Life Cycle Assessment as a Tool for the Selection of Optimal Power Systems

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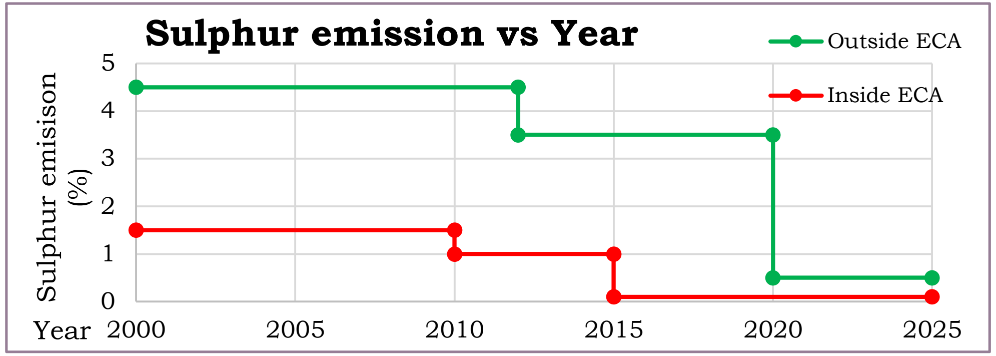
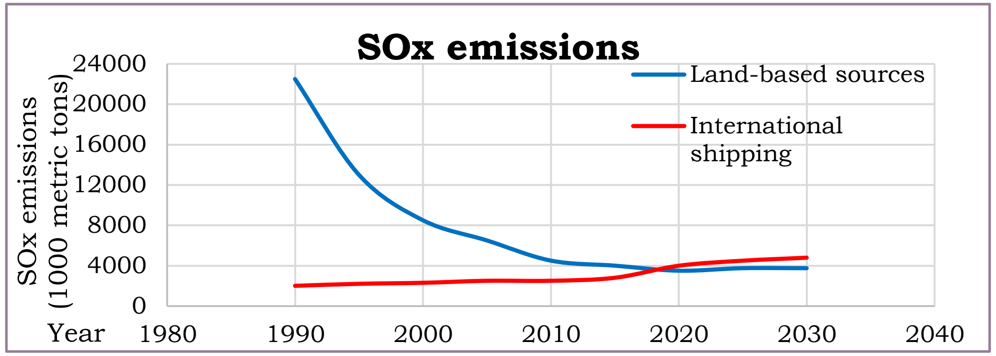
Outline

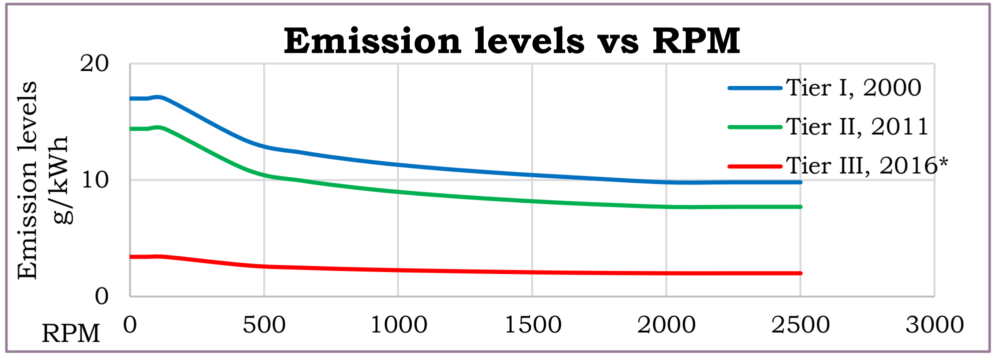
- **Background**
  - ship industry, life cycle assessment
- **Methodology**
  - LCA, LCCA, RA and MCDA
- **Case study and results**
  - Previous works
- **Discussions and Conclusions**
- **Future Work**

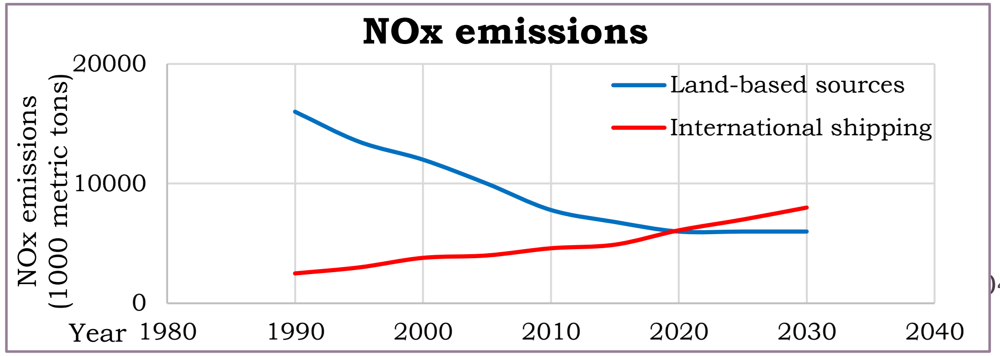
Background

- **Environmental** issues have been continuously drawing attentions;
- Owing to high operation cost (**OPEX**) of traditional power systems and serious environmental situation, the usage of hybrid power system on board is increasingly attracting attentions;



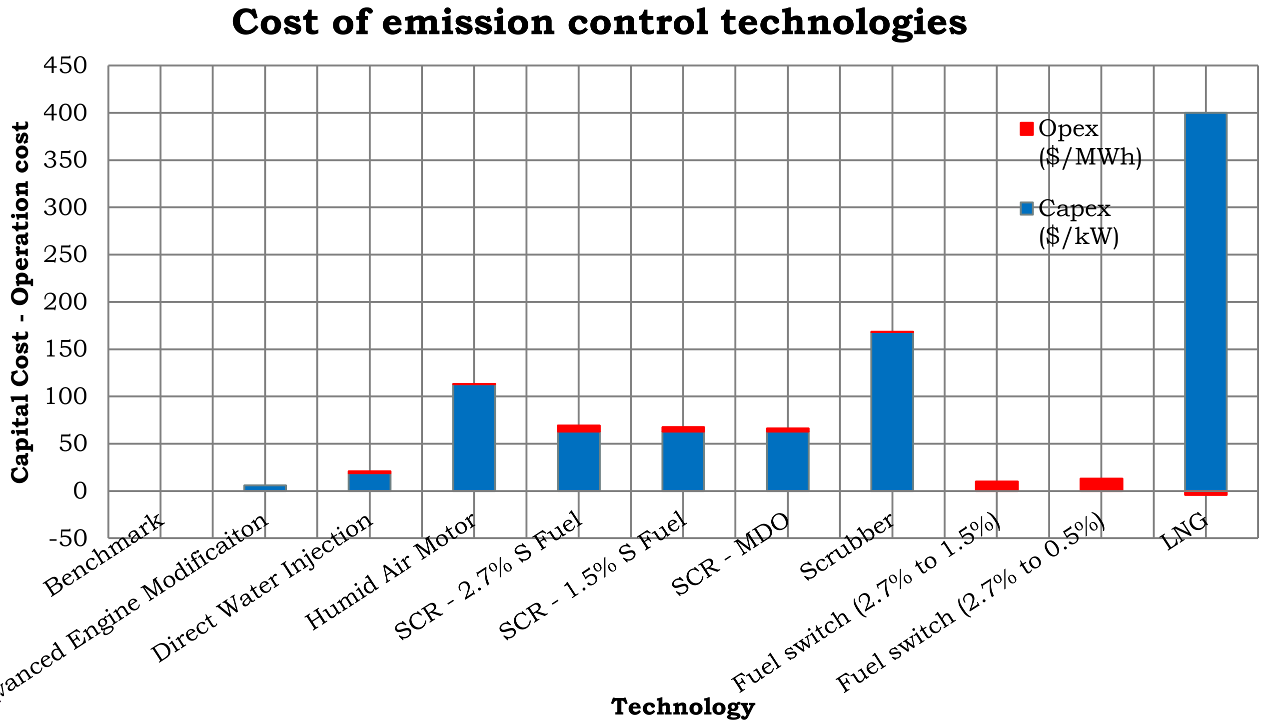






Background

- Available emission control technologies
- Many other alternatives available
- High demands in performance evaluation
- Cost consideration
- Environmental impacts
- Other factors
- Multiple impacts decision making



Cost or environmental friendly?
Why not both?
How?

Background

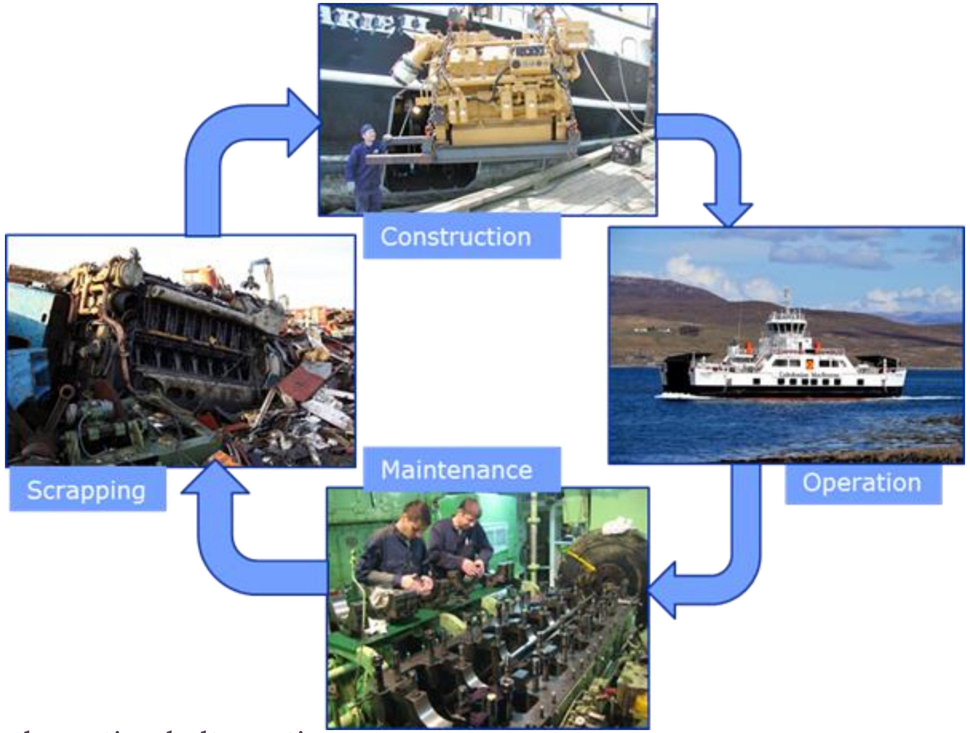
- **Life Cycle Assessment:**
  - compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
- **Life Cycle Cost Assessment:**
  - a method for assessing the total cost which takes into account all costs of acquiring, owning, and disposing of a product or system
- **Risk Assessment:**
  - a systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking.
- **Multi-criteria decision making:**
  - making preference decisions (such as evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes

Background

- LCA has been considered to be a widely used evaluation method to determine the benefit or performance of a product or a system from its cradle to grave.
- With LCA, the life phases and main activities of the product/system will be identified and the related cost and emission release will be determined.
- With the help of decision making method, it is a feasible and trustworthy way to evaluate the performance of the target.
- Considering many different aspects of the target, i.e. environmental, cost and risk impact, the evaluation could be extensively comprehensive.

Methodology

- **Life Cycle Assessment**
  - From cradle to grave
  - Environmental impacts
  - Optimal alternative

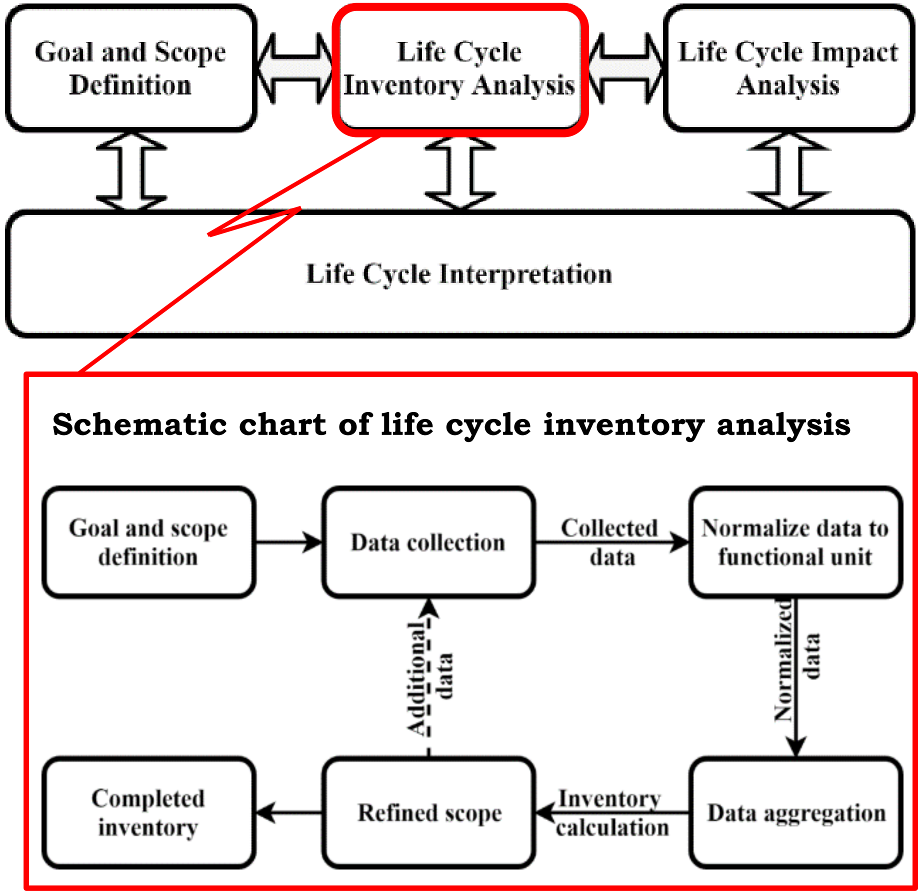


- **Literatures**
  - ISO 15686-5:2017, 14040:2006 & 14044:2006;
  - Jeong et al., 2018, An effective framework for life cycle and cost assessment for marine vessels aiming to select optimal propulsion systems. J. Clean. Prod. 187, 111–130.
  - Blanco-Davis, E., Zhou, P., 2014. LCA as a tool to aid in the selection of retrofitting alternatives. Ocean Eng. 77, 33–41.
  - Alkaner, S., Zhou, P., 2006. A comparative study on life cycle analysis of molten carbon fuel cells and diesel engines for marine application. J. Power Sources

Methodology

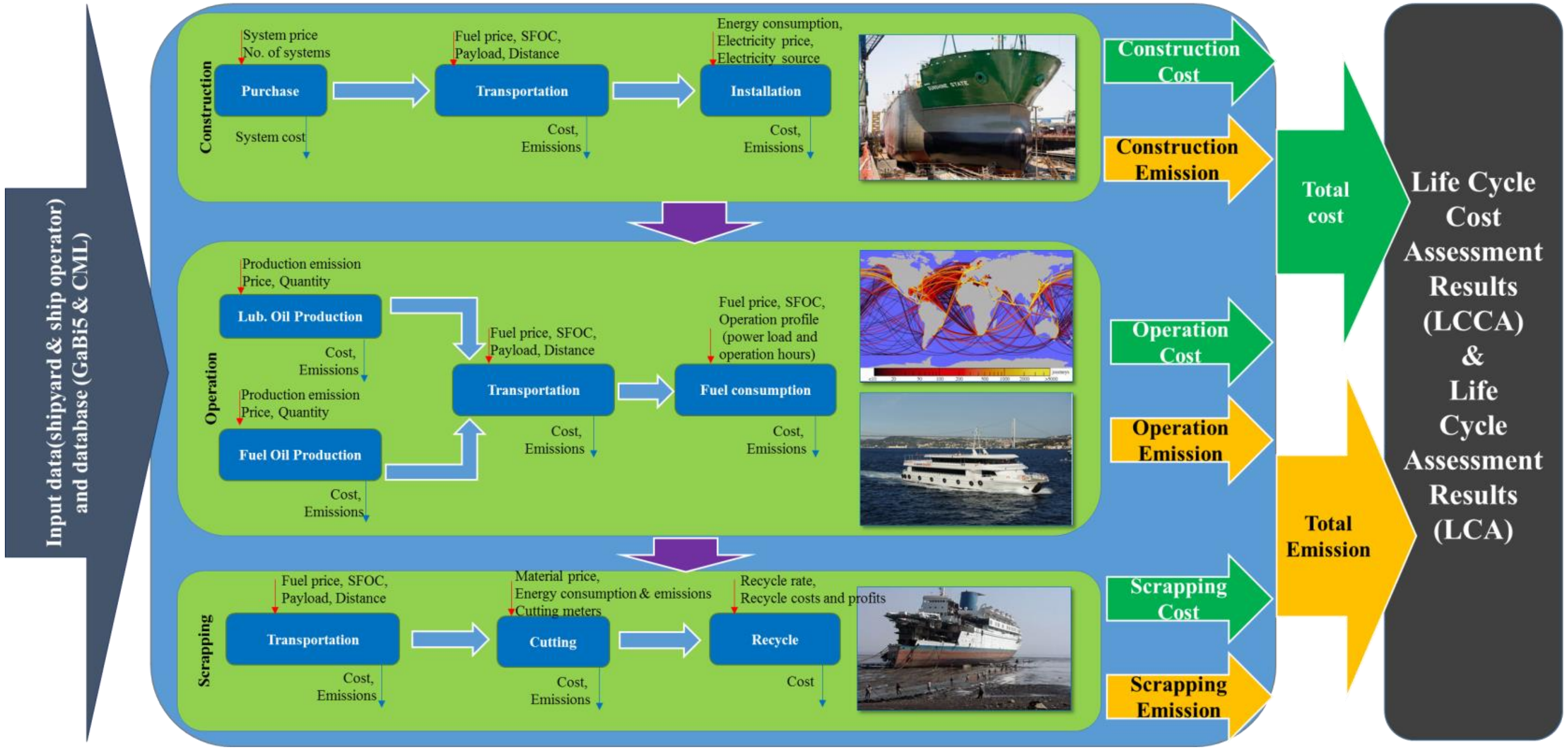
- **Set up goal and scope by**
  - Target
  - Results
  - Assumptions
- **Inventory setup**
  - Data collection
  - Normalize to functional unit
  - Data aggregation
  - Refine scope
- **Determine impacts/performance**
  - Select impact categories
  - Assign emission to categories
  - Determine results

Schematic chart of life cycle assessment



Methodology

- One example of LCA and LCCA flow



Overview procedure of LCA study

Case study 1: Hybrid system

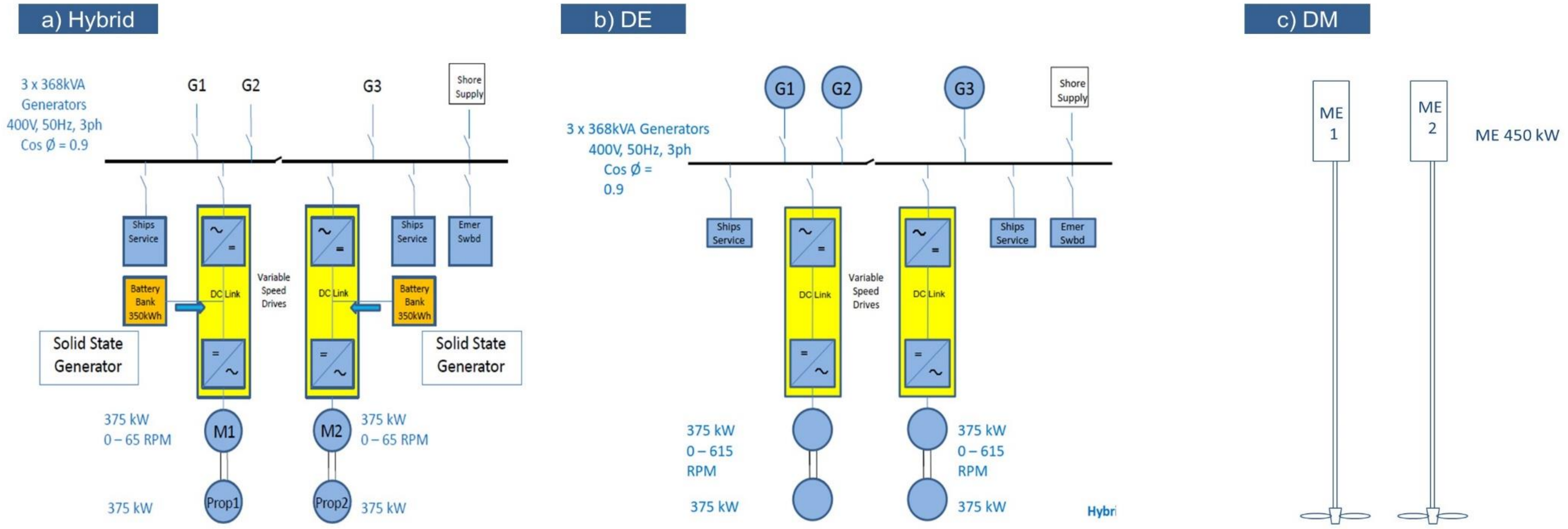
- **Hybrid Propulsion System**
  - **Goal:** to compare the performance of different propulsion system
  - **Functional unit:** cost spent through whole life span (30 years)
  - **Data**: collection from different sources or use engineers' judgements

Case vessel specification and operation profile

Specification			
Length × Breadth × Depth	39.99 m × 12.2 m × 1.73 m		
Displacement (t)	100 tons (Steel)		
Engine configuration	Hybrid (Actual)	Alternative 1 (DE)	Alternative 2 (DM)
	360 kW × 3 sets (3.2 tons) + 350 kW lithium-ion battery × 2 sets (3.5 tons)	360 kW × 3 sets (3.2 tons)	450 kW × 2 sets (4 tons)
Operational profile			
Category	Sailing	Manoeuvring	Port
Daily operation hours	6	0.6	3.72
Required propulsion power (kW)	322	144	87

Case study 1

- **Hybrid Propulsion System**
  - Drawing for various propulsion systems



Case study 1

- **Characteristics of Hybrid Propulsion Systems**

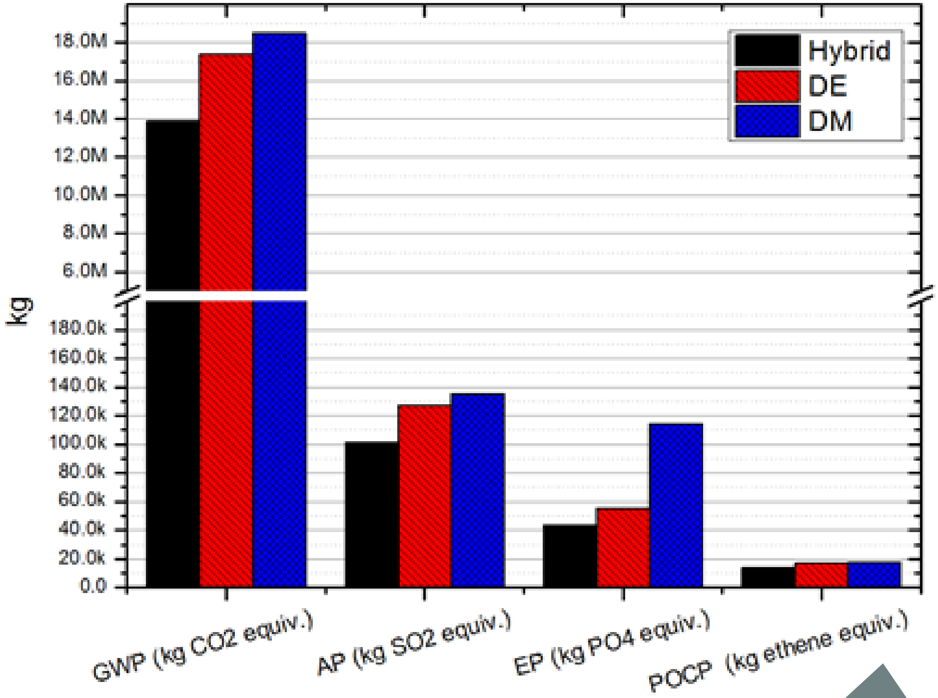
  - **Advantages**
    - Low Fuel Consumption
      - MDO 0.05 €/kWh;
    - Emission release due to fuel consumption reduced;
    - Long maintenance intervals: Hybrid system has less engine operating hours than other systems;

  - **Disadvantages**
    - More shore power required
      - Electricity (day) 0.15€/kWh
      - Electricity (night) 0.07€/kWh
    - More upstream emission from electricity production;
    - High capital investment on battery packs

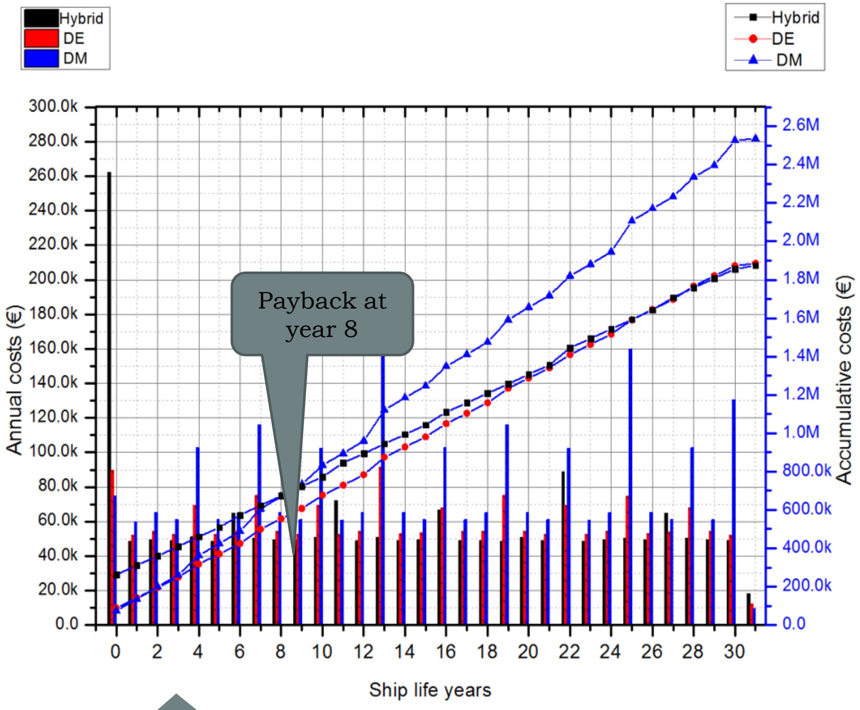
Case study 1

- **Results of LCA and accumulative cost over ship life years**

Environment impact of three alternatives



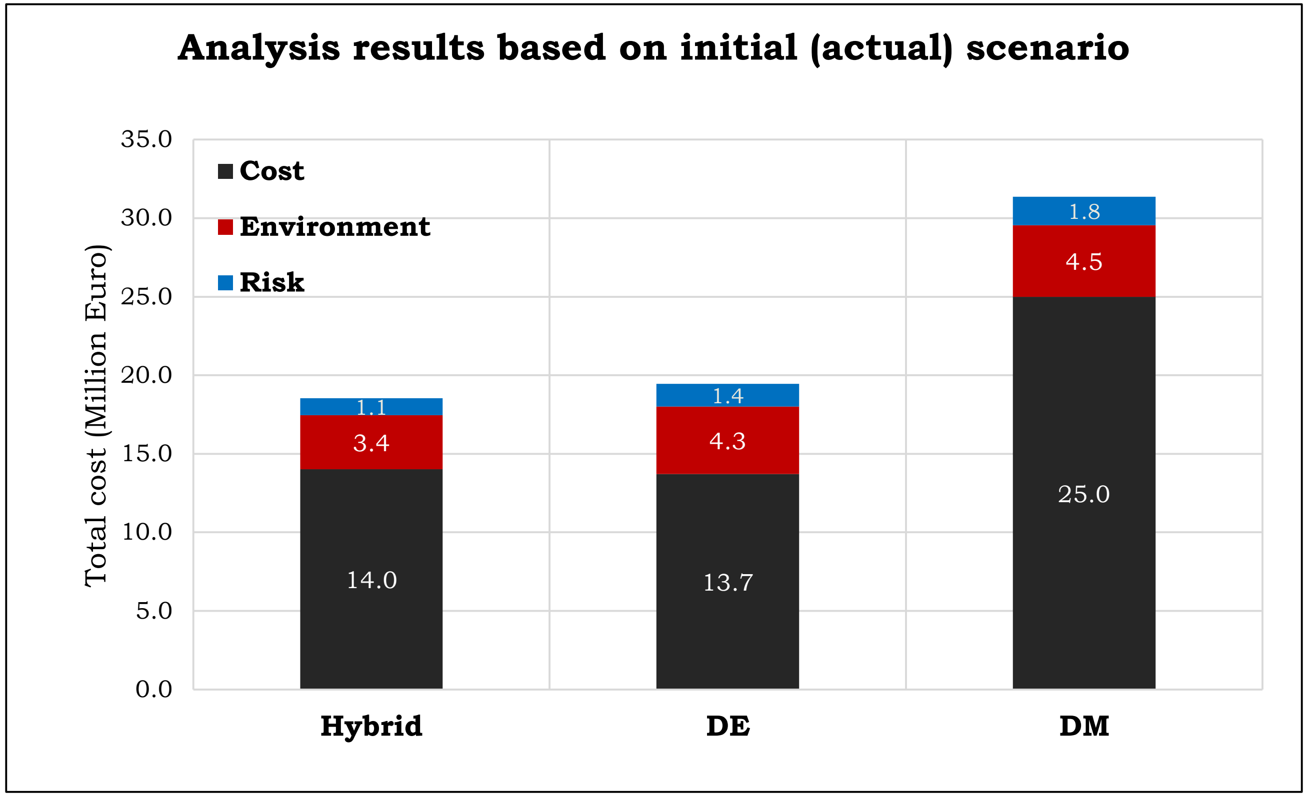
Cost accumulation of three alternatives



Hybrid system is the optimal alternative.

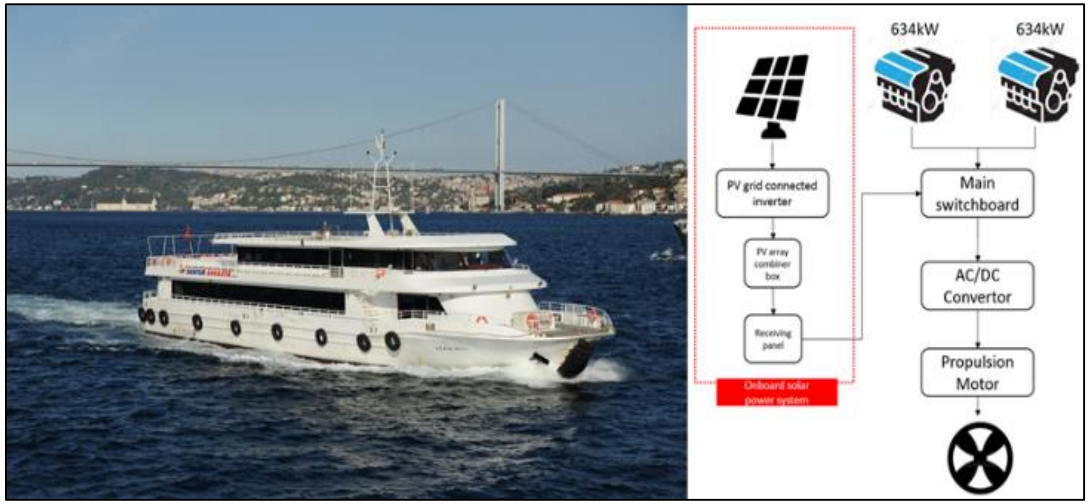
Case study 1

- **Overall comparison: cost-environment-risk perspective**



Case study 2: Solar system

- **Utilization of Solar Panel Array**

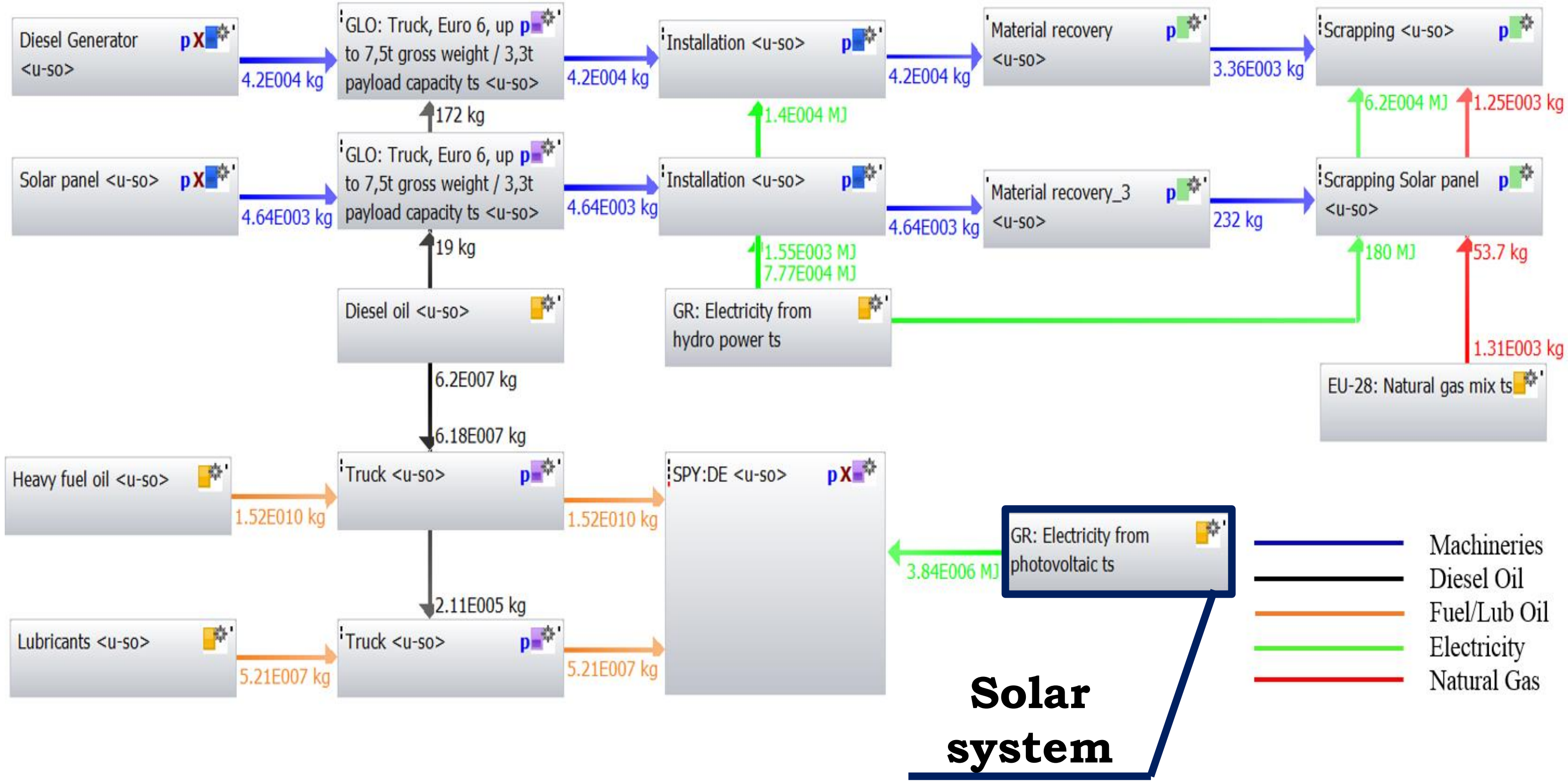


- **Case study ship specifications**
  - Solar panel cost ~$28,840

Vessel specification		Operational profile		
Name	Hizir Reis	Category	Sailing	Manoeuvring
Flag	Turkey	Operation profile (hours)	9	1
LOA (m)	41.98	Engine Load (%)	85%	50%
B (m)	10	Power required (kW)	1078	634
Gross tonnage (tonne)	327	SFOC (g/kWh)	190	194
		SLOC (g/kWh)	2.85	4.85
Fuel type	HFO	**Solar panel installations**		
Annual operation days	325	Available area	400	m^2
		Area per panel	1.94	m^2
Engine power (kW)	634×2	Number of panels used	206	
Life span (years)	25	Power output per panel	0.35	kW
Year built	2012	Total output power	72.1	kW

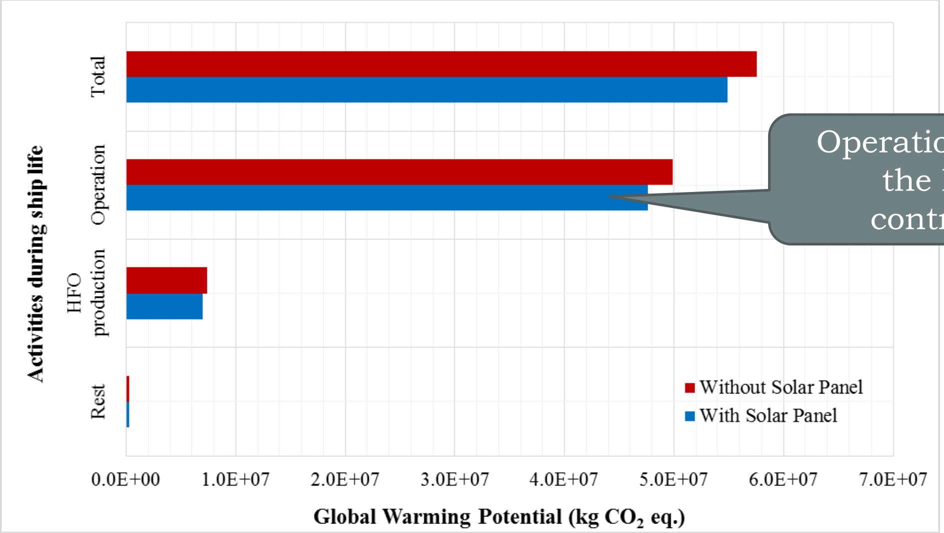
Case study 2

- **LCA model established With GaBi software**



Case study 2

- **Comparison of LCA results**



Operation phase is the largest contributor.

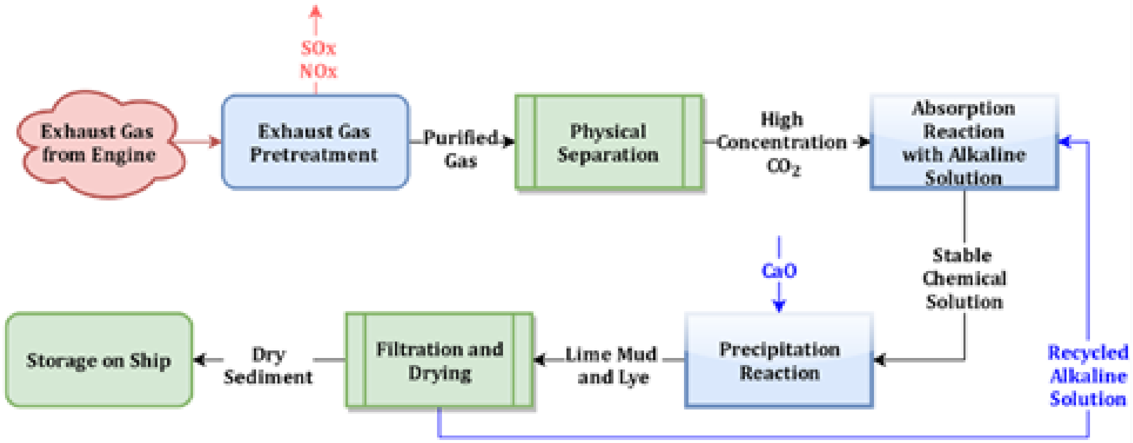
- **Comparison of LCCA results**

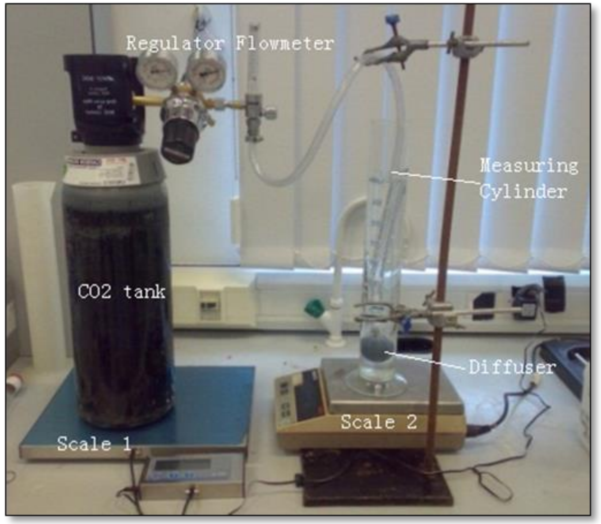
We are saving fuel!

Item	Quantity	Units
Daily fuel consumption (FC)	1,966	kg/day
FC1 (6.7 hours sunny)	1,270	kg/day
FC2 (3.3 hours not sunny)	602	kg/day
New daily FC (total)	1,872	kg/day
Annual fuel consumption (benchmark)	638,961	kg/Y
Annual fuel consumption (Scenario 2)	608,489	kg/Y
Annual fuel saved	30.5	tonne/Y
Fuel price	401	$/tonne
Annual fuel cost saved	12,204	$/Y
Life Cycle fuel cost saved	305,101	$
Present value	130,275	$
Payback period with carbon credit of $21/ton	3	Years

Case study 3: CCS system

- **Carbon Capture on Ships**
  - Principles of the CCS system
    - $CO_2(g) + 2NaOH(l) = Na_2CO_3(l) + H_2O(l) - \Delta H_1$ (1)
    - $Na_2CO_3(l) + Ca(OH)_2(s) = CaCO_3\downarrow(s) + 2NaOH(l) - \Delta H_2$ (2)
  - Flow diagram of the CCS processes
  - Experiment rig



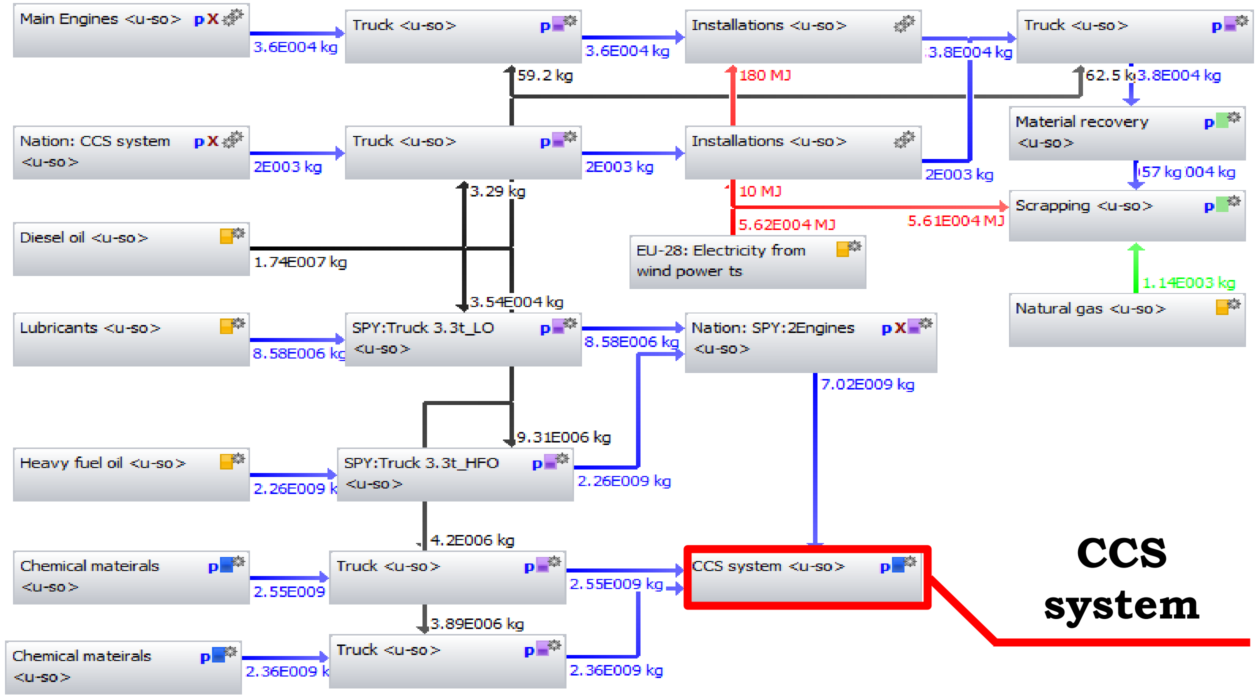


Case study 3

- **CCS applied on marine vessel**
  - Vessel specifications

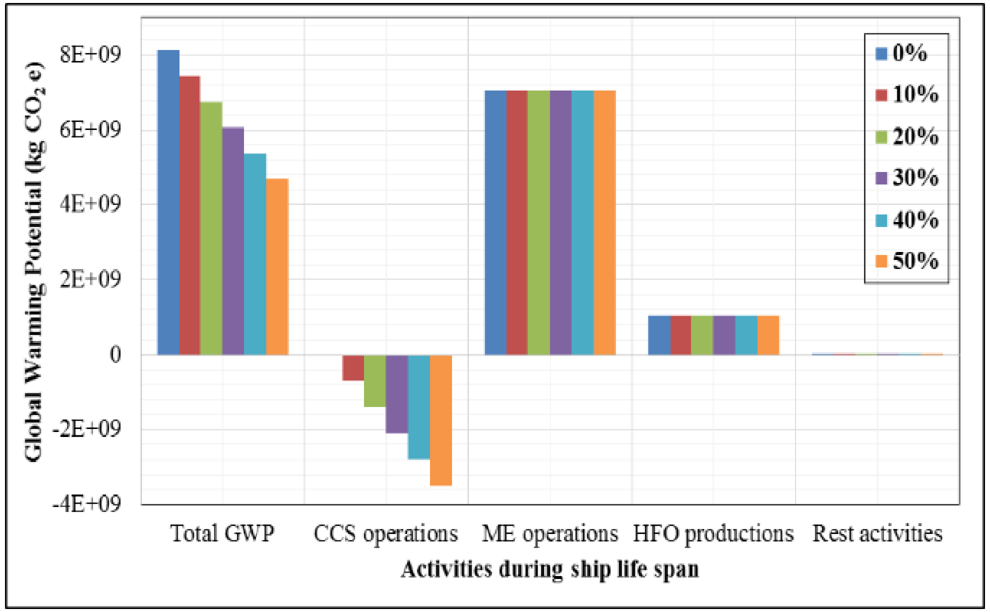
Type	Bulk Carrier	
LOA	292	m
LBP	283.5	m
Breadth	45	m
Depth	24.8	m
Draught	16.5	m
Gross	94, 360	ton
DWT	157, 500	ton
Water ballast	78, 000	m^3
Fuel type	HFO	

- LCA model established in GaBi



Case study 3

- **Results and comparison of different reduction target**
  - Global Warming Potential (kg CO_2 e)



  - Cost estimation (€)

Reduction target	Cost with CCS (€)	Cost without CCS (€)	Difference (€)
0	5.17×10^8	5.17×10^8	0.00×10^0
10%	5.24×10^8	5.19×10^8	-4.44×10^6
20%	5.01×10^8	5.25×10^8	2.41×10^7
30%	4.49×10^8	5.34×10^8	8.56×10^7
40%	3.68×10^8	5.48×10^8	1.80×10^8
50%	2.58×10^8	5.65×10^8	3.08×10^8

Not always helpful!

Case study 4: Maintenance

- **Maintenance plan**
  - Problem:
    - Bio-fouling
    - Hull renewal

  - T

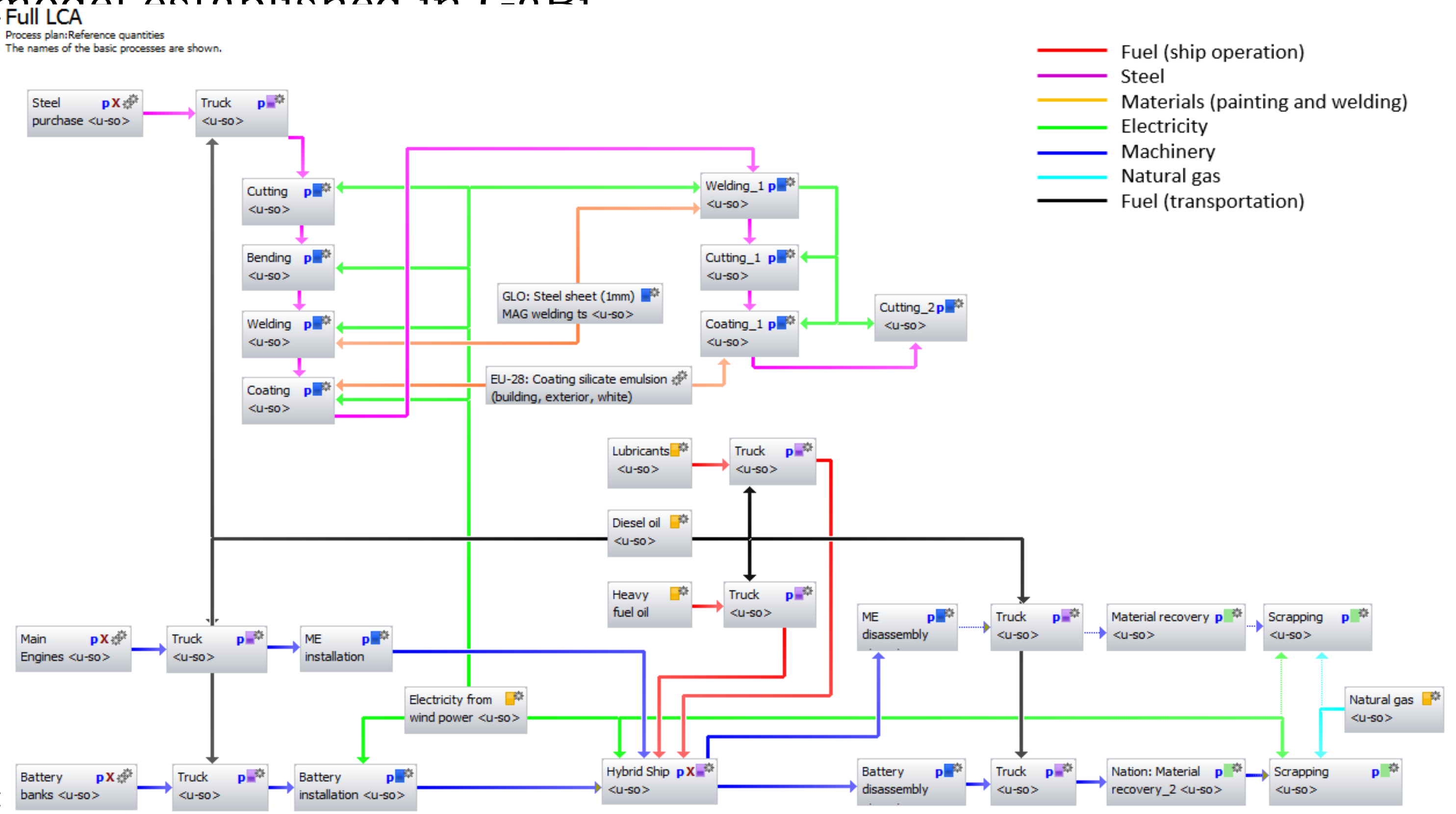
Name	MV Catriona
Type	Hybrid Ferry
Gross weight	499 tons
Length	43.50 m
Breadth	12.20 m
Depth	3 m
Draught	1.73 m
Block coefficient (Cb)	0.45
Power	360 kW × 3
Superstructure decks	2
Builders	Ferguson Shipyard Ltd.
Built year	2015
Life span	30

- Maintenance Strategy

No.	Maintenance Strategy
Case 1:	Re-coating annually;
Case 2:	Re-coating every two years;
Case 3:	Re-coating every three years;
Case 4:	Re-coating yearly and renewal hull steel every 10 years;
Case 5:	Re-coating yearly and renewal hull steel every 7 years

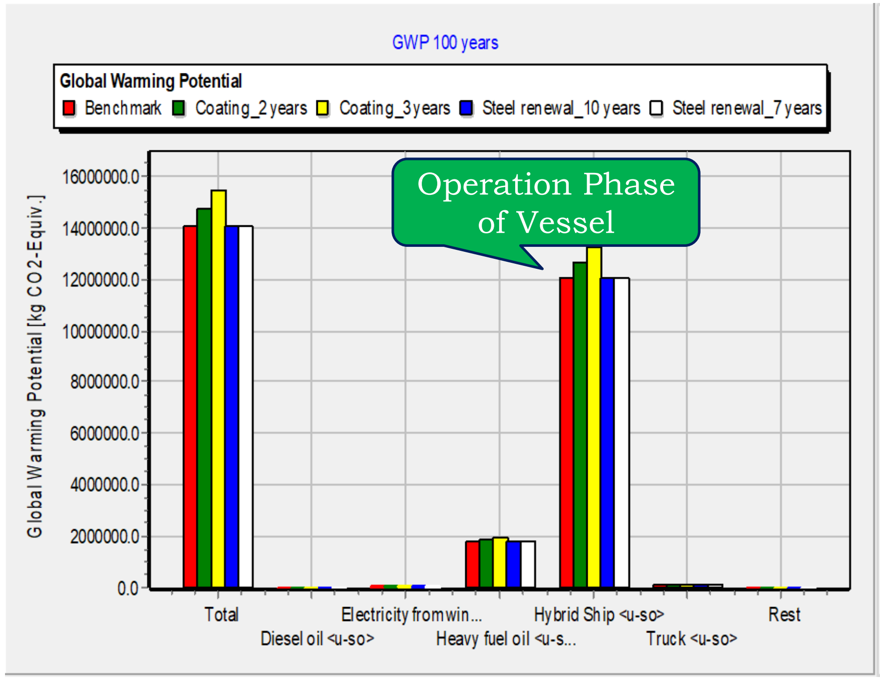
Case study 4

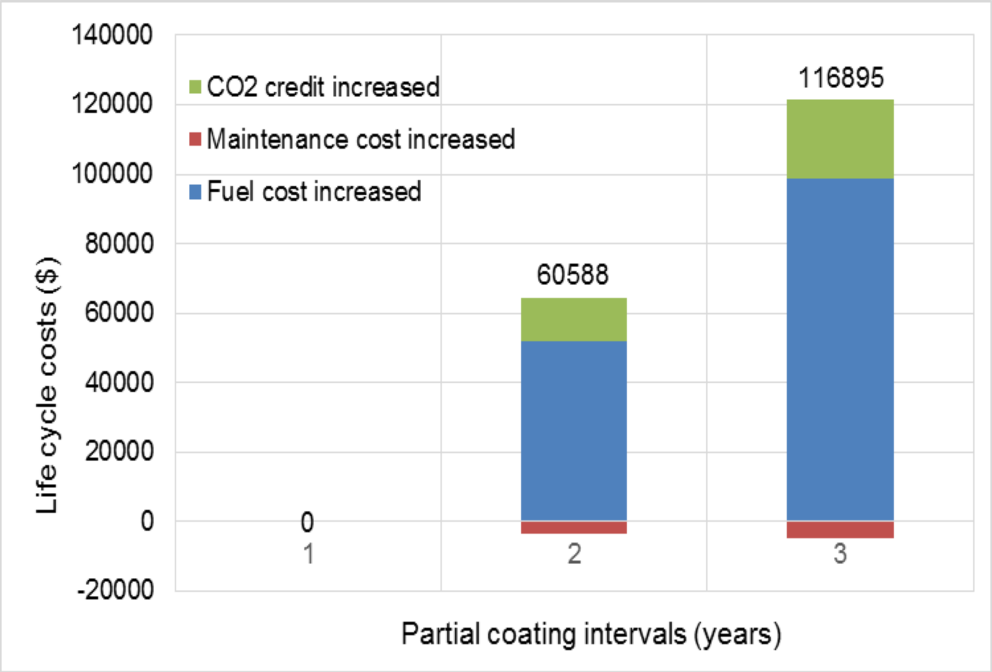
- **Maintenance plan**
  - LCA model established in GaBi



Case study 4

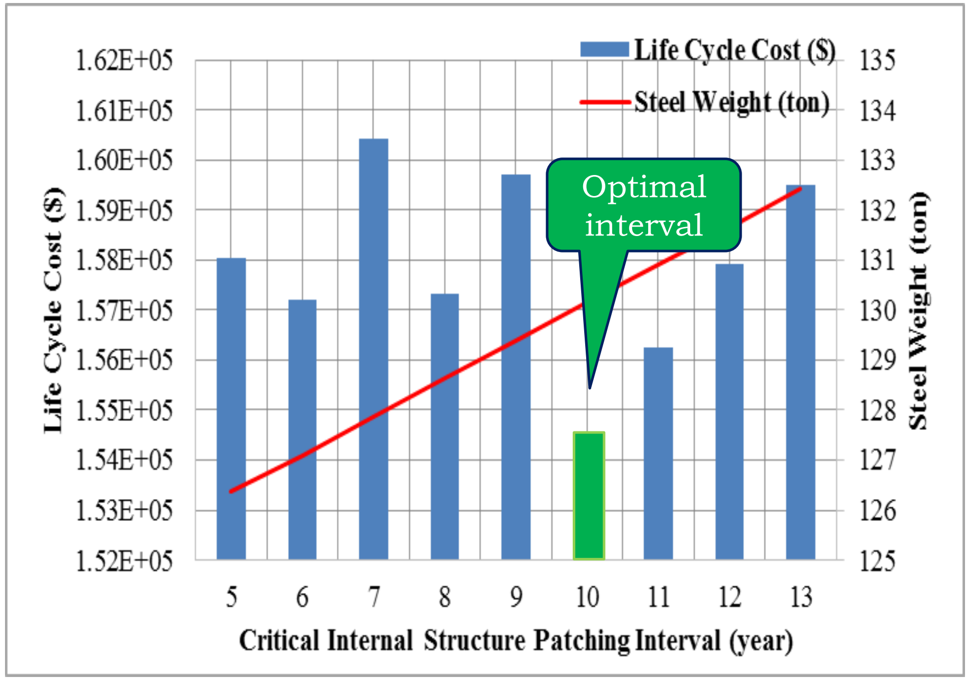
- **Maintenance plan**
  - GWP and cost results & comparisons under various **coating** intervals





Case study 4

- **Maintenance plan**
  - Cost results & comparisons for different **patching** interval



Discussions and conclusions

- Comprehensively considering activities and life stages for ship performance evaluations;
- In every emission category, the environmental impact could be determined by convert emissions to one indicative emission, which will be a fundamental for further decision making processes;
- Three types of flows can be considered: cash, energy, emission; they could meet most the evaluation purposes with quantified results;
- Based on the targets of the analysis, the aim and scope of the evaluation could be modified and provide a reasonable comparison to determine the optimal alternative;
- Be able to determine different formats of results with further considerations: present value, payback period etc.;
- Assumptions could be made based on experiences and practices to keep the accuracy of results in a reasonable range;
- The LCA model could be modified for a new evaluation purpose with most of the general activity modules unchanged to reduce time scale of the evaluation process;
- The relationships between different life stages and between different activities can be simulated in LCA model so that the interactions can be taken into account.

Future work

- Database establishment for ship building industry;
- Determine trustable information from engineers or workers to replace assumptions;
- Expand work to other marine applications, i.e. wind farms;
- …

Thank you for your attentions!

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