Introduction

When assessing green technologies for a new build or retrofit ship design, several financial metrics are crucial for evaluating their economic viability. Here, the payback period (P), net present value (NPV), and marginal abatement cost curve (MACC) are discussed from which models are also presented. By using these three metrics in combination, shipping companies can make well-considered decisions that balance short-term financial concerns (P), long-term profitability (NPV), combined with the environmental impact (MACC).

The payback period (P) measures the time required for an investment to recoup its initial costs through savings or earnings, helping stakeholders understand the timeline for financial recovery. It's a straightforward way to evaluate what the time span is for an investment to reach its break-even point. One limitation of the P is that the profitability of the investment is not taken into account in this calculation as it doesn't account for the time value of money and ignores the future cashflow when the break-even point is reached. Although, the P allows for an easy and comparison between different options providing a quick risk assessment in terms of time. [1], [2].

The net present value (NPV) assesses the overall profitability of an investment by calculating the difference between the present value of cash inflows and outflows over time, allowing for a more comprehensive view of long-term benefits. When a project has a positive NPV, it's deemed as a profitable project. In the case multiple projects are compared with each other and all have positive NPVs, the project with the highest NPV is assumed as the most profitable one. If a project has a negative NPV it is considered as financially unprofitable, but it does not necessary mean that it has to be rejected. Rejecting and accepting a project is based on multiple requirements where the finance is just a part of, for example if a project support crucial strategic objectives or the environmental impact is more prioritized. [1], [3], [4], [5]

The marginal abatement cost curve (MACC) is a graphical representation providing insight into the cost-effectiveness of various technologies in reducing emissions, helping prioritize options that offer the most significant environmental benefits for the lowest cost per reduced tonne CO_2. Figure 1 shows an example of a MACC for a bulk carrier. The abatement options are ranked by their costs values: from negative costs (savings), indicating a win-win situation where reducing emissions also lowers costs, to most expensive options. The width of the bars indicate the emission abatement potential. Error bars are optional in case certain (financial) parameters are not fixed, such as estimate for life time or investment costs. The MACC is a representation of one particular situation. After the implementation of a measure, the respective MACC needs to be updated as the implementation costs and/or emission abatement potential of the other measures can be changes, for example the installation of a rotor sail can complicate the installation of a DynaRig sail due to space limitations. [1], [6], [7]

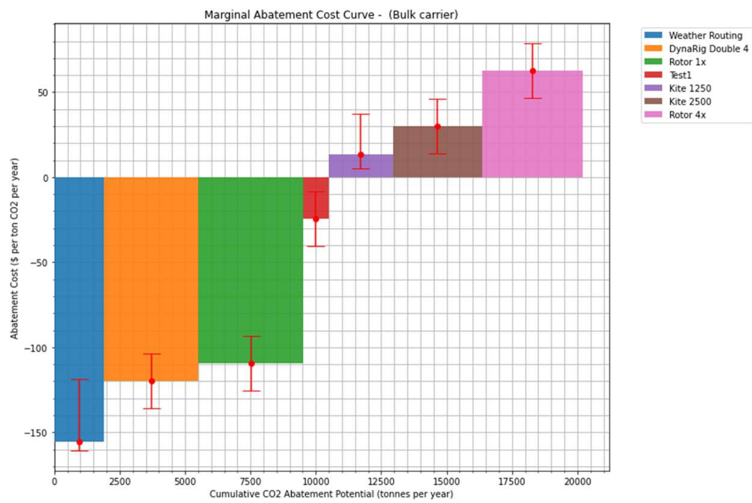

Figure 1: Example MACC bulk carrier, example values

In the following sections, the constructed models of the P, NPV and MACC are discussed. The payback period model is made in an Excel, and the NPV & MACC models are both written in the same Python script due to convenience of similar input values.

Model for payback period estimation (Excel: paybackP_excelmodel.xlsx)

The calculation of the payback period (P) is based on formula (1) [2]:

$$P = \frac{B + C}{A - D} \tag{1}$$

Where the financial parameters represent:

A: $-savings per **sailing hour** using the selected green technology

B: Purchase and installation costs of the system (OPEX)

C: The out of service costs including dry docking expenses

D: Operational and maintenance costs of the technology per **hour** (CAPEX)

The costs ‘C’ per living lab (ship type) are provided in its dedicated worksheet in the model and is composed of dry docking estimates provided by Remontowa and charter estimates found online representing the out of service costs.

Figure 2 shows a screenshot of the payback period model for a towing kite. Refer to this figure in the next paragraphs where certain model things will be addressed such as the yellow and green cells.

	A	B	C	D	E	F	G
1							
2	Green shipping technology/measure	Towing kite					
3	Type/characteristic	1280 m2 sail, 250m high					
4		min	max				
5	Bunker price per tonne	$ 550.00	$ 650.00			min	max
6	Percentage maintenance/operational costs wrt purchase price	2.00%	2.00%		Maintenance & operational costs per day	$ 96.16	$ 96.16
7	Purchase price	$ 1,755,000.00	$ 1,755,000.00				
8	Drydocking time [days]	0	2				
9	Sailing rate	0.7	0.8	*between 0 and 1*			
10	Utilisation rate GS technology/measure during sailing	0.9	1	*between 0 and 1*			
11		min	max			min	max
12	**LL1: crude oil tanker**						
13	Fuel savings per tonne per sailing hour	0.18	0.20		Fuel savings per day	$ 1,496.88	$ 2,496.00
14	Fuel savings per tonne per sailing day	4.32	4.80		Payback (days)	731.3	1360.6
15	Fuel savings per tonne per sailing day corrected for sailing rate	2.72	3.84		**Payback (years)**	**2.0**	**3.7**
16	**LL2: container vessel**						
17	Fuel savings per tonne per sailing hour	0.18	0.20		Fuel savings per day	$ 1,496.88	$ 2,496.00
18	Fuel savings per tonne per sailing day	4.32	4.80		Payback (days)	731.3	1304.3
19	Fuel savings per tonne per sailing day corrected for sailing rate	2.72	3.84		**Payback (years)**	**2.0**	**3.6**
20	**LL3: ROPAX**						
21	Fuel savings per tonne per sailing hour	0.18	0.20		Fuel savings per day	$ 1,496.88	$ 2,496.00
22	Fuel savings per tonne per sailing day	4.32	4.80		Payback (days)	731.3	1485.9
23	Fuel savings per tonne per sailing day corrected for sailing rate	2.72	3.84		**Payback (years)**	**2.0**	**4.1**
24	**LL4: bulk carrier**						
25	Fuel savings per tonne per sailing hour	0.18	0.20		Fuel savings per day	$ 1,496.88	$ 2,496.00
26	Fuel savings per tonne per sailing day	4.32	4.80		Payback (days)	731.3	1310.9
27	Fuel savings per tonne per sailing day corrected for sailing rate	2.72	3.84		**Payback (years)**	**2.0**	**3.6**

Towing kite (P) | DynaRig Sail (P) | Rotor (P) | Hull coating (P) | new_tech (P) | new_tech2 (P) | new_tech3 (P) | new_tech4 (P) | Main info GS techs | Costs C

Figure 2: Screenshot Excel model payback period - Towing kite sheet

Each green technology has its own worksheet in the Excel-model, with as title format: "[tech] (P)". In a worksheet you can select from a dropdown menu in the orange cell (B3) which type or characteristic you want to investigate from the respective technology. Then, in the yellow cells the minimum and maximum values need to be filled in for the:

- bunker price per tonne
- percentage of maintenance & operational costs of the technology (OPEX) with respect to the purchase price
- the rate of the ship sailing during the year
- the utilisation rate of the investigated technology during sailing

Both the sailing and utilisation rate need to be in the range of [0.0-1.0]. Van der Kolk et al. (2019) provide an estimate of the OPEX percentage as 2% with regard to the purchase price (CAPEX), which is recommended to be used when this value is not known. A common value for the sailing rate is 0.7, which relates to 255 days of sailing per year.

Next, to derive the estimate of the minimum and maximum payback period (green cells) only the minimum and maximum value of the fuel savings per tonne fuel per sailing hour have to be provided. These need to be filled in the yellow cells of the respective living lab. The values of these savings are subsequently the outcome of fuel prediction models of the respective living labs including the installed/operating green technology.

The following green technologies already have an existing worksheet in the provided model:

- Towing kite
  - 300 m2 sail area, operating at 77.6m above sea level

    - 800 m2 sail area, operating at 150m above sea level
    - 1280 m2 sail area, operating at 250m above sea level
    - 2500 m2 sail area, operating at 400m above sea level
- DynaRig sail
    - 1 sail, 37.1m height, 20m width
    - 2 sails, 37.1m height, 20m width, 2.5 gap distance ratio
    - 2 sails, 23.2m height, 12.5m width, 4 gap distance ratio
- Flettner rotor
    - 1 rotor, 35m height, 5m rotor diameter, 10m top plate diameter
    - 4 rotors, 35m height, 5m rotor diameter, 10m top plate diameter
- Hull coating
    - Coating 1
    - Coating 2

The configurations of the towing kite, DynaRig sail and Flettner rotor are the resultant of used configurations of the MSc thesis Hermans (2024) which supported the DT4GS project. The cost estimates are based on information provided by the GLOMEEP project. Additional information on the respective configuration selection can be found in the thesis. The two hull coating options are estimates provided by MEPC (2011).

In order to extend this model, 4 additional template worksheets are added which can be used for further green technologies to be investigated. Simply change the values in the respective tables of the new technologies in the worksheet "Main info GS techs".

In the model additional notes and comments are provided to give information where necessary.

Model for NPV and MACC (Python: MACC_NPV_script.py)

The calculation of the MACC ais based on formula (2) [1]:

$$MACC = \frac{(D + C) \cdot \frac{r}{1 - (1 + r)^{-l}} + B - A}{E} \quad (2)$$

Where the parameters represent:

A: $-savings per **year** using the selected green technology

B: Purchase and installation costs of the system (OPEX)

C: The out of service costs including dry docking expenses

D: Operational and maintenance costs of the technology per **year** (CAPEX)

E: The CO_2 savings per **year** by using the selected green technology

r: The discount rate which reflects the level of risk inherent in the cash flow

l: the lifetime of the selected green technology in **years**; in case this is longer than the remaining lifetime of the vessel, then the remaining lifetime of the vessel needs to be filled in

The provided Python is able to calculate and plot the MACC and NPVs of selected green technologies per ship (living lab). In the script, different green technologies can be made as an object with their respective financial properties. Next, a ship object can be made and linked to a list of selected green technologies object. Then, the respective MACC for that ship can be plotted together with a graph showing the NPVs of the techs including the minimum and maximum values depicted as error bars.

In the first cell, the following parameters need to be provided:

- The carbon factor of the marine fuel with which it is compared, in units [tonnes CO_2 / tonnes fuel]; 3.114 is the value for marine diesel oil
- The range of bunker price (eg. minimum, maximum and current) to be investigated, in units [$/tonne]

To make a green technology object, the following parameters are required:

- Name of the technology
- Fuel savings with regard to the situation the respective tech is not installed and operating, in units [tonnes/hr]
- Lifetime of the technology, in [years]; in case this is longer than the remaining lifetime of the vessel, then the remaining lifetime of the vessel needs to be filled in
- The capital expenses of the technology (CAPEX), in [$]
- The yearly operational costs of the technology (OPEX), in [$/year]; default is 2% of the CAPEX if no value is provided
- The discount rate over cashflow with regard to the technology, default is 0.11 (11%) which is commonly been used in literature as average estimate
- Number of days the respective ship should be in dry dock to install the technology, in [days]

Optional parameters to increase the sensitivity analysis are the minimum and maximum values for:

- Lifetime, if no value is provided these are both set to the initial provided lifetime
- CAPEX, if no value is provided these are both set to the initial provided CAPEX
- OPEX, if no value is provided the minimum and maximum values are set to 2% of respectively the minimum and maximum CAPEX values

To make a ship object, the following parameters are required:

- Name of the ship
- Ship type
- The out of service costs, in [$/day]; these are the same as the costs “C” provided and used in the previous discussed Excel model for the payback period
- Utilisation rate (sailing rate) of the ship, default is set to 0.7 (70%)
- List of green technologies to be investigated with the respective ship

Optional parameters:

- Minimum and maximum value for the out of service costs, in [$/day], if no value is provided these are both set to the provided out of service costs
- A fuel savings factor, that functions as a conversion factor between ship types if not all fuel savings are known for a respective technology, default is set to 1.0

In the last cell of the script an example is provided (see Figure 3) how to make objects and how to plot the MACC and NPV.

```python
#%% Example usage:
if __name__ == "__main__":
    # Create Green_Tech instances
    tech1 = Green_Tech(name="Kite 2500", fuel_savings=0.1988, lifetime=10, capex=2590000, dry_docking_days=2,
                       min_lifetime=8, max_lifetime=11, opex=51800, discount_rate=0.2)
    tech2 = Green_Tech(name="DynaRig Double 4", fuel_savings=0.188, lifetime=10, capex=600000, dry_docking_days=7,
                       min_lifetime=8, max_lifetime=12, opex = 12000, min_capex=500000, max_capex=700000)
    tech3 = Green_Tech(name="Rotor 1x", fuel_savings=0.2108, lifetime=10, capex=950000, dry_docking_days=7,
                       min_lifetime=8, max_lifetime=11, min_opex=15000, max_opex=18000, min_capex=900000, max_capex=1000000)
    tech4 = Green_Tech(name="Weather Routing", fuel_savings=0.1, lifetime=10, opex=40000, dry_docking_days=0, discount_rate=0.5,
                       min_lifetime=8, max_lifetime=12, min_opex=35000, max_opex=45000, min_capex=0, max_capex=0)
    tech5 = Green_Tech(name='Test1', fuel_savings=0.05, lifetime=5, capex=500000)
    tech6 = Green_Tech(name='Rotor 4x', fuel_savings=0.2815, lifetime=20, capex=3600000, dry_docking_days=7, opex=72000, discount_rate=0.2)

    # Create a list of technologies you want to include in the ship
    chosen_techs = [tech1, tech2, tech3, tech4, tech5, tech6]

    # Create a ship with the chosen technologies
    ship1 = Ships(name="Maharaj", ship_type= 'Bulk carrier', out_of_service_costs=40632.86, green_tech_list=chosen_techs, min_out_of_service_costs=35000, max_out_of_service_costs=45000)
    ship2 = Ships(name='Alex', ship_type= 'Crude oil tanker', out_of_service_costs=75428.57, green_tech_list= [tech1, tech2, tech6])
    ship3 = Ships(name='Zim Rio Grande', ship_type='Container vessel', out_of_service_costs=35982.14)
    ship4 = Ships(name='Trinacria', ship_type= 'ROPAX', out_of_service_costs=163179.14)

    # Calculate MACC for the ship using the corresponding green tech solutions
    print(f"Calculating MACC for {ship1.name}\n")
    MACC_results = ship1.calculate_MACC()
    print(f"MACC Results for {ship1.name}: \n{MACC_results}")
    MACC_results2 = ship2.calculate_MACC()
    print(MACC_results2)
```

Figure 3: Screenshot last cell in script, containing example how to use the script

Refs:

[1] IMO (2011). Marginal Abatement Cost and Cost Effectiveness of Energy-Efficiency Measures. Document: MEPC 62/INF.7. https://www.unccleam.org/wp-content/uploads/library/marginal_abatement_cost.pdf

[2] *Payback period (2024)*. Definition, Formula, Calculation and Example. (n.d.). https://www.mysa.io/glossary/payback-period

[3] Inspired Economist, & About The Author Inspired Economist Inspired Economist's mission is to explore people. (2023, November 27). *Net present value (NPV): Understanding its role in investment decisions*. Inspired Economist. https://inspiredeconomist.com/articles/net-present-value-npv/

[4] Schwartz, H., Gustafsson, M., & Spohr, J. (2020). Emission abatement in shipping–is it possible to reduce carbon dioxide emissions profitably?. *Journal of Cleaner Production*, *254*, 120069.

[5] Porter, M. E. (1996). What is strategy? Harvard Business Review, 74(6), 61-78

[6] Irena, K., Ernst, W., & Alexandros, C. G. (2021). The cost-effectiveness of CO2 mitigation measures for the decarbonisation of shipping. The case study of a globally operating ship-management company. *Journal of Cleaner Production*, *316*, 128094.

[7] de Oliveira, M. A. N., Szklo, A., & Branco, D. A. C. (2022). Implementation of Maritime Transport Mitigation Measures according to their marginal abatement costs and their mitigation potentials. *Energy Policy*, *160*, 112699.