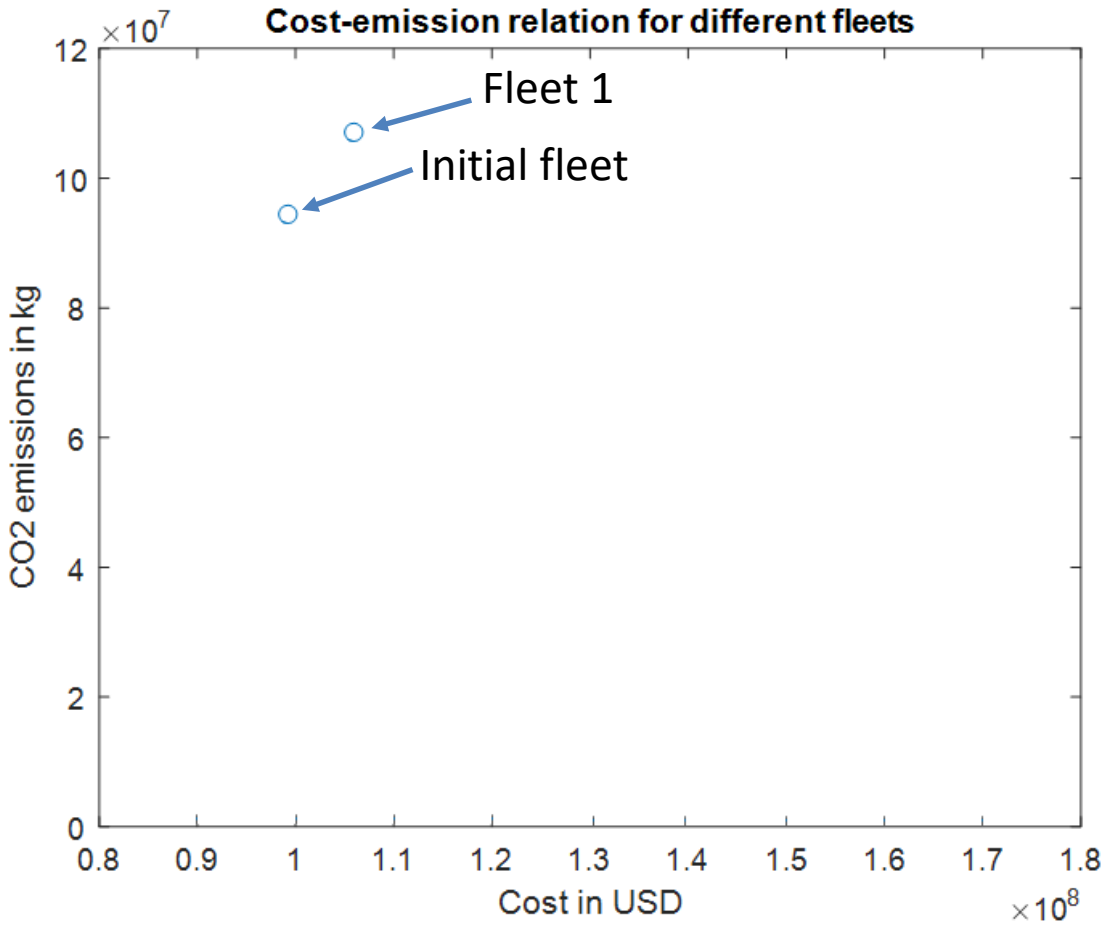


6. Adjust cost and emissions for mission coverage

- Fleet 1:
  - Cost = 93 686 570 USD
  - Emissions = 94 793 151 kg
  - Mission coverage = 88.46%

- Adjusted cost = 105 908 399 USD
- Adjusted emissions = 107 159 339 kg

7. Analyze results



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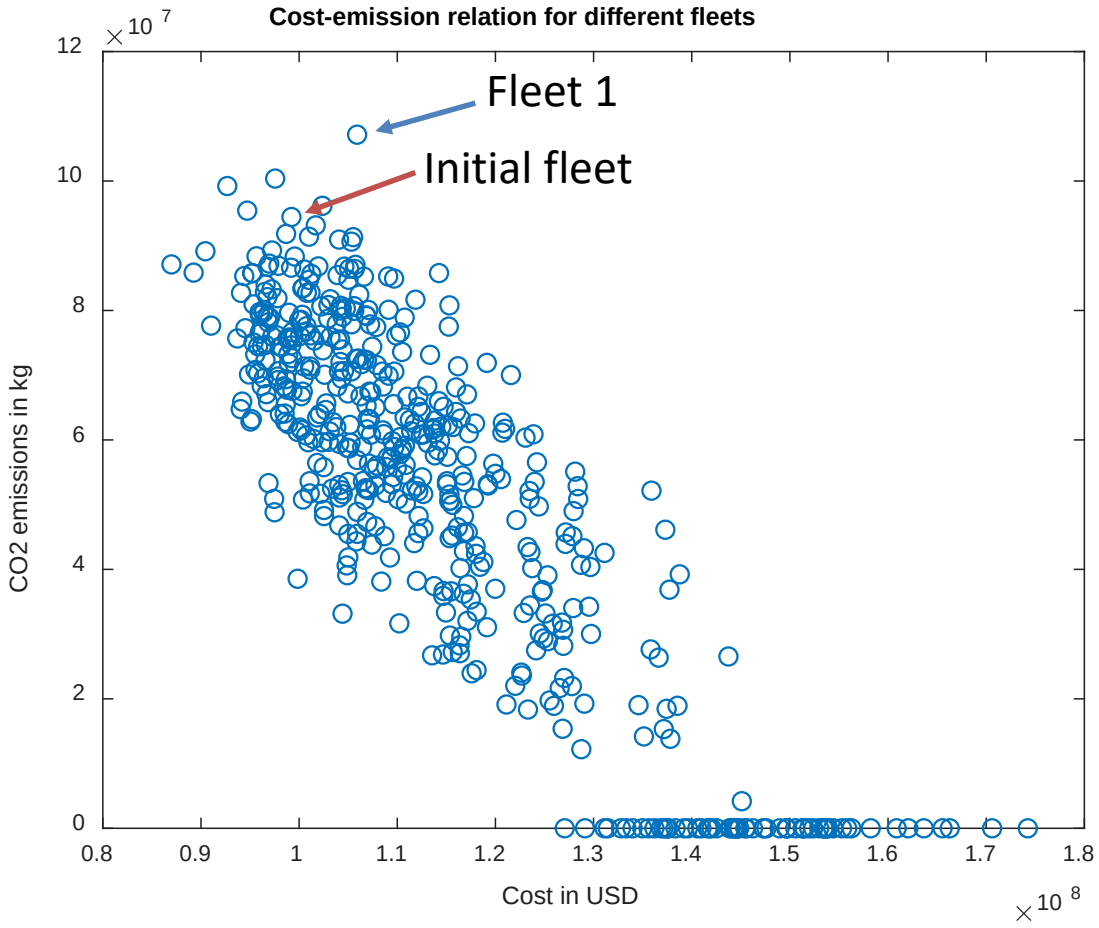

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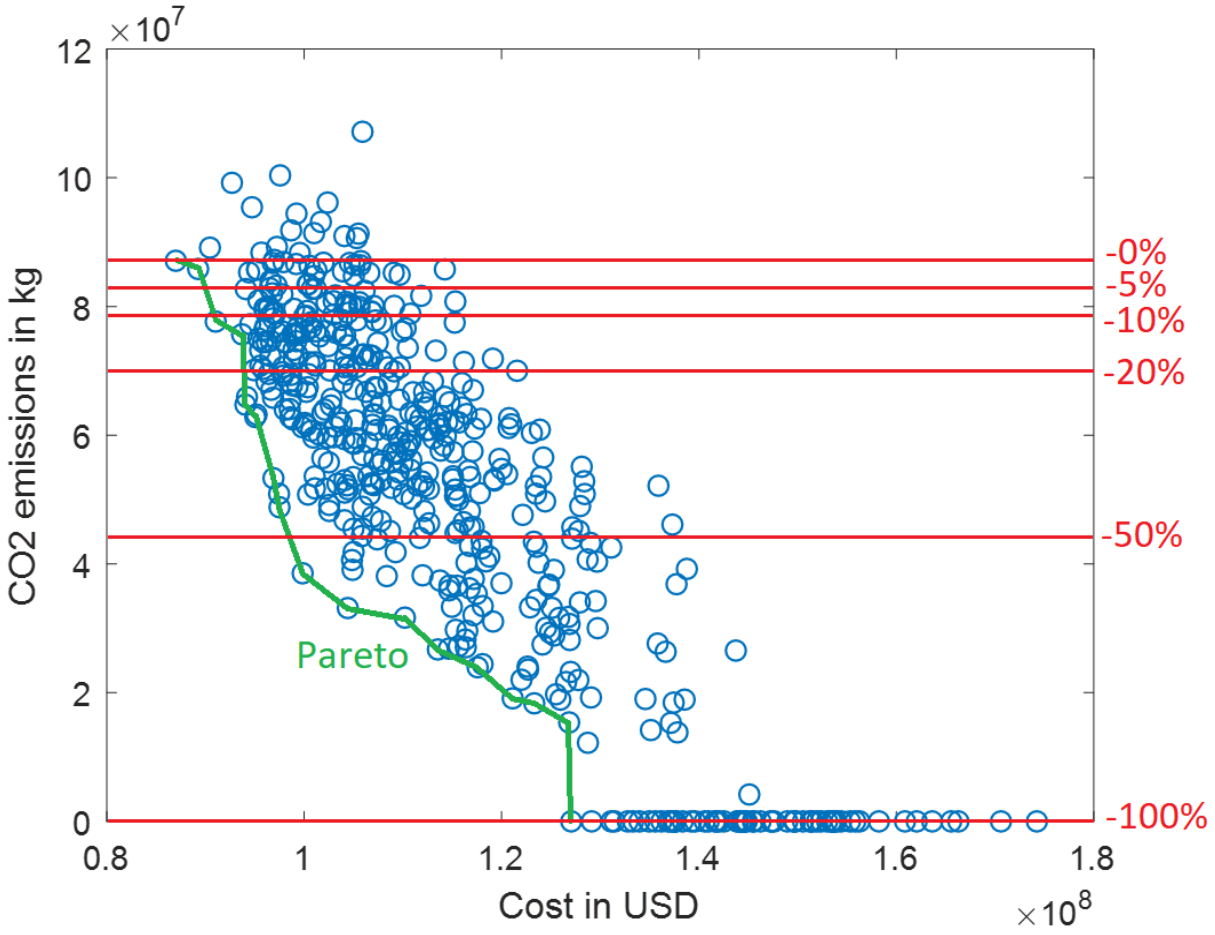

Discussion on the value and usefulness of the method

- Establishes a cost-emission relation for a given operating environment and a set of tasks
- Not directly applicable as decision support in fleet renewal
- Improving knowledge of policy makers and others who look at the bigger picture
  - E.g. taxes and incentives

Discussion on the assumptions, simplifications and shortcomings

- Assuming a representative mission list can be generated
- Improved process of generating fleet alternatives
  - Narrowing the search more effectively
- Assuming that fleets with <100% mission coverage can be linearly scaled to hit exactly 100%
  - Punish or discard?
- Improved testing of the fleets
  - No refueling
  - Hydrodynamical effects
  - Machinery performance
  - Routing heuristic or route optimization

Thank you!

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