POLITECNICO MILANO 1863 | DEPARTMENT OF MANAGEMENT ECONOMICS AND INDUSTRIAL ENGINEERING

ANIMP - WEBINAR

Risk-based approach to measure CO_2 lifecycle

30.01.2025 | Alessandro Paravano, Alessandra Neri, Giorgio Locatelli, Enrico Cagno

Introduction

01

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Disclaimer
Cases selection criteria

Given the nature of this research project, which aims to produce basic research funded by public funds and whose results are intended to be disseminated and made accessible to the public, the cases presented have been selected based on the availability and accessibility of public data.

These cases have been selected for their convenience in illustrating the methodology's potential and do not represent a judgment of merit on the technology itself.

The cases were selected based on the experiences and expertise of the researchers conducting the study. In particular, the nuclear case was selected by Professor Locatelli who has extensive experience in the nuclear sector.

ANIMP was not involved in selecting these cases. The responsibility for the content of the research lies solely with the authors.

The data collection and analysis for the first case was conducted with the support of Giacomo Galeotti, while the second case with the support of Gregorio Brizzante and Alessandro Bosani. They developed their MSc Theses on these topics, supervised by Prof. Locatelli. We acknowledge and sincerely thank them for their support.

Po River in 2022

Drought events in the World over time. Source: ISPI (2023)

Contents

Research aim and theoretical foundation

02

The context

Role of power plants in Net Zero Transition

The Net Zero Challenge

- GHG are primary drivers of climate change.
- Achieving Net-Zero emissions is an urgent challenge.
- Electricity Decarbonisation and Electrification are essential for the Net-Zero transition

Environmental impact of power plants

- Direct and indirect GHG emissions depend on.
  - Power plant technology (Solar, Wind, Gas, Nuclear)
  - Lifecycle stages (construction, operation, decommissioning) and technologies
  - **Different power plants face different risks that can change their GHG emissions / KWh productions**
    - **Early closure due to unforeseen events**
    - **Failure due to environmental factors**
    - ...

Measuring environmental footprint: the role of LCA

Life Cycle Assessment (LCA) methods are widely used in the power and energy sectors

Typical LCA indicators for power plants include [kg CO_2/kWh] and [kg NO_x/kWh].

LCA methods, in the power and energy sector have 3 main limitations, which might mislead policy and decision-makers .

Measuring environmental footprint: the role of LCA
Limitation 1. Undervaluation of risks

Given the stochastic nature of inputs/outputs, the GHG emissions over the life cycle are more uncertain for some technologies than others, with the **risk level** being a **function of the technology itself**.

Example

The LCA performance of a Combined Cycle Gas Turbine (CCGT) power plant is more predictable than that of a nuclear power plant, which is characterized by several uncertainties.

Measuring environmental footprint: the role of LCA
Limitation 2. Time scales of KWh produced and GHG emitted

Different timescales of inputs and outputs arise **due to diverse systems' life cycle lengths**.

> ***Example***
>
> *Modern Large Nuclear Reactor: 10 years construction + 60 years operations*
>
> *Small solar PV: 1 year construction + 25 years operations*

Considering the various market, technological and regulatory uncertainties affecting the electricity generation sector, the **risk level is also a function of time**: all things being equal, the longer the timescale, the higher the risk and the probability of not fully achieving what was planned.

> ***Example***
>
> *Caorso nuclear power plant closed at 25% of its expected life. With a shorter life cycle and less electricity delivered than planned, applying LCA to the Caorso plant would produce a distorted assessment.*

Measuring environmental footprint: the role of LCA

Limitation 3. Undervaluation of degrees of freedom / options to mitigate

Other things being equal, **a longer life provides less flexibility** (or degrees of freedom) than a shorter one.

Different plants see different risks but also have different options for mitigations.

Example

A wind farm has a life cycle of about 25-30 years, after which there is an option to start a new life cycle or to build something different.

Instead, a fission nuclear power plant with a 100-year life cycle offers no degrees of freedom for a long time.

Example

Traditional stick-built energy infrastructure has a predetermined life base, whereas modular infrastructures could allow reconfigurability and extended/adapted life cycles by decoupling the life of the infrastructure from that of the modules.

Measuring environmental footprint: the role of LCA
Improvements/Novelty 1. Integration of LCA with the Discount Cash Flow

Discounted Cash Flow (DCF) is the standard method for the economic appraisal of infrastructure.

- In a DCF appraisal, **present and future** cash flows are discounted to their present value.
- The discount rate reflects the **risk perceived** by the decision-maker.

We propose to:

- ➪ Use the DCF framework, not on cash flow, but **on the power plant's GHG produced / saved**.
- ➪ **integrate LCA with DCF**, projecting future impact and discounting (*social discount rate*) them to their present value.

DCF might help overcoming the limitations related to undervaluation of risks and time scales of KWh produced and impacts.

Measuring environmental footprint: the role of LCA

Improvements/Novelty 2. Real Option Analysis

Real Options Analysis (ROA) is a set of mathematical models that extend DCF to evaluate the value of the **degrees of freedom** available to decision-makers.

Options thus give the holder the right, but not the obligation, to make choices, such as the right to build a power plant.

We used ROA integrated with an LCA based on a DCF, to account for uncertainty and managerial flexibility, considering the **value of different degrees of freedom**

ROA overcoming the limitations related to undervaluation of risks and undervaluation of the degrees of freedom.

So, for each application...

Risk and CO2 impact assessment

1. Define the problem and context
2. Assess uncertainties/risks
3. Evaluation of the CO2 impact in the different lifecycle stages (construction, operations, dismissing)

→

Real options analysis

4. Identify real options - *determine the relevant strategic options (e.g., expansion, abandonment, deferral) that can add flexibility and value to the project*
5. Build the base model
6. Select the valuation method
7. Calculate the value of the options

→

Support decision-making

8. Interpret the results
9. Support decision-making

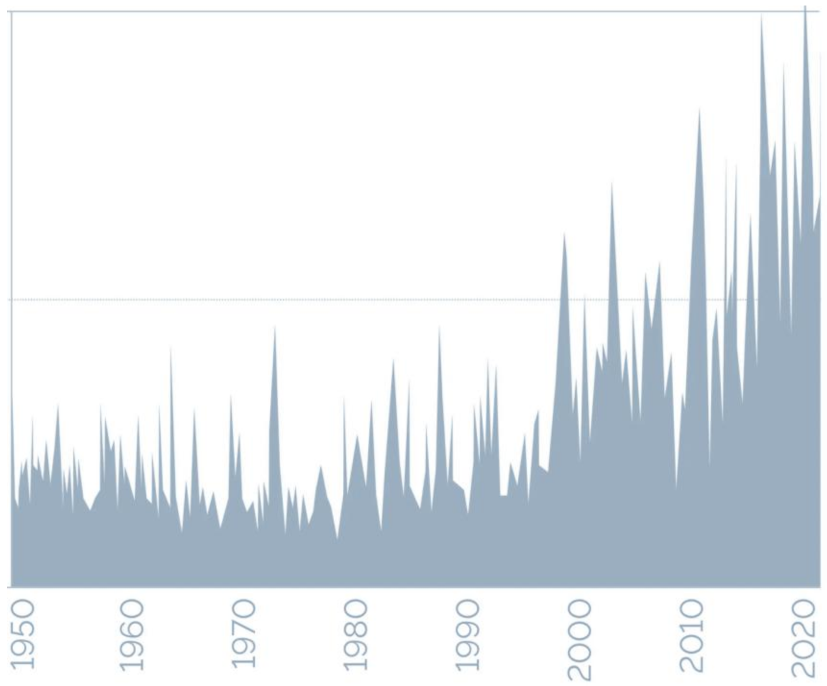
Case study

A new Nuclear power plant

03

A new Nuclear power plant
Selection of the risk – Risk of drought

Drought risk is defined as the risk of unmet energy demand due to drought, which encompasses both the possibility **that water availability is too low**, and **that demand is too high**.



Drought events in the World over time. Source: ISPI (2023)

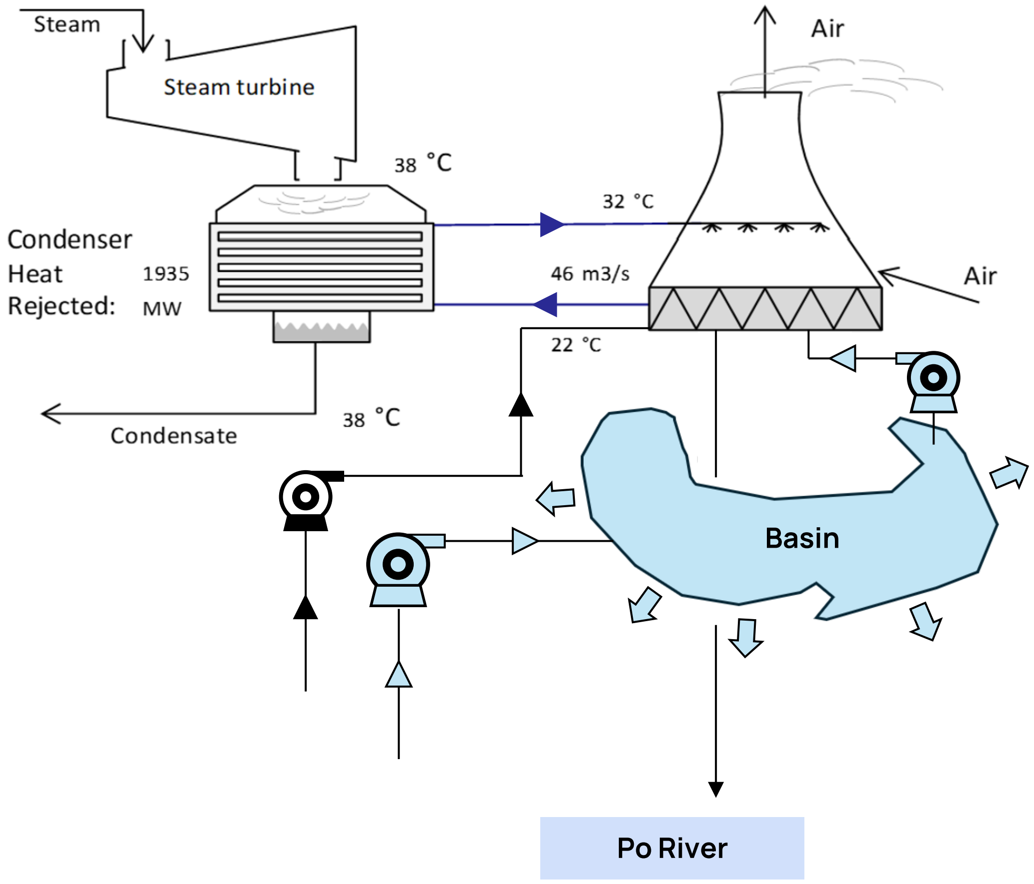
Po River in 2022

A new Nuclear power plant

Selection of the option – Construction of a backup water basin

The selected option consist in the **building a backup water basin**:

- Yearly nuclear energy loss between **5% and 10%***
- CO_2 Costs*. A large amount of CO_2 cost to build the basin*
- CO_2 Savings*. The **recovery is up to 10% efficiency**; the electricity that is not lost can be used instead of drawing power from the grid, which has a specific CO_2 value associated with it (carbon index).



Nuclear power plant scheme. Source Authors

* From LCA

A new Nuclear power plant in Caorso
The Caorso Case

Key Plant Features

APR 1000 MWe

- 2700 MWth
- Efficiency η = 0.37
- Live Steam Temperature 295°C
- Expected Power Plant Life of 60 years
- Manufactured in Korea by Korea Hydro Nuclear Power Corporation

Cooling System

- Couple of forced draft evaporative cooling towers
- Backup water reserve of 31’000 m^3
- Eventual Bigger water reserve of 0.9 million m^3
- Expected reserve lifetime of 20 year
- Extra required pump of 1.5 m^3/s

A new Nuclear power plant in Caorso
Research Design

01 Setup Phase

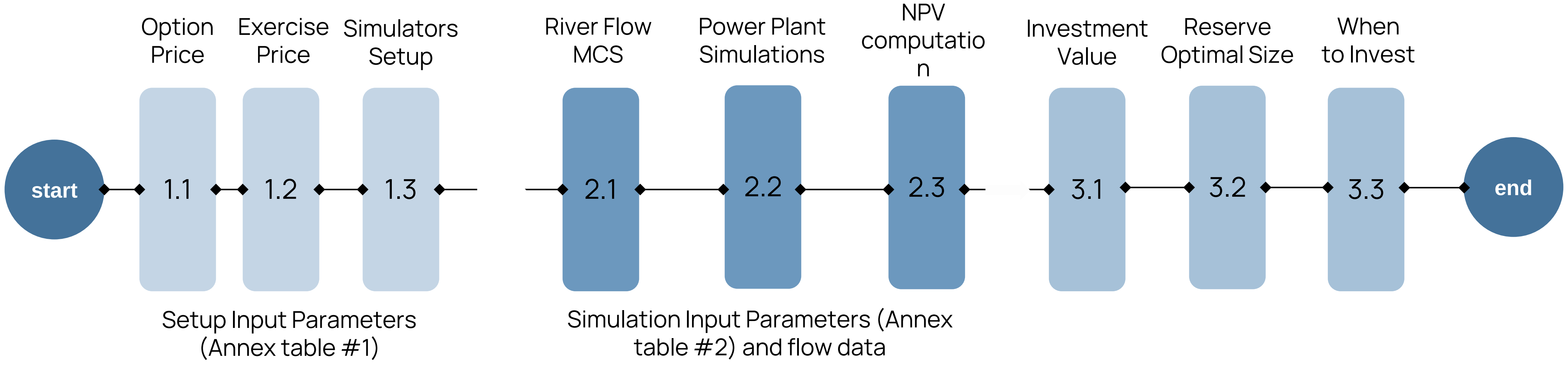
- Deterministic Variables Study (i.e. future carbon intensity, option price computation, option exercise computation)
- Stochastic Variables Data Analysis (River Flow Data Analysis)
- Power Plant Simulators Setup (through IAEA WAMP program)

02 Simulation Phase

- Monte Carlo simulations of future river flow values
- Power Plant simulations over the river ones to compute the power produced on daily basis (and thus CO_2 emissions)
- Scenario analysis for carbon intensity forecasts

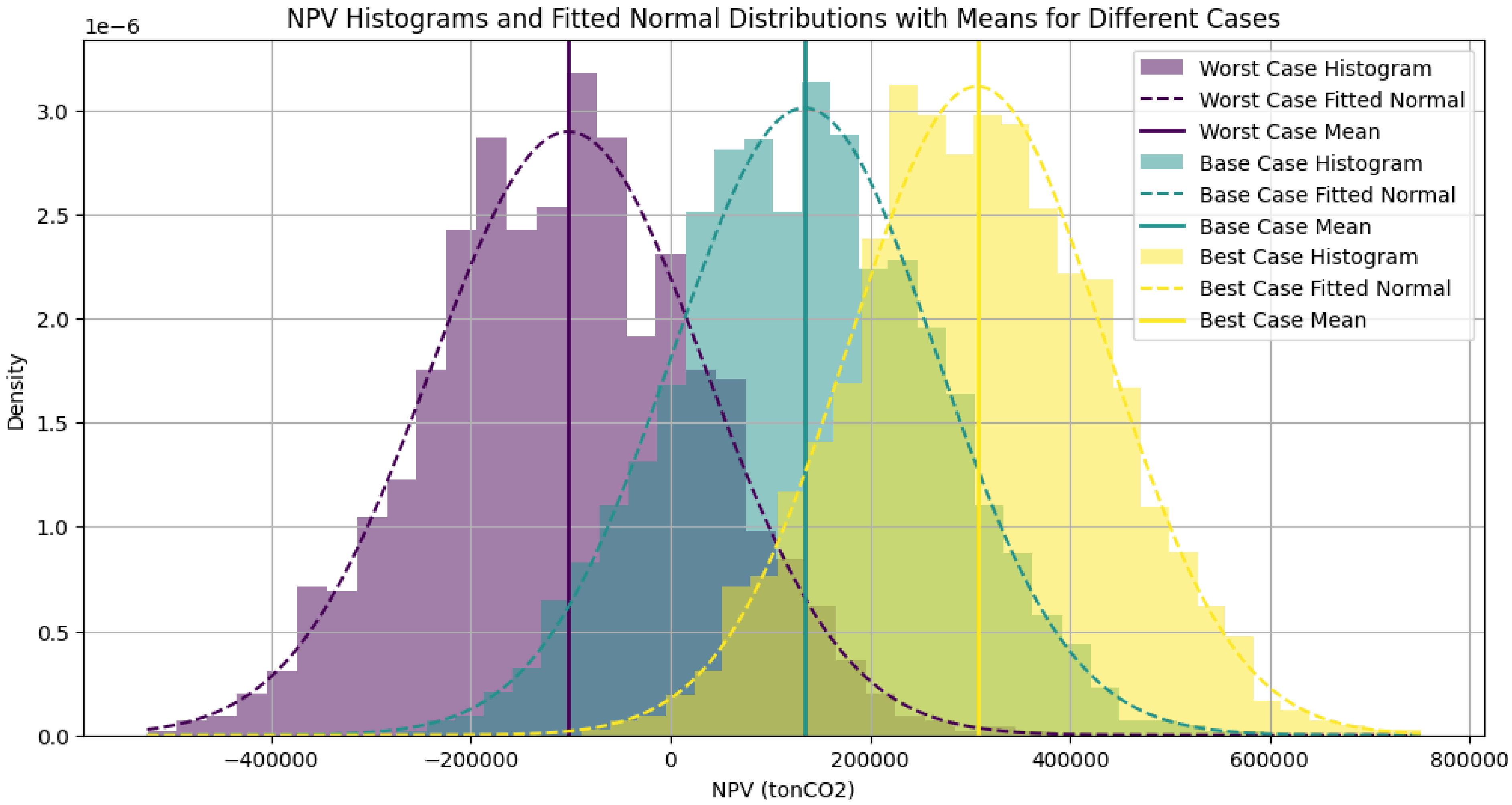
03 Suggestions to Decision Makers Phase

- Sensitivity Analysis on several deterministic input parameters
- Optimized dimension for the reserve size
- Threshold Analysis on the three-years moving average of river flow

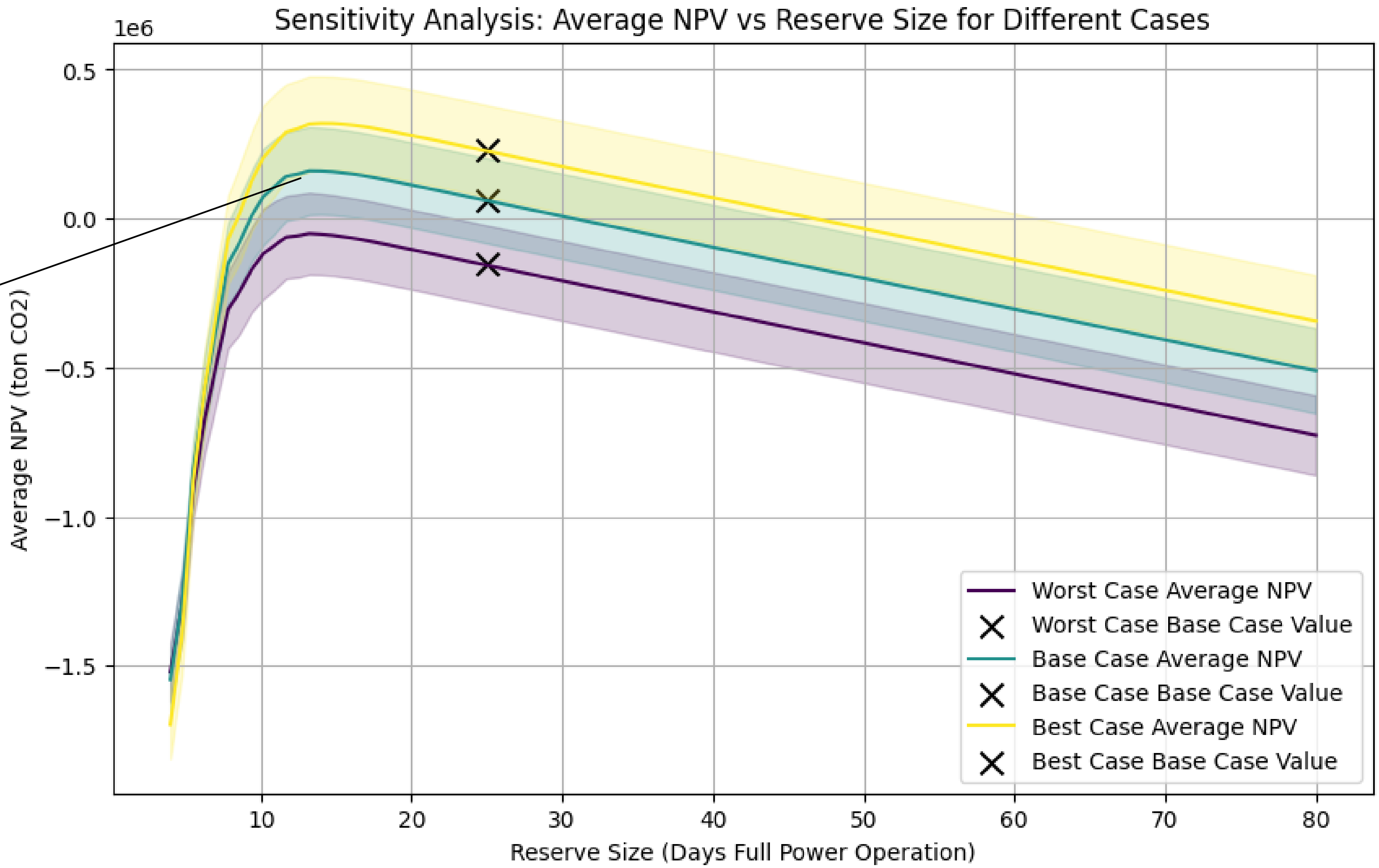


A new Nuclear power plant in Caorso

Key results – CO2 savings by exercising the option



A new Nuclear power plant in Caorso
Key results



The optimized size for the reserve is 12.5 days of equivalent full power operation water consumption. This is equivalent to 0.45 million cubic meters of water.

Key takeaways

The real option involves an initial investment to construct a small backup basin, which serves as the option price. This basin measures 50m x 50m x 9m and is capable of supplying water to a 1,000 MWe nuclear power plant under average weather conditions (air temperature of 25°C and water temperature of 15°C).

Flexible and scalable methodology

Considering the risks and degrees of freedom.

Overcoing the limitations related to the undervaluation of risks and the time scales of KWh produced and its impacts.

Case study

Installing batteries on floating offshore windfarm plant in Canale di Sicilia

04

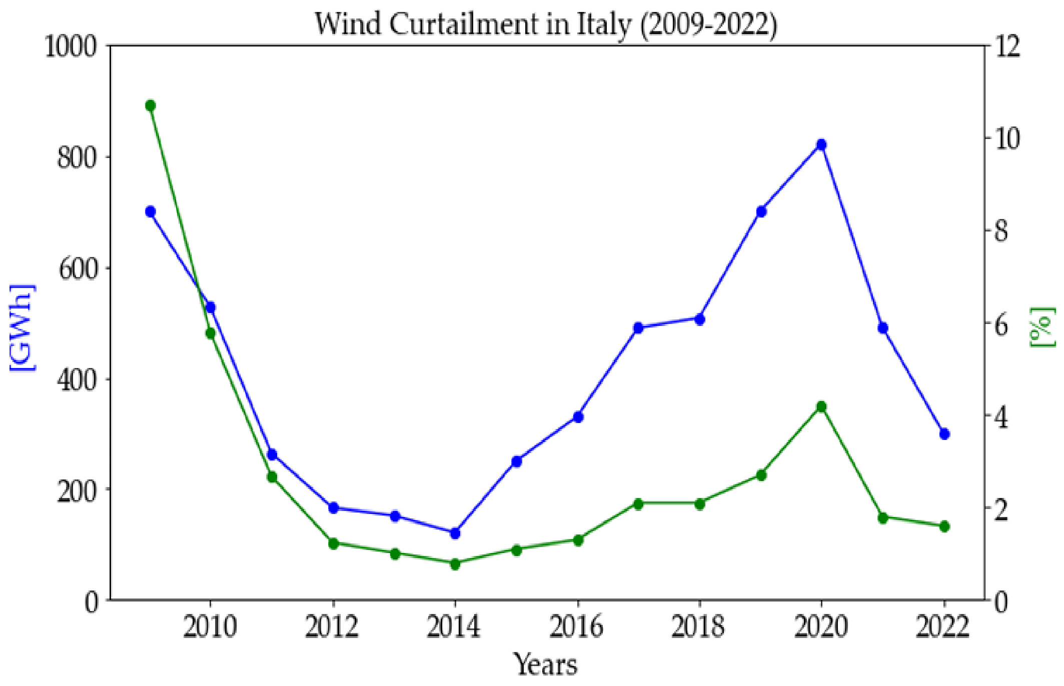
Floating offshore windfarm in Canale di Sicilia

Selection of the risk – Risk of Curtailment

Curtailment is when network system operators or electricity producers **limit the output of certain generators** to avoid **overloading the grid**.

ENTSO-E estimates that in Europe, without network reinforcements after 2025, 35 TWh/year would be curtailed by 2030 and up to 78 TWh/year by 2040 (≈ consumption of 20m households).*

Loss of 50 – 300 ktons CO_2-eq per year



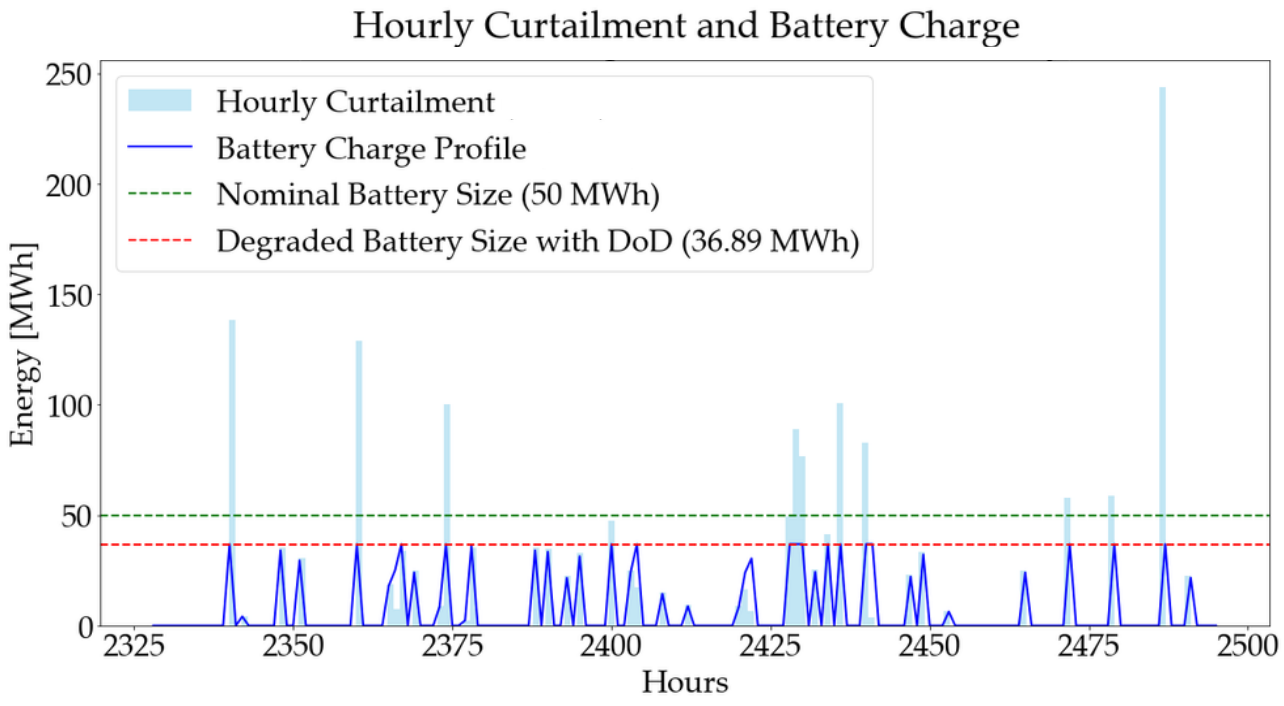
Wind curtailment in Italy (2009-2022). Source: Terna, 2023

* From LCA

Floating offshore windfarm in Canale di Sicilia
Selection of the option – Installing Battery Energy Storage Systems (BESS)

Battery State-of-Charge Model

- BESS does not perform full cycles to slow down degradation
- BESS charging power is constrained by nominal charging limits to prevent unsafe currents*
- Yearly degradation considers both calendar and cycling aging
- BESS discharges immediately after curtailment ends maximizing the energy saved from curtailment*



Hourly Curtailment and battery charge. Source Baumann, 2017

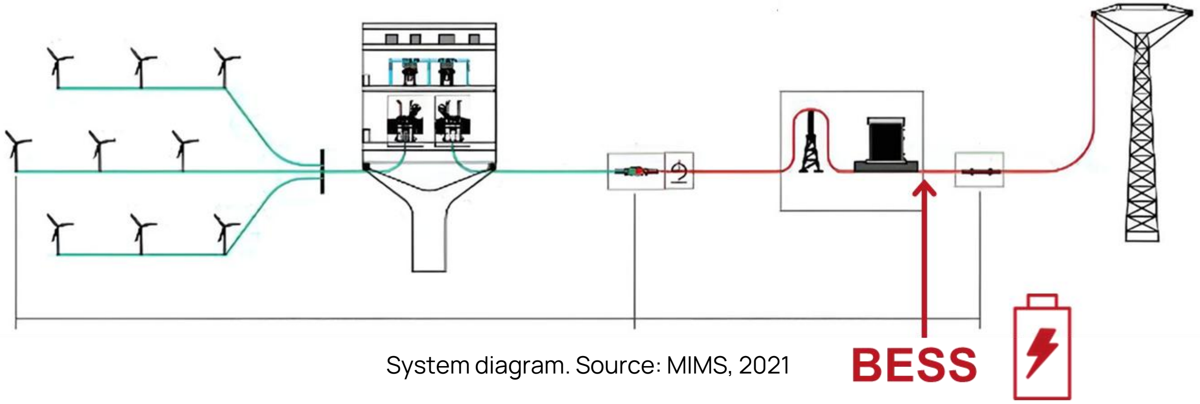
* From LCA

Floating offshore windfarm in Canale di Sicilia
Empirical setting

7SeasMed
- VIA approved in March 2024
- Size: 250 MW
- Capacity Factor: 39.7%
- Lifetime: 25 years

35 km offshore
150 m deep

Battery*
- Chemistry: LFP
- Capacity: 200 MWh
- Power: 100 MW
- Auxiliary power: 945 kWh
- Lifetime: 12 years
- Efficiency: 96%
- Depth of Discharge: 80%
- Degradation: 2%



System diagram. Source: MIMS, 2021

* From LCA

Floating offshore windfarm in Canale di Sicilia
Aim and model architecture

Quantifies CO_2 costs and benefits of installing BESS to mitigate the curtailment in a floating offshore windfarm plant

Deterministic Inputs

- Option price
- Option exercise price
- Italian grid carbon intensity
- Carbon discount rate

ROA Model with optimized exercise threshold →

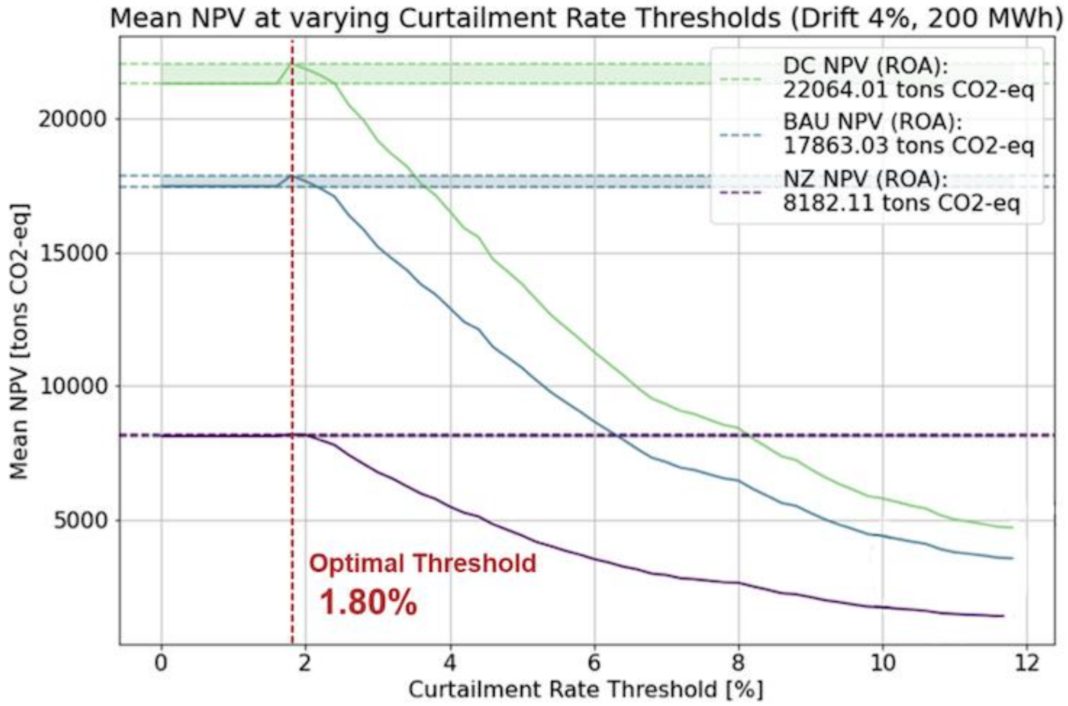
Outputs

- Mean NPV curve
- PBT curve
- Std Dev NPV curve
- Option Value
- Optimal Exercise Threshold

Stochastic Inputs

- Energy saved from curtailment

Floating offshore windfarm in Canale di Sicilia
Key results

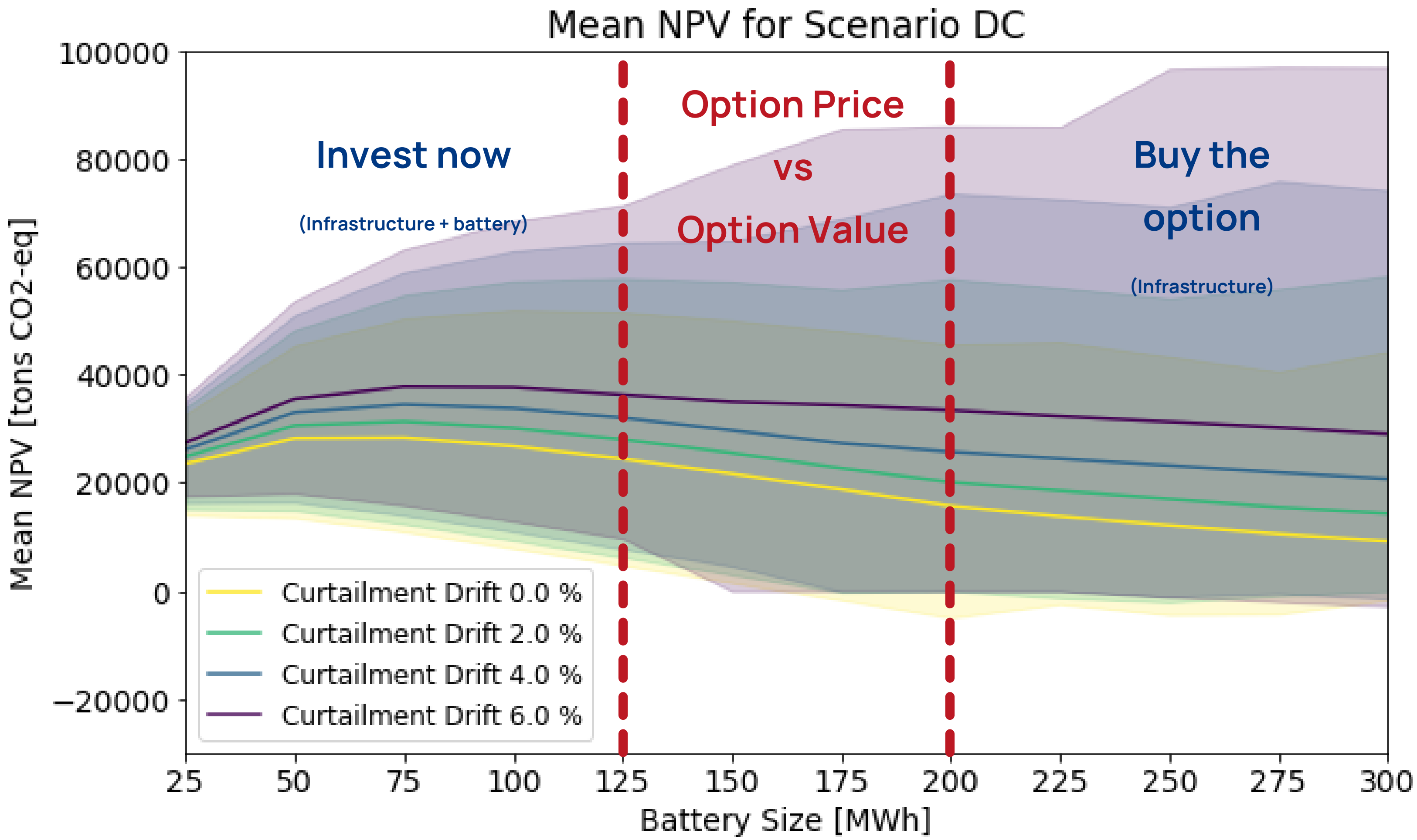


	Investing Without Option	Waiting Optimal Threshold
Payback time	5.8 years	4.8 years
Probability NPV > 0	88%	91%

Option Value		
	Decelerated	**766** tons CO_2-eq
	Business As Usual	**397** tons CO_2-eq
	Net Zero	**67** tons CO_2-eq

Floating offshore windfarm in Canale di Sicilia

Key results



Option value becomes positive at BESS size:

125 – 200 MWh

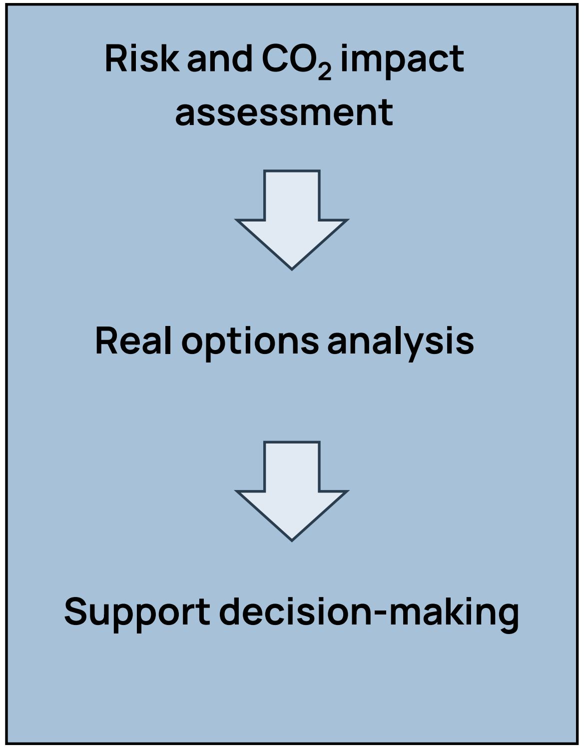
(*Larger BESS yield more uncertain returns, leading to higher option value*)

Q&A Session

05

Summarising

Key steps



Benefits of the Methodology

DCF, calculated in GHG, overcomes the limitations related to the undervaluation of risks and the time scales of KWh produced and its impacts.
(e.g., CO2-savings in the Nuclear and Offshore wind plants operations)

ROA overcomes the limitations related to the undervaluation of risks and degrees of freedom.
(e.g., modelling the uncertainty of the risks in the Nuclear plant)

The "Big question"

- **Cool, right? How can we work together to apply this in your company/ business?**
    - Typical economic analysis (as always done)
    - Focus on environmental aspects (such as the GHG-based examples presented)

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