4TU.Energy

Decision support for CRM value chain actors

Dr. C.F. Blanco Rocha
Senior Scientist | Circularity & Sustainability Impact
Energy and Materials Transition Unit (TNO)

TU Delft Delft University of Technology

TU/e Eindhoven University of Technology

University of Twente.

Wageningen University & Research

Smart solutions for clients & partners

Knowledge transfer

Knowledge exploitation by spin-offs, licences, in partnership with other companies

Knowledge application

Contract research for and with clients

Develop fundamental knowledge

Together with universities

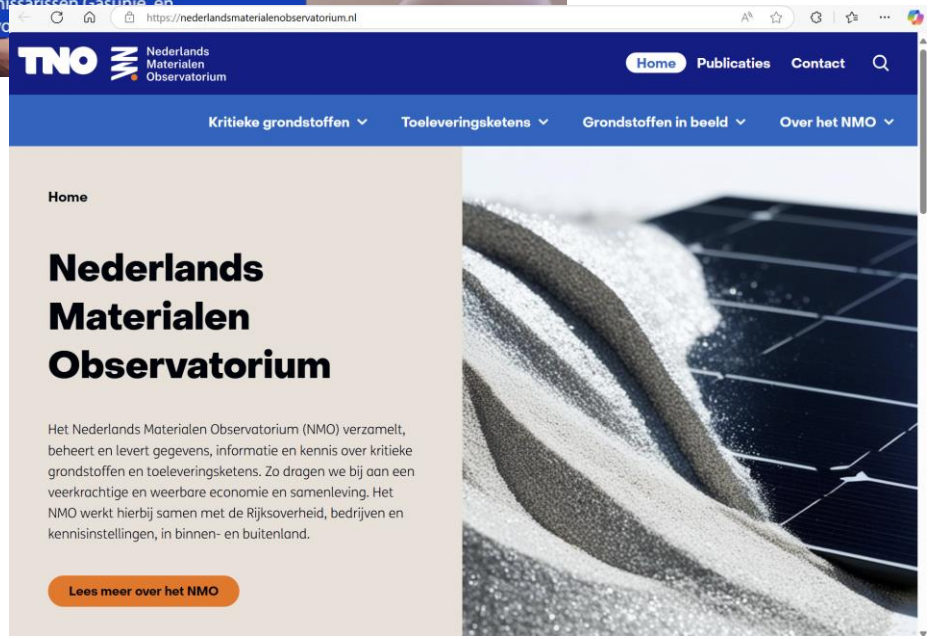
Knowledge development

In public-private partnership with partners from the golden triangle

6 Units


Defence, Safety & Security
Mobility & Built Environment
ICT, Strategy & Policy
Energy & Materials Transition
Healthy Living & Work
High Tech Industry
TNO innovation for life

Netherlands Material Observatory (NMO)



Opening 12 Feb 2025

TNO Kesslerpark, Rijswijk

TNO Nederlands Materialen Observatorium

https://nederlandsmaterialenobservatorium.nl/

Dutch National Raw Material Strategy (NGS)

Launched in December 2022 by EZK before the CRMA

In line with the EC CRM Act (CRMA), the Netherlands aims to strengthen its economic resilience while reducing dependency risks on critical and strategic raw materials.

This is partly in the context of the growing demand for critical raw materials, for example due to the energy transition and the digital transformation. NGS themes are:

1. Circularity and innovation
2. Sustainable European mining & refining
3. Diversification
4. Sustainable international chains
5. Knowledge building and monitoring

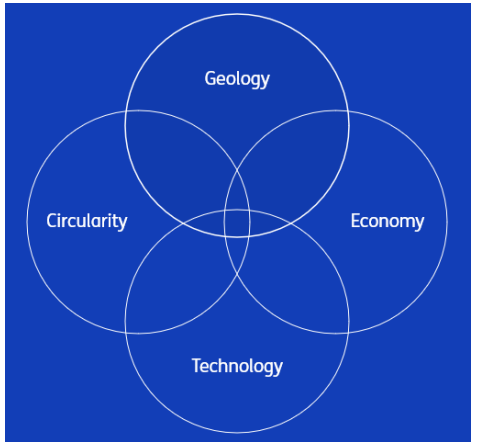
TNO Nederlands Materialen Observatorium

NMO scope

- Acquiring, collecting, managing and providing **data, information and insights** on the current and future demand, supply and availability of critical raw materials within the Netherlands.
- Gain insight into the **dependency on critical raw materials** and processed materials throughout the value chain.
- Determining the **effects of circular policies** on the supply and demand of critical raw materials, processed materials and finished products.
- Evaluation of **supply risks and measures** taken by governments.
- Evaluating **technological innovations** relevant to the supply and demand of critical raw materials and processed materials.

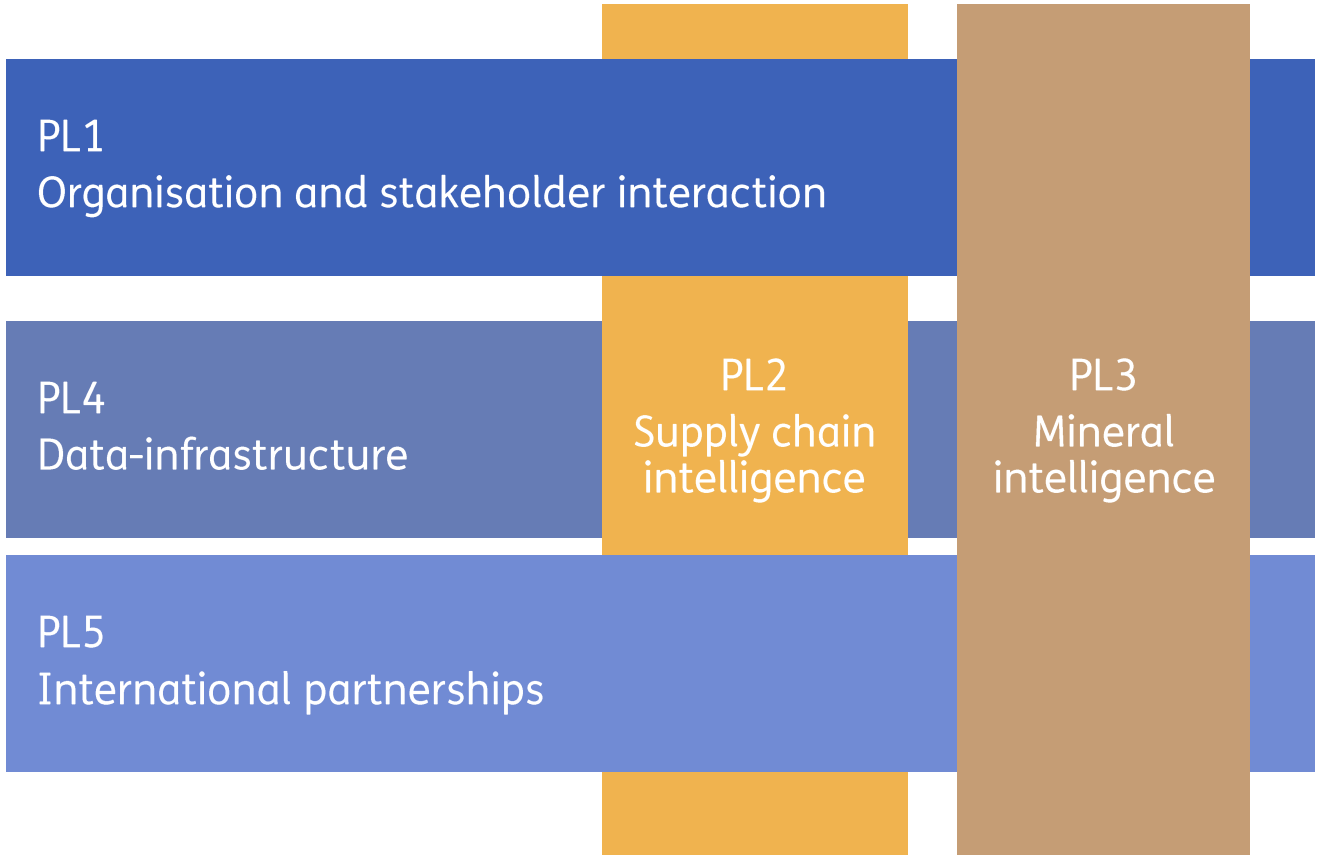
Specific tasks:

- Compose and execute on the Netherlands **exploration program**
- Constitute a central point of contact regarding **advise** to government.



Netherlands Material Observatory (NMO)

The platform for information exchange on critical materials for The Netherlands serving industry, society, and government.



Signalling network

Observatory (incl. advice)

Developed & published methodologies

Selected supply chain vulnerabilities

Exploration program

Deep dive:
Deep Sea Mining

Data & Information stakeholders and requirements

Data & Information infrastructure (initial)

TNO Nederlands Materialen Observatorium

Answering the *what if* questions

A decision support framework for CRM value chain actors

Critical Raw Materials are… well, critical

USA TODAY NEWS

Donald Trump's interest in buying Greenland 'not a joke', Marco Rubio says

Reuters

Show Caption

WASHINGTON - President Donald Trump's interest in buying Greenland is "not a joke," Secretary of State Marco Rubio said in an interview on Thursday, adding that acquiring Greenland was in U.S. national interest and needs to be solved.

The New York Times

Subscribe for €0.50/week

Russia-Ukraine War › | The Latest | Photos | Debate Over Europe's Defenses

Trump Urges Trading Ukraine's Rare Earth Minerals for More U.S. Aid

Ukraine has already emphasized that by supporting its war effort, the U.S. could get access to the country's wealth of critical minerals like lithium and uranium.

Share full article | 31

POLITICO

German election | War in Ukraine | Newsletters | Podcasts | Poll of Polls | Policy news | Events

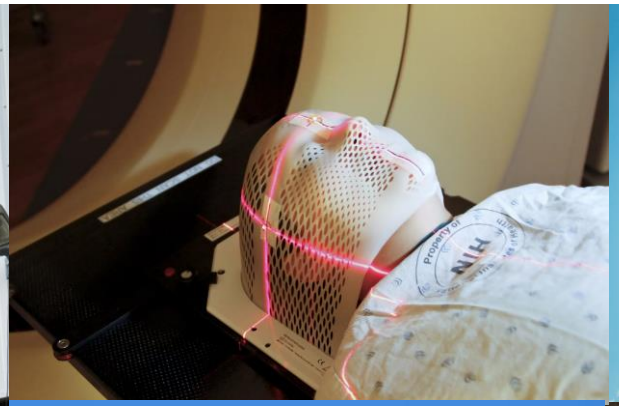
NEWS › TRADE

EU offers its own 'win-win' minerals deal to Ukraine

"The added value Europe offers is that we will never demand a deal that's not mutually beneficial," top official Stéphane Séjourné says.

LISTEN | SHARE

Critical Raw Materials are… well, critical



But what do we ultimately care about?

An ethical question.

Our role:

- Bring worldviews & interests to light
- Understand impact mechanisms
- Measure
- Identify conflicts
- Identify non-conflicts
- Simplify and focus the decision space

Our CRM Decision Support Framework

Objective

Improve **resilience**, **sustainability**, **circularity**, and **competitiveness** of CRM supply chains in NL & EU.

We model material flows and environmental impacts

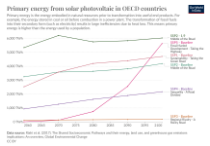
Assess material flows and **socioeconomic/environmental implications** of macro (policy changes, economic shifts, supply disruptions), meso (sector trends), and micro-level (technological innovations) interventions and events.

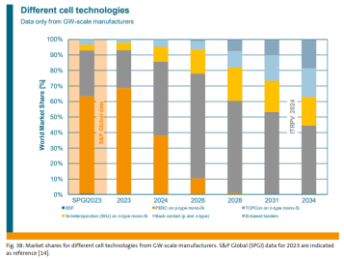
To provide decision-support

- Assessing uncertainties & **identifying key influencing factors**.
- Identifying decisions that can lead to **black swans**
- Using multi-objective optimization to **determine optimal strategies** amidst trade-offs.

The engine: from macro to micro and back

Scenarios





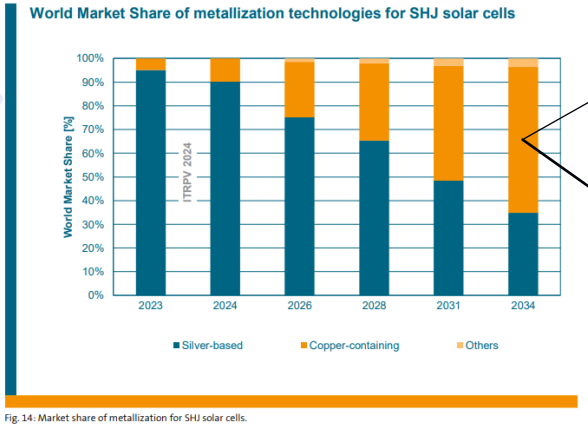
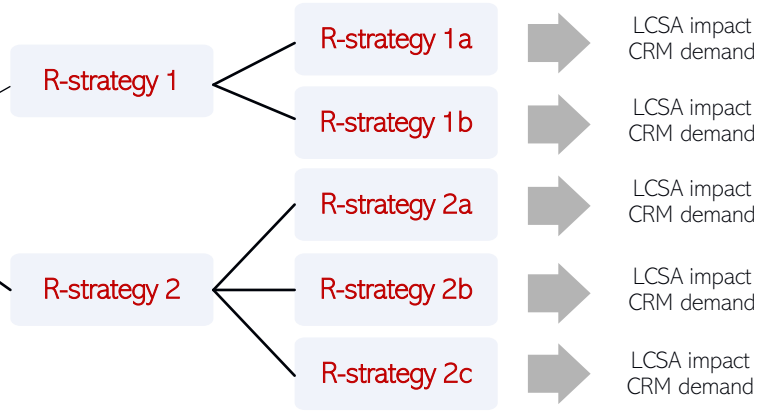


Fig. 14: Market share of metallization for SHJ solar cells.



macro indicators — micro indicators

climate change
freshwater ecotoxicity
occupational hazards
copper demand
economic value added
competition
% secondary
"N-1"
...
(of transition)

climate change
freshwater ecotoxicity
occupational hazards
copper demand
economic value added
competition
...
(of sector)

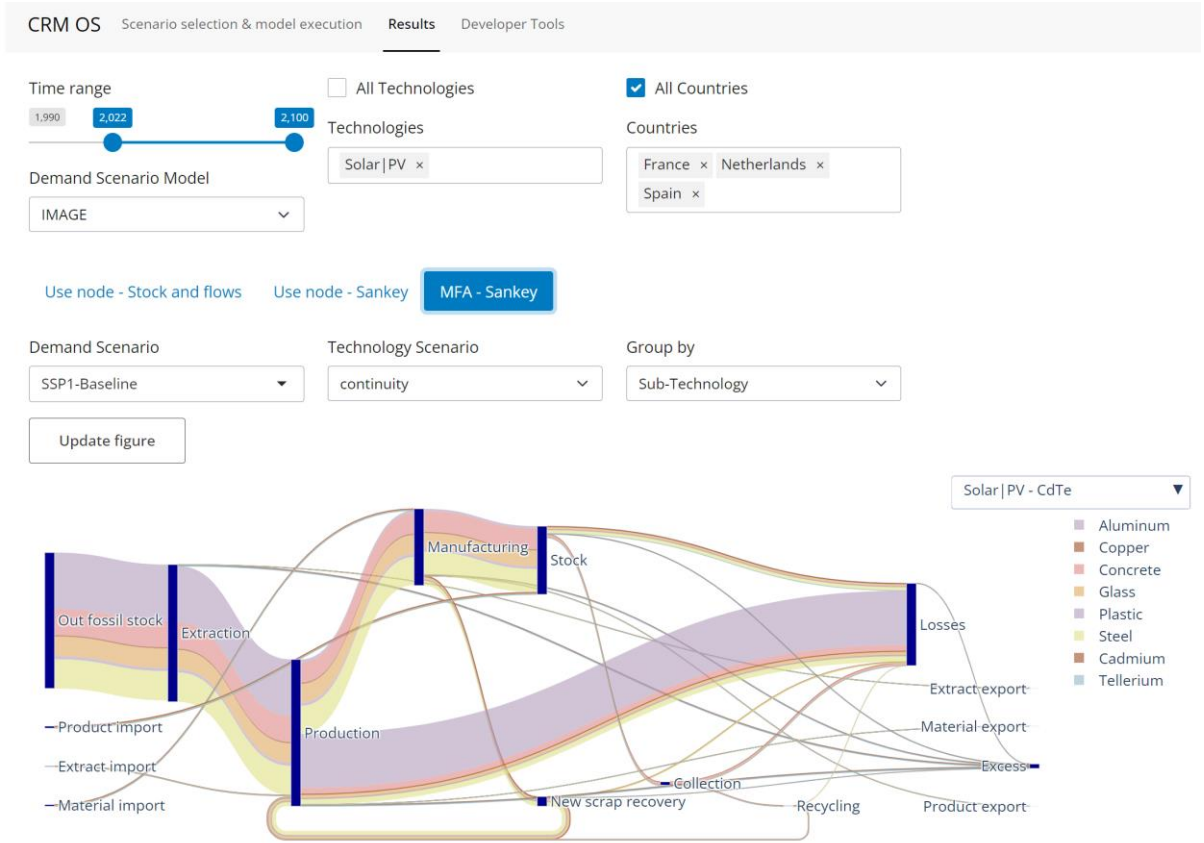
climate change
freshwater ecotoxicity
occupational hazards
copper demand
...
(of value chain)

climate change
freshwater ecotoxicity
occupational hazards
copper demand
...
(of technological pathway)

The engine: from macro to micro and back

Dynamic Materials Flow Analysis

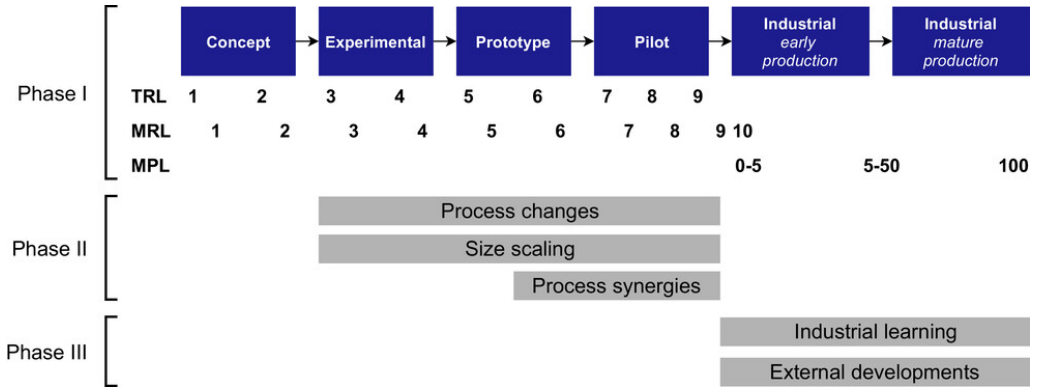
- Quantified material and product flows of the full CRM value chains per (sub)technology, country and scenario/model => over time
- What is the role of recycling versus the need for primary materials?
- Do we expect supply/processing bottlenecks?
- How is the current system performing? Is there potential for increasing collection and recycling?
- What is the effect of policy interventions, material substitution and technology innovations?



The engine: from macro to micro and back

Prospective Life Cycle Assessment

CRM-relevant technologies



van der Hulst, M. K. et al. A systematic approach to assess the environmental impact of emerging technologies: A case study for the GHG footprint of CIGS solar photovoltaic laminate. J. Ind. Ecol. 24, 1234–1249 (2020).

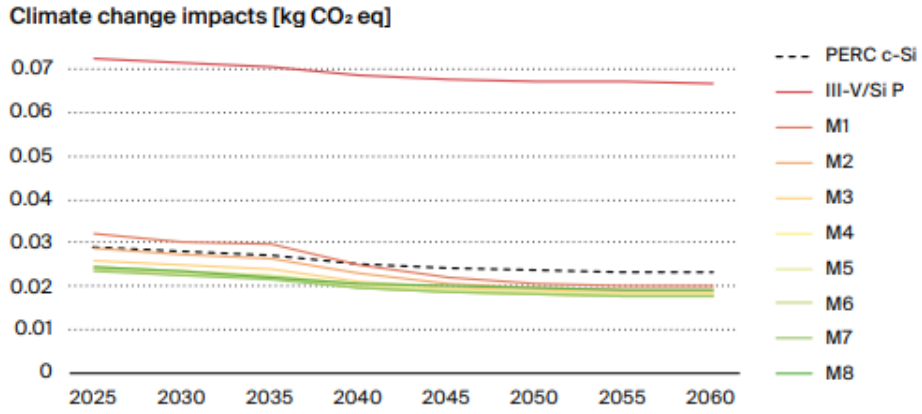


Figure 5 | Evolution of the climate change impact score of each future foreground scenario (milestones 1–8, see the previous section) modelled on future background SSP2-450 scenarios from IMAGE for the period 2020–2060

Cucurachi, S., & Blanco, C. F. (2022). Practical solutions for ex-ante LCA illustrated by emerging PV technologies. In M.-V. Florin (Ed.)

Broad criteria & indicators

A comprehensive literature review yielded > 100 indicators.

A preliminary selection that fulfil the following criteria:

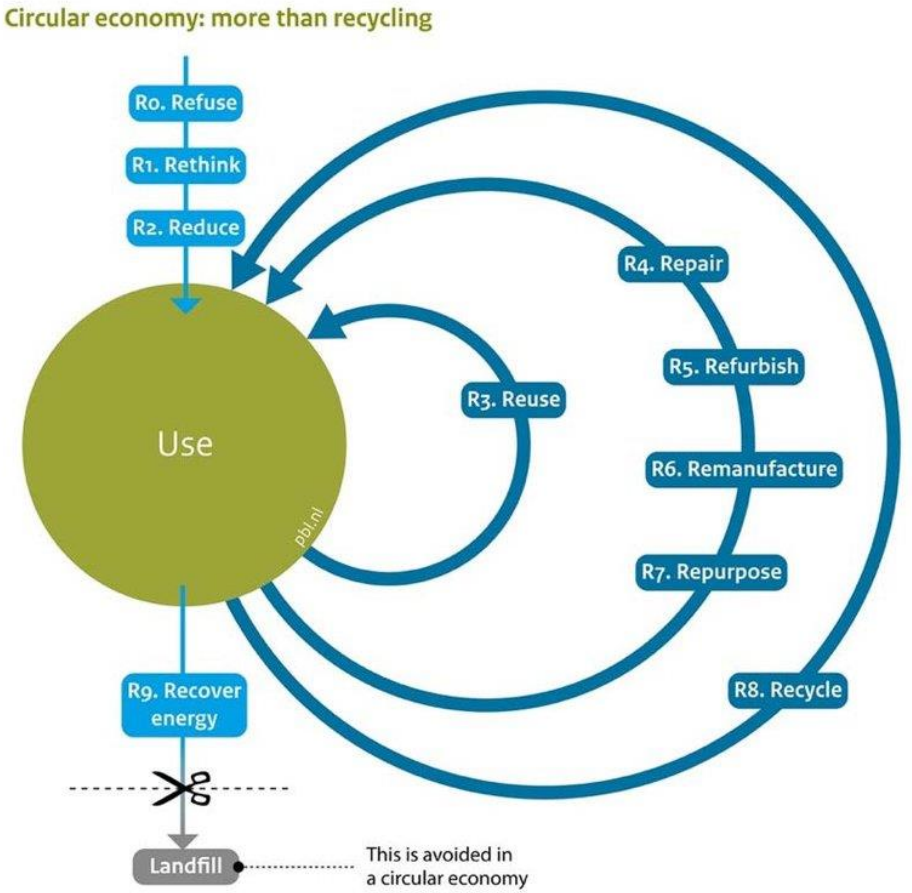
- incorporate resilience, vulnerability, or sustainability dimensions.
- serve as actionable tools for policymakers to design interventions (e.g., diversifying supply sources, supporting circular policies).
- enable CRM stakeholders to identify risks, prioritize actions, and align with market and regulatory demands.

Category	Indicator
Sustainability	Environmental LCA indicators
	Material Footprint
Circularity	End-of-life recycling input rate (EoL-RiR)
	End-of-life recycling rate (EoL-RR)
	Dissipative losses
	Material Substitution Potential
Resilience	Self-sufficiency of extraction, processing and manufacturing
	Buffer Capacity
	Import Dependency Ratio (non-EU)
	Scarcity potential

Category	Indicator
Vulnerability	Criticality Index
	Exposure to Strategic Sectors
	By-product dependence
	Political instability
Competitiveness	Cost Competitiveness
	Earning Power Contribution
	Resource competition
	Cost of extraction

Flexible intervention archetypes

Intervention Archetype	Examples
Regulatory or Policy Interventions	- Mandatory recycling targets - Tax on virgin material extraction - Bans on single-use products
Technological or Process Innovations	- Electrochemical recycling for CRMs - Rare-earth material substitution - Digital material tracking systems
Economic or Market-Based Instruments	- Subsidies for secondary raw materials - Deposit-refund schemes - Resource extraction taxes
Circular Business Model Transformations	- Product-as-a-service models - Modular product design - Take-back programs
Behavioral or Social Change Interventions	- Public awareness campaigns - Nudging for waste sorting - Educational programs on circularity
Supply Chain Restructuring	- Localizing supply chains - Manufacturer-recycler partnerships - Diversified sourcing for CRMs
Material Efficiency or Resource Optimization	- Lightweighting products - Reducing manufacturing scrap - Industrial symbiosis
Research and Development	- Funding alternative material research - Increased technology efficiencies - Innovative recycling technologies
Infrastructure Development	- Recycling facilities - Renewable energy infrastructure - Smart city waste systems
Governance and Institutional Change	- Certification schemes - Harmonized international standards



“But models are always wrong…

Forbes

Subscribe: Less than $1.50/wk

Sign In

BUSINESS > ENERGY

Why Apocalyptic Claims About Climate Change Are Wrong

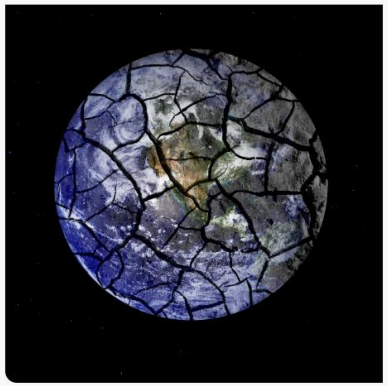
By Michael Shellenberger , Former Contributor. I write about energy and the...

Nov 25, 2019, 01:06am EST

Save Article

This article is more than 5 years

HOOVER INSTITUTION



defining ideas

ARTICLES

Flawed Climate Models

The relationship between CO_2 and temperature is more complicated than the polemics suggest.

Tuesday, April 4, 2017 • 5 min read

By: David R. Henderson, Charles L. Hooper

Support us

Sign in

The Guardian

Eur

News | Opinion | Sport | Culture | Lifestyle

Business | Economics | Banking | Money | Markets | Project Syndicate | B2B | Retail

Economics

This article is more than 2 years old

Letters

Why economic models have never been able to predict a downturn

Dismissing instances of direct trade as ‘outliers’ that don’t fit statistical theory is a major failing, writes **Prof Scott Moss**

Letters

Fri 12 Aug 2022 18.49 CEST

Share

CATO INSTITUTE

CATO AT LIBERTY

OCTOBER 10, 2013 1:31PM

Climate Models’ Tendency to Simulate Too Much Warming and the IPCC’s Attempt to Cover That Up

By **Paul C. “Chip” Knappenberger** and **Patrick J. Michaels**

SHARE

…thly articles in which … Knappenberger, from …, review interesting …ic literature that may … that they deserved, or …r press.

BBC

Register

Sign In

ADVERTISEMENT

What is the latest on ETFs?

MarketViews

Advertisement by Dianomi

Climate change: Key UN finding widely misinterpreted

16 April 2022

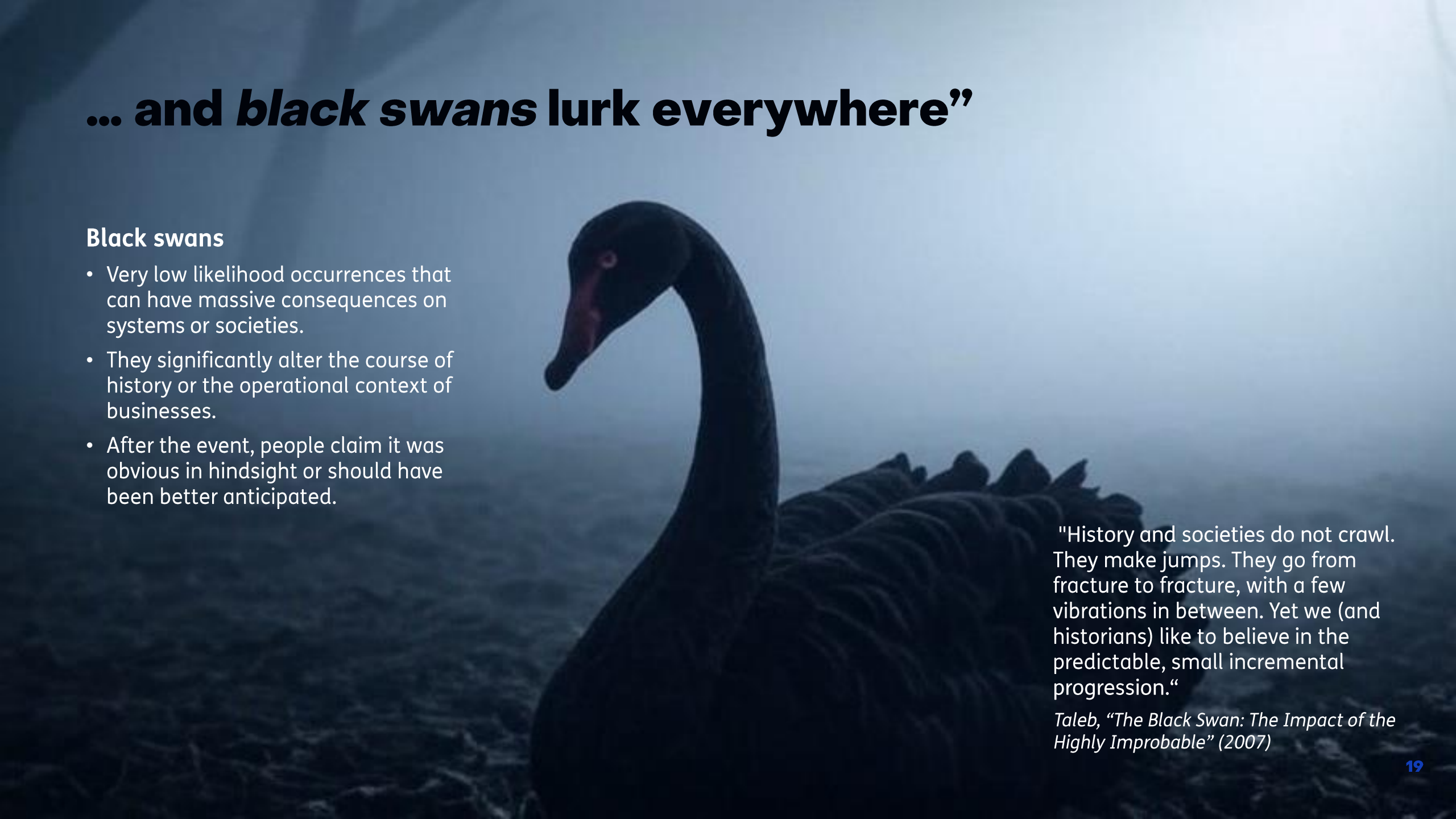
Share

Save

Matt McGrath

Environment correspondent

… and *black swans* lurk everywhere”



Black swans

- Very low likelihood occurrences that can have massive consequences on systems or societies.
- They significantly alter the course of history or the operational context of businesses.
- After the event, people claim it was obvious in hindsight or should have been better anticipated.

"History and societies do not crawl. They make jumps. They go from fracture to fracture, with a few vibrations in between. Yet we (and historians) like to believe in the predictable, small incremental progression.“

Taleb, “The Black Swan: The Impact of the Highly Improbable” (2007)

Would we rather go blind into the future?

A response:

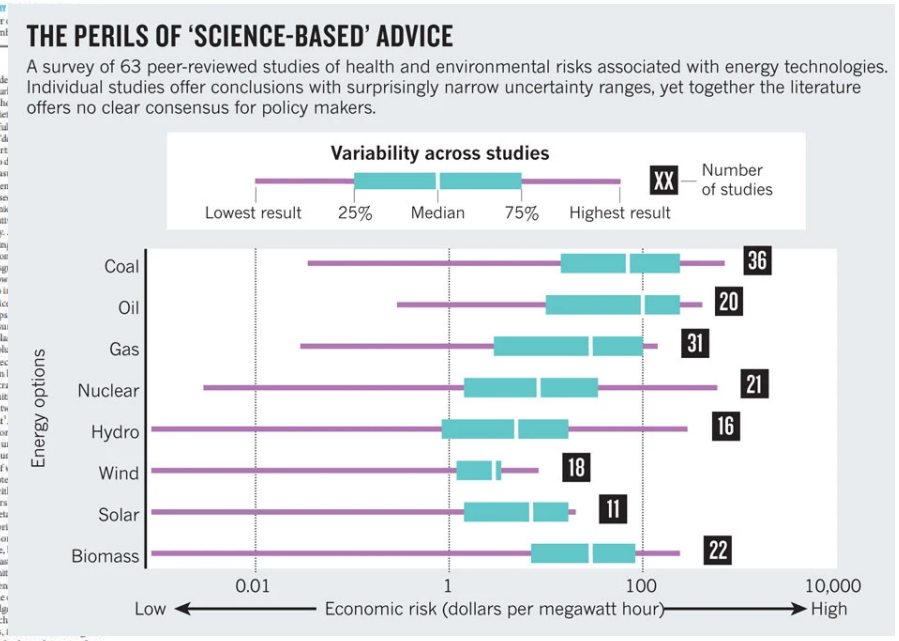
COMMENT

CONSERVATION Threats to Adélie penguins assessed p.1034 | MATHEMATICS Roger Penrose reflects on 50 years and 6 volumes of work p.1039 | REVIEWING Pool of peers grows to cope with submissions' surge p.1041 | OBITUARY keeper of ... remembered

A UK crop circle, created by activists to signify uncertainty over where genetic contamination can occur.

Keep it complex

When knowledge is uncertain, experts should avoid pressures to simplify their advice. Render decision-makers accountable for decisions, says **Andy Stirling**.



"Torture the data until it confesses"

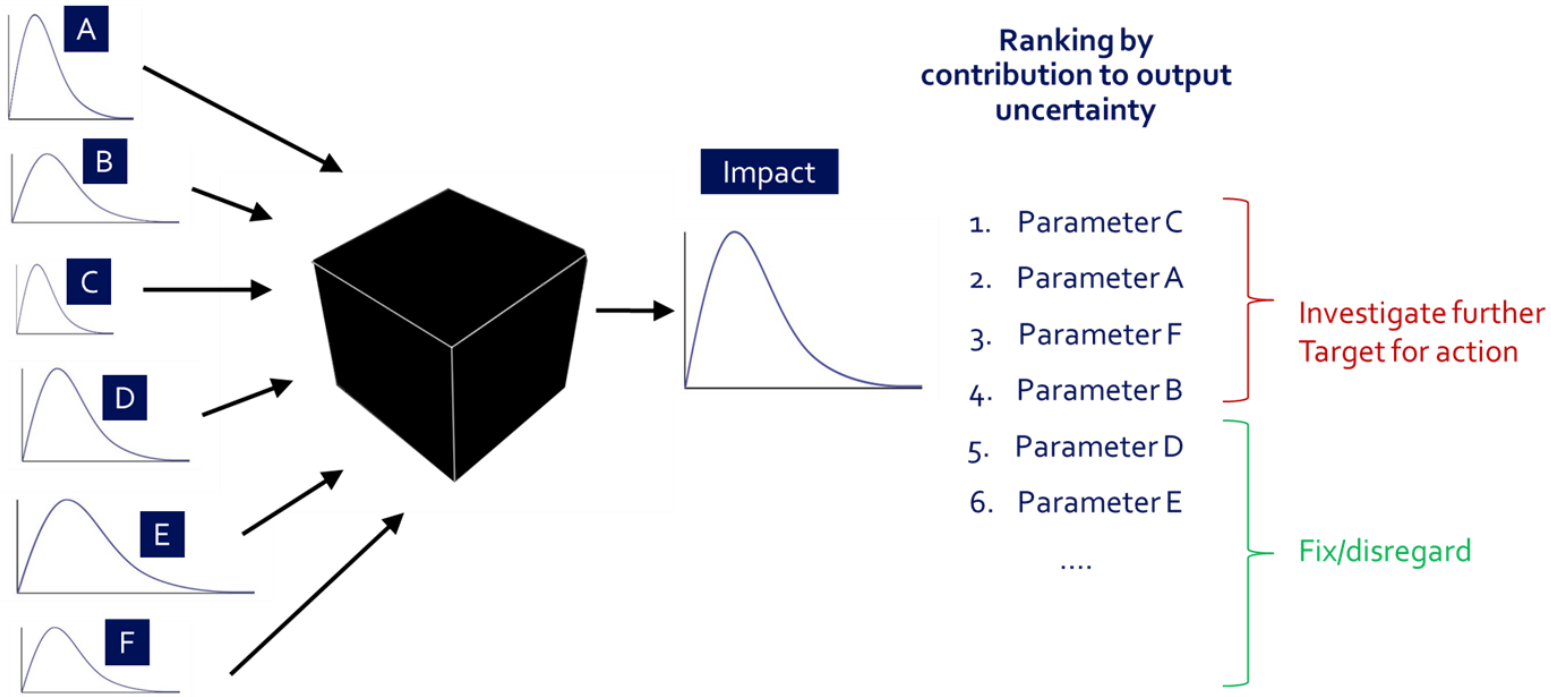
"Torture the data until it ~~confesses~~ proves innocent"

E. Plischke (2015)

Robust decision support strategy #1:

Global Sensitivity Analysis

"What are the most influential factors towards uncertainty in the models' results?"



Robust decision support strategy #2:

Scenario Discovery

"Under what conditions does the 25×25 policy* results in unacceptably high economic costs?"

**policy requiring 25 percent of electricity and motor fuels to be derived from renewable sources by 2025.*

Bryant & Lempert, 2010

Table 1
Range of values considered for uncertain model input parameters.

Uncertain Model Input Parameter	Low	High	Units
Biofuel Production Cost	67	134	$ per unit input
Low-cost biomass supply	450	1000	millions of tons
Feedstock supply distribution	0	1	pessimistic to optimistic
Biofuel yield	80	100	gallons per ton
Oil supply elasticity	0.2	0.6	
Transportation demand elasticity	-0.2	-0.8	
Electricity co-product	0	2	kWh per gallon
Shift in oil supply curve	-10	10	% change
Biomass backstop price	90	200	$ per ton

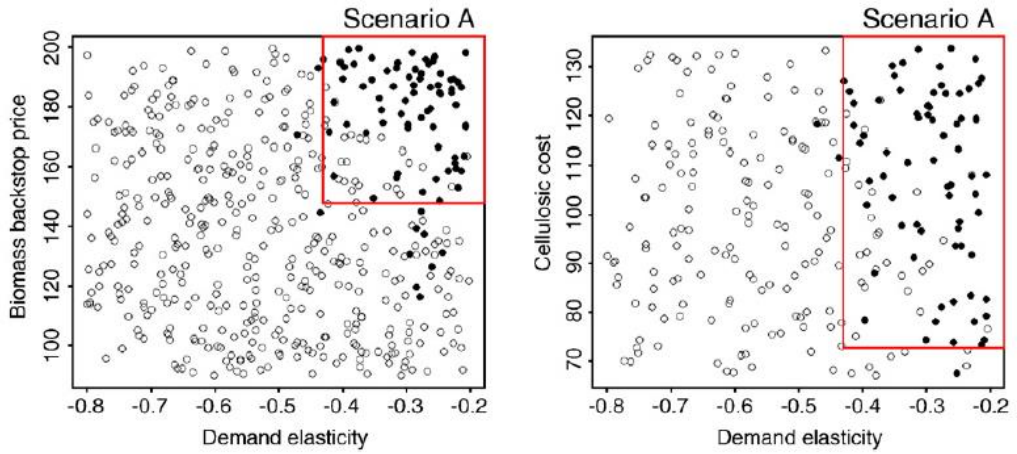
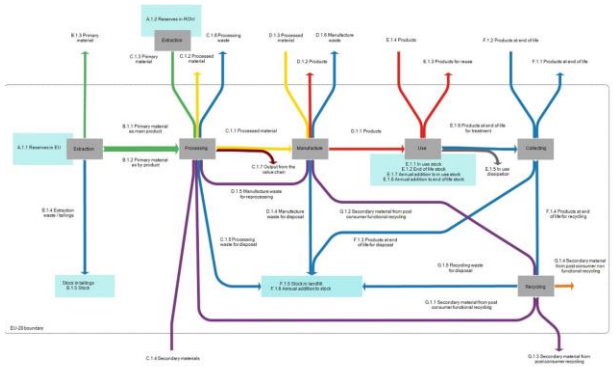


Fig. 5. Cases in database plotted as function of: a) first two parameters and b) first and fourth parameters shown in Fig. 4. Black and open dots show high-cost and lower cost cases, respectively. Red lines show parameters values corresponding to the boundaries of Scenario A.

Robust decision support strategy #3:

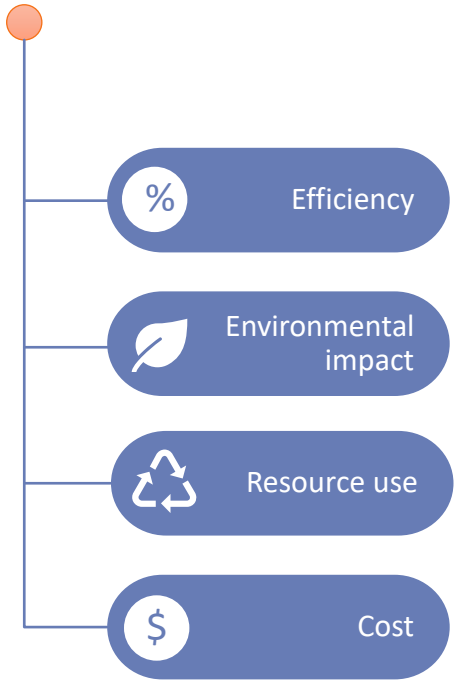
Multi-objective optimization

System model

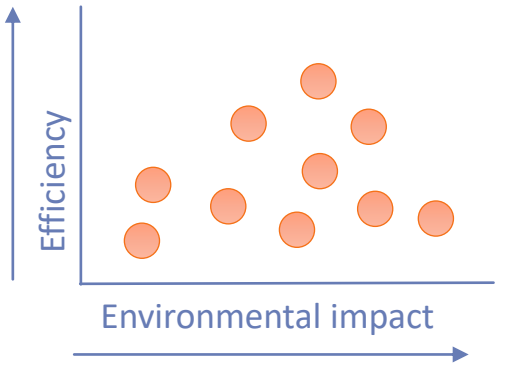


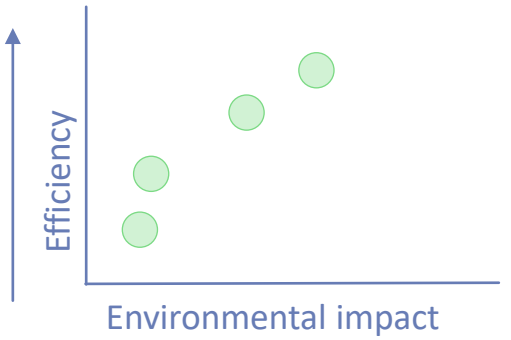
Possible solutions

Define objectives

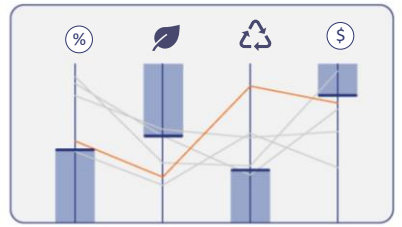


Multi-objective optimization





Decision-making



Thank you for your attention

TNO Energy & Materials Transition, Princetonlaan 6, Utrecht

felipe.blancorocha@tno.nl

+31 6 275 22402