Energy Economics, Winter Semester 2023-4
Lecture 12: Carbon Markets

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Introduction to Climate Damages

Global Warming Damages

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Global warming causes net damages to ecosystems and economies. The costs of some of these damages (and benefits) can be quantified, although uncertainties both about the climate impacts and the economic consequences are high. Damages occur over **hundreds of years**.

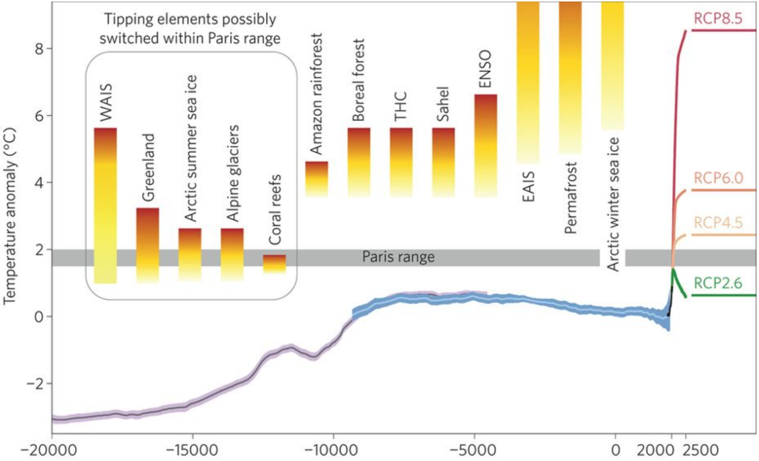
Direct costs:

- **Weather extremes** impact agriculture and built environment (hurricanes, heatwaves, drought, flooding, fires)
- **Rising sea levels** increase flood damage, make large areas uninhabitable
- **Crop/livestock losses** due to rising average temperatures
- **Biodiversity loss** due to changing habitats
- **Expansion of deserts** makes land uninhabitable
- **Reduction of drinking water** due to changing precipitation

Adaptation costs:

- **Dams and levees** against rising sea
- **Resilience measures** for infrastructure
- **Air conditioning** in buildings
- **Mass migration** from hot regions
- **Crop changes**

The 2015 Paris Agreement pledged its signatories to 'pursue efforts to limit [global warming above pre-industrial levels] to **1.5°C**' and hold 'the increase...to **well below 2°C**'. These targets were chosen to avoid potentially irreversible **tipping points** in the Earth's systems.



WAIS: West Antarctic Ice Sheet (⇒ 5m sea level rise)

Greenland (7m)

THC: thermohaline circulation (warms Europe)

ENSO: El Niño–Southern Oscillation (extreme weather)

EAIS: East Antarctic Ice Sheet (> 50 m)

Source: **'Why the right climate target was agreed in Paris'**, Nature Climate Change, 2016

Quantifying Climate Damages

We can attempt to quantify the net damages as a **Social Cost of Carbon** in €/tCO_2. These damages depend strongly on what damages are included, the discount rate (how we weight damages in the future), total emissions and the year of emission. Values in the literature range widely! Example from German Environment Agency (UBA):

Tabelle 1: UBA-Empfehlung zu den Klimakosten in $€_{2020}$ / t $CO_{2\,äq}$

	Klimakosten in $€_{2020}$ / t $CO_{2\,äq}$		
	2020	**2030**	**2050**
1% reine Zeitpräferenzrate	195	215	250
0% reine Zeitpräferenzrate	680	700	765

Quelle: Eigene Darstellung.

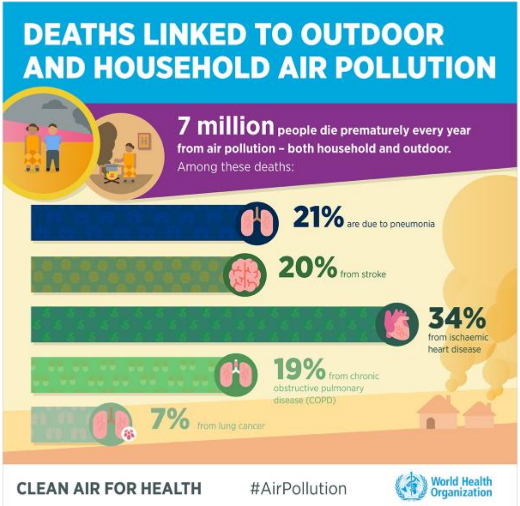
0% discount rate ⇒ future generations weighted same as current.

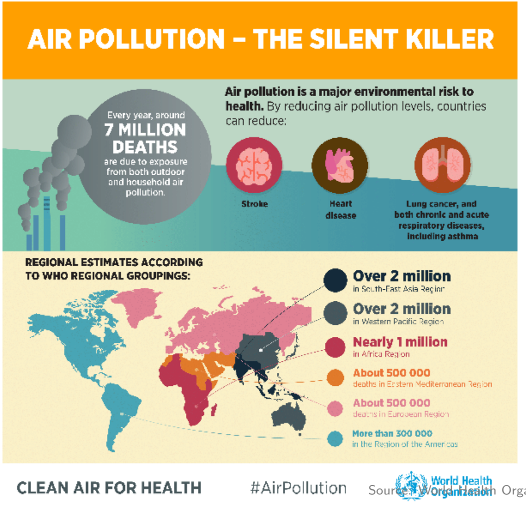
1% discount rate ⇒ damages in 30 years weighted by $\frac{1}{1.01^{30}} = 0.74$.

Source: UBA, 2020

Not just climate change: air pollution is a silent killer

Air pollution from fossil fuel burning is linked to higher mortality (deaths) and morbidity (diseases, e.g. aggravation of asthma).





Source: World Health Organisation

Global Warming as a ‘Negative Externality’

The unabated use of fossil fuels has an unintended indirect effect on third parties: the emissions of CO_2 lead to climate costs for current and future generations, an **externality**.

Definitions:

- **Emissions** are released by a facility into the environment; can include substances, noise, odours, radiation.
- **External effects** are impacts of economic activities on outsiders without compensation. In the case of damages, these impacts are **negative** external effects; if the impacts are advantageous, they are called **positive** external effects.
- **External cost** is the negative external effects expressed in monetary units.

Examples of negative externalities: cigarette smoke in indoor spaces; oil spills; soot damage on people and buildings; nuclear accidents; noisy traffic/neighbours.

Examples of positive externalities: keeping honey bees next to apple orchard ensures trees are pollenated; education people makes them less likely to support war.

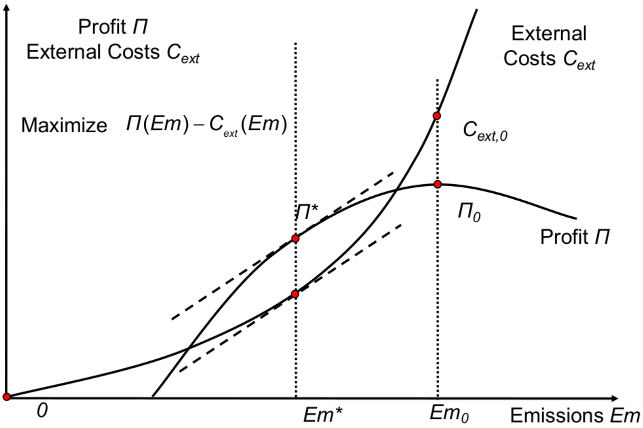
Characteristics of climate problem

- **Globality**: The location of emissions does not matter (leakage problem)
- **Timeline**: Damages affect future generations while the current generation has relatively minor impairments
- **Cost/unavailability** of reliable abatement technologies for hard-to-debarbonise sectors (like aviation, shipping, cement and petrochemicals)
- **Free-rider problem**: Solutions require an internationally coordinated and future-oriented approach: Who should provide what contributions? (International and intra-national distributive conflicts; developing countries against grandfathering)
- **Measurement, reporting and verification**

Strategies for Negative Externalities

Profits versus External Costs

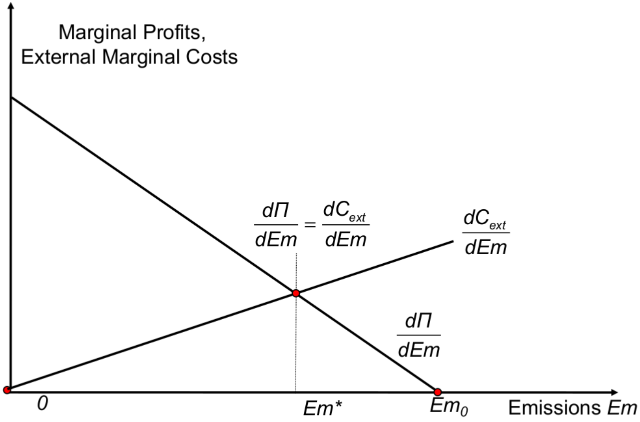
Suppose a company's profits Π depend on their emissions Em. There are external costs $C_{ext}(Em)$ borne by a third party.



- If external costs are ignored, profits reach maximum at Π_0 with emissions Em_0. External costs $C_{ext}(Em_0)$ are higher than firm's profits - inefficient from a societal perspective - a **market failure**.
- If instead we maximise for **society** $\Pi(Em) - C_{ext}(Em)$ we find an optimum at Em^* where external costs are lower than profits. The company can compensate the third party for their costs.

Source: Zweifel, Praktiknjo & Erdmann (2017)

Now consider the marginal costs and profits.



If we find the emissions level that maximises profits minus costs, i.e. the benefit for the whole society:

$$\max_{Em} [\Pi(Em) - C_{ext}(Em)]$$

then at the optimum we have **marginal external costs** equal **marginal abatement costs** (cost to firm in lost profits):

$$\frac{d\Pi}{dEm} - \frac{dC_{ext}}{dEm} = 0$$

Source: Zweifel, Praktiknjo & Erdmann (2017)

Strategies for dealing with negative externalities

There are three major strategies for dealing with negative externalities:

- **Standards/norms**: Society sets voluntary or binding requirements for maximum emissions levels. Example: for 2020-2024 there is an EU fleet-wide CO2 emission **target** for passenger cars of 95 gCO_2/km. Example: insulation standards for new/renovated buildings. Example: efficiency standards/ratings for fridges/TVs.
- **Pigouvian tax**: Tax the externality (e.g. CO_2 emissions) to internalise the social costs of the externality. Example: German CO_2 tax on oil and gas in transport and heating. Example: cigarette tax.
- **Cap-and-Trade System**: Set a volume limit on the externality (e.g. CO_2 emissions), distribute certificates for the volume and require polluters to purchase certificates. Example: EU Emissions Trading System (ETS) for CO_2 energy, industry and domestic aviation. Example: US sulphur dioxide (SO_2) Allowance Trading System.

Pigouvian Tax

Pigou (1931) suggested to tax negative externalities so that producers can internalise the external costs they cause, and thereby reduce production to the socially most efficient level.

Suppose we set a tax λ on CO_2 emissions in €/tCO_2.

Now the producer optimises:

$$\max_{Em} \Pi(Em) - \lambda \cdot Em$$

So that at the optimal point:

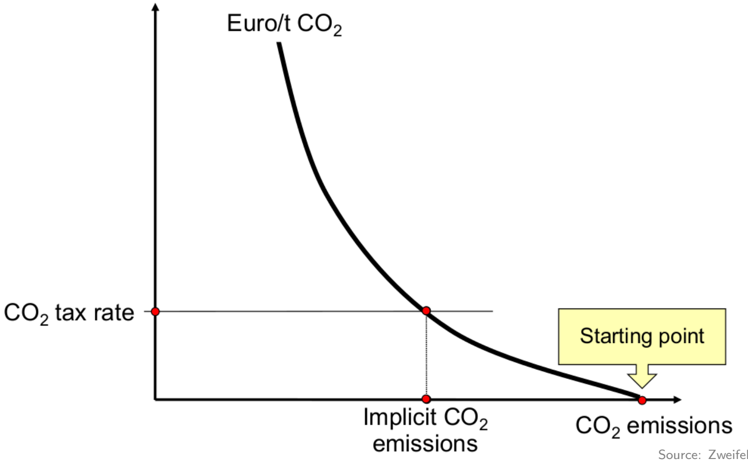
$$\frac{d\Pi}{dEm} - \lambda = 0$$

In other words: they reduce their emissions until the marginal abatement cost (i.e. the cost to the company of reducing the next tonne of CO_2) is equal to the tax.

(NB: Compared to the socially optimal solution, we have replaced nonlinear external costs $C_{ext}(Em)$ with a linear function for the firm $\lambda \cdot Em$.)

Pigouvian Tax

Under a Pigouvian tax, the optimal solution is to reduce emissions until the marginal abatement cost is equal to the tax λ. The exact volume of emissions can be implicitly derived if you know λ and the shape of the marginal abatement cost curve.

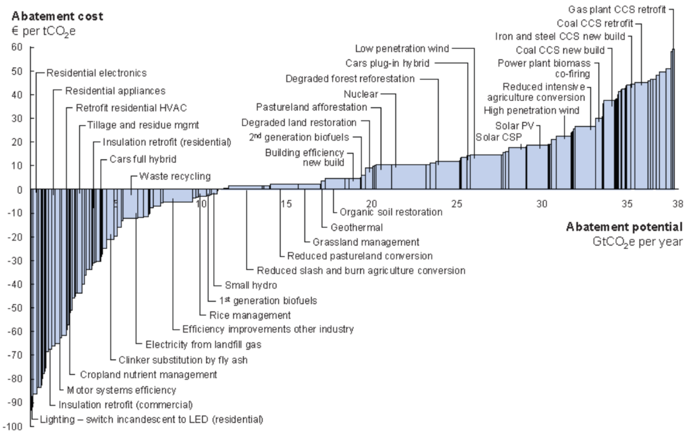


Source: Zweifel, Praktiknjo & Erdmann (2017)

Example Marginal Abatement Cost Curve for 2030

Consider this example marginal abatement cost (MAC) curve for the whole world for the year 2030. NB: x-axis is reversed compared to previous graphic, i.e. rising MAC goes to right.

FIG. 1: MCKINSEY'S GLOBAL COST CURVE FOR THE YEAR 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Nauclér, T. and P. A. Enkvist (2009)

Calculating the Marginal Abatement Cost Curve

Suppose a firm has emissions of 100,000 tCO_2/a based on a fossil-fueled furnace emitting 50,000 tCO_2/a and consuming coal of 100 GWh_{th}/a, and a coal electricity generator emitting 50,000 tCO_2/a and generating 50 GWh_{el}/a. Coal costs 10 €/MWh_{th} and coal electricity LCOE is 40 €/MWh_{el}.

It has the following options:

- Insulate the fossil-fueled furnace at an annualised cost of 50,000 €/a, which reduces coal use by 20 GWh_{th}/a and emissions by 10,000 tCO2/a.
- Replace coal generator with cost including fuel of 2 million €/a, generation of 50 GWh_{el}/a and emissions of 50,000 tCO_2, with a solar-battery combination with cost of 3 million €/a (LCOE of 60 €/MWh_{el}).
- Replace remaining 80 GWh_{th}/a coal for furnace generator with cost of 0.8 million €/a with green hydrogen at cost of 90 €/MWh_{th}.

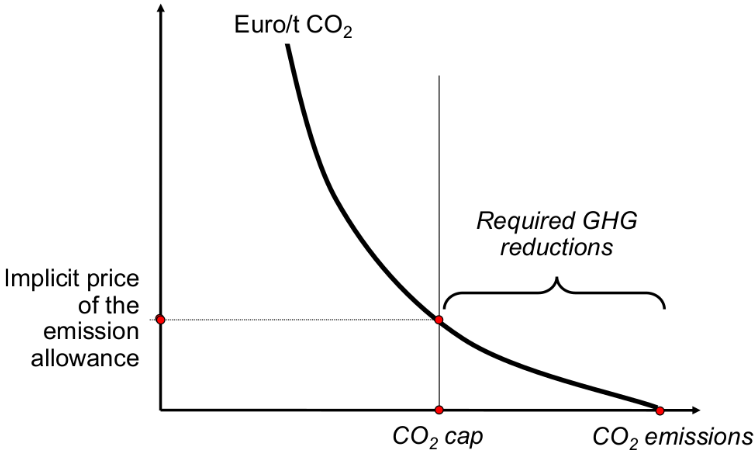
What does the MAC curve look like?

- Insulation: 10,000 tCO_2/a reduction at net cost of (50,000 - 200,000) €/a = -150,000 €/a ⇒ MAC of -15 €/tCO_2.
- Clean generation: 50,000 tCO_2/a reduction at net cost of (3-2) million €/a = 1 million €/a ⇒ MAC of 20 €/tCO_2.
- Clean heating fuel for furnace: 40,000 tCO_2/a reduction at net cost of $(90 - 10)$€/$MWh_{th} \cdot$ 80 GWh_{th}/a = 6.4 million €/a ⇒ 160 €/tCO_2.

What would the firm do with a tax of 10€/tCO_2? 100 €/tCO_2? 200 €/tCO_2?

Cap-and-Trade System

For Pigouvian tax, price is known, volume is unknown. For Cap-and-Trade we fix known volume for emission certificates, then an implicit price is found by trading the certificates.



Source: Zweifel, Praktiknjo & Erdmann (2017)

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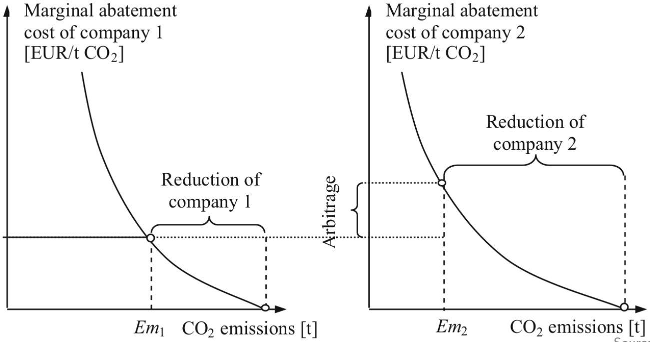
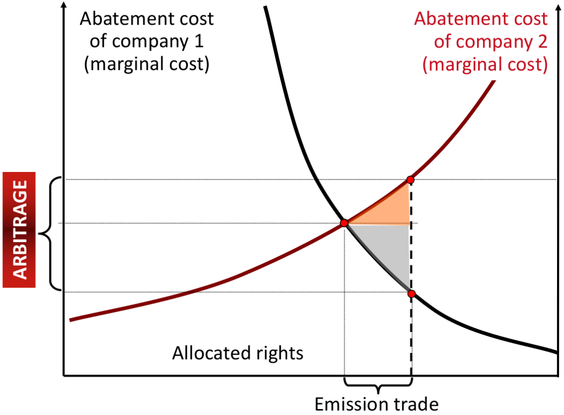
Suppose two companies with different MAC(Em) curves are allotted allowances Em_1 and Em_2. Since $MAC_1(Em_1)$ is lower than that $MAC_2(Em_2)$, the first company has an **arbitrage opportunity**: it reduces its emissions to $Em_1 - \delta$ and sells the corresponding δ emission certificates to company 2 at a cost above $MAC_1(Em_1 - \delta)$. Company 2 increases its emissions to $Em_2 + \delta$. As long as $MAC_1(Em_1 - \delta) < MAC_2(Em_2 + \delta)$, both companies will profit from this transaction. Trading reaches equilibrium at $MAC_1(Em_1 - \delta) = MAC_2(Em_2 + \delta)$.



Source: Zweifel, Praktiknjo & Erdmann (2017)

Cap-and-Trade System

Equilibrium is found at $MAC_1(Em_1 - \delta) = MAC_2(Em_2 + \delta)$ for an emissions trade of δ tCO_2. Certificate price is set by intersection of MAC curves. Company 1 benefits since the price is higher than its abatement costs for the range it reduces $[Em_1 - \delta, Em_1]$; company 2 benefits since the price is below its abatement costs for the range it increases $[Em_2, Em_2 + \delta]$.



Coase Theorem

The **Coase Theorem** says that in such a system, it doesn't matter how the initial certificates or emissions allowances are distributed to market participants; from the resulting trading, the system will still reach equilibrium at the socially optimum point, thus solving the problem of externalities and allocating resources efficiently.

The main thing is to have a recognised system of allowances.

However, benefits may be **distributed differently** depending on the initial allocation.

Relevance for EU emissions trading system (ETS): some certificates are sold by government, while others are allocated to industry for free (since they have to compete with foreign firms).

Pigouvian Tax versus Cap-and-Trade

	Pigouvian Tax	Cap-and-Trade
Price	Set by government	Determined implicitly by MAC and cap
Volume	Determined implicitly by MAC and price	Set by government
Benefits	Price certainty for industry	Allows targetting of CO_2 volume precisely
Drawbacks	Can under- or overshoot CO_2 volume target	Can lead to price volatility

EU Emissions Trading System

Why an Emissions Trading System?

Answer: combination of advantages of Cap-and-Trade and ease of legislation.

For tax issues all EU member states must agree, but majority vote is sufficient for an Emissions Trading System (ETS) $\Rightarrow$ ETS was easier to legislate than a carbon tax.

The ETS is a mandatory Greenhouse Gas (GHG) Cap-and-Trade system for power, refinery, steel, glass, cement industries (2071 MtCO_2eq verified emissions in 2005, about 40% of total).

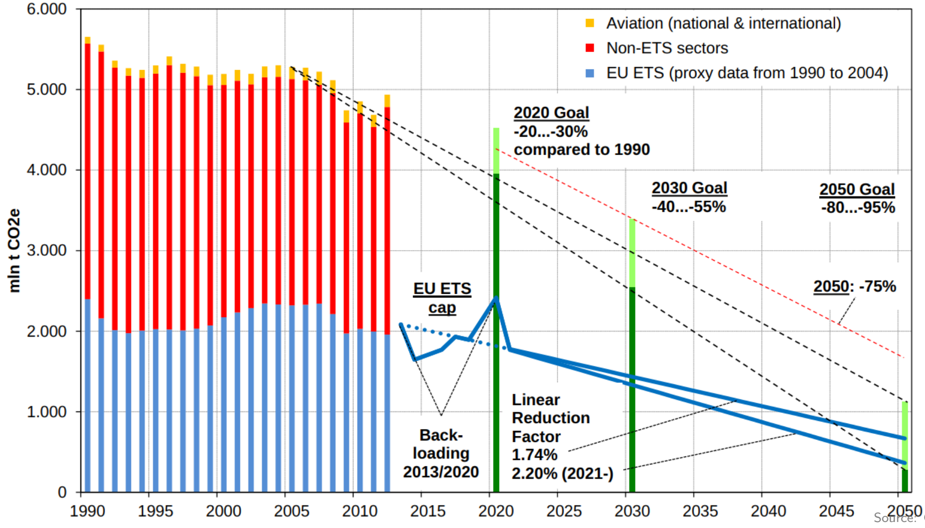
Included aviation within EEA from 2012. Domestic maritime to be included from 2024.

Emissions from buildings, road transport, agriculture, waste and small facilities currently covered by separate **Effort Sharing Regulation** (ESR). Road transport, buildings and additional industrial sectors to move into **new ETS 2** from 2027, with certificates bought by fuel distributors; price should be initially stabilised below 45 €/tCO_2.

Almost free allocation of emission rights in the first two trading periods 2005-7 and 2008-12 led to **windfall profits**.

System is intended to become the prototype for a global Cap-and-Trade system.

NB: EU now has net-zero 2050 target. Most non-ETS emissions go into ETS 2 from 2027.



Source: Öko-Institut, 2014

Design of an Emissions Trading System

Trading period length of time:

- If the trading period is too long, the incentives are weak (e.g. decades).
- If the trading period is too short, there is lack of certainty for investments.

Allocation of emissions allowances:

- **Auctioning**, i.e. operators buy allowances in auctions. Government collects and redistributes auctioning revenues.
- **Free allocation** based on **grandfathering**, i.e. industries are given free allowances based on past emissions.
- **Free allocation** based on **benchmarking**, i.e. industries are given free allowances based on their activities (e.g. product sales) and a per-sector benchmark.

In past free allocation led to windfall profits, since CO_2 prices are opportunity costs of power plant operators (certificates could be sold) and, thus, included into the product price anyway.

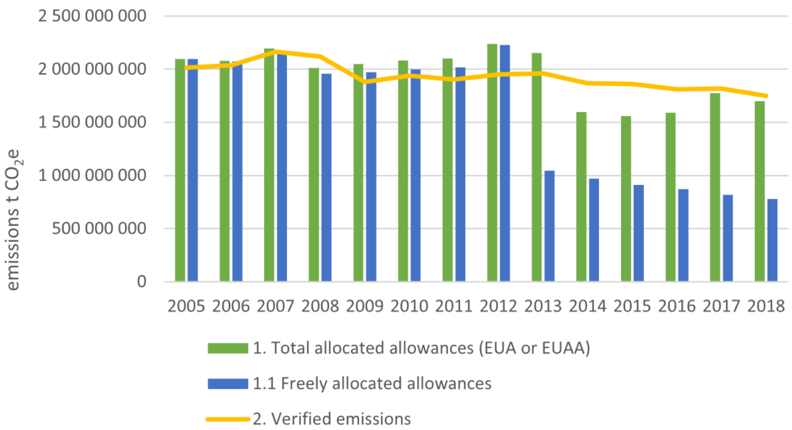
European Emissions Trading System (ETS)

Main features:

- 27 EU member states + Norway, Iceland and Liechtenstein (UK has own ETS since 2021)
- Covers around 40% of EU GHG emissions ($\sim$ 2 billion tCO_2eq as of 2014)
- 4% of world's GHG emissions
- A quantitative limit is put on the aggregate annual amount of emissions for all plants participating in ETS (cap).
- A single EU-wide cap; allowances issued correspond to cap.
- Declining by 1.74% annually until 2020; 2021 onwards at 2.2% (higher from 2024).

EUA (EU Allowance): An EUA permits operators of an industry installation or electricity generation unit to emit 1 t of CO2 under the EU emissions trading system. Each regulated operator must surrender every year the amount of EUA corresponding to the amount of its emissions.

ETS Free Allowances and Auctioning



Auctioning as the main allocation principle:

- for energy utilities – since 2013
- for other industries – growing %, to be fully phased in by 2027
- free allocation to industries threatened by **carbon leakage**

NB: **Backloading**, removal of 900 million allowances in 2014-6, because of surplus in years before.

Source: **European Court of Auditors, 2020**

Phases of ETS

Phase I (2005-7)

- Pilot phase for EU energy + industry
- Most allowances given for free; power sector based on fuel-specific benchmarks

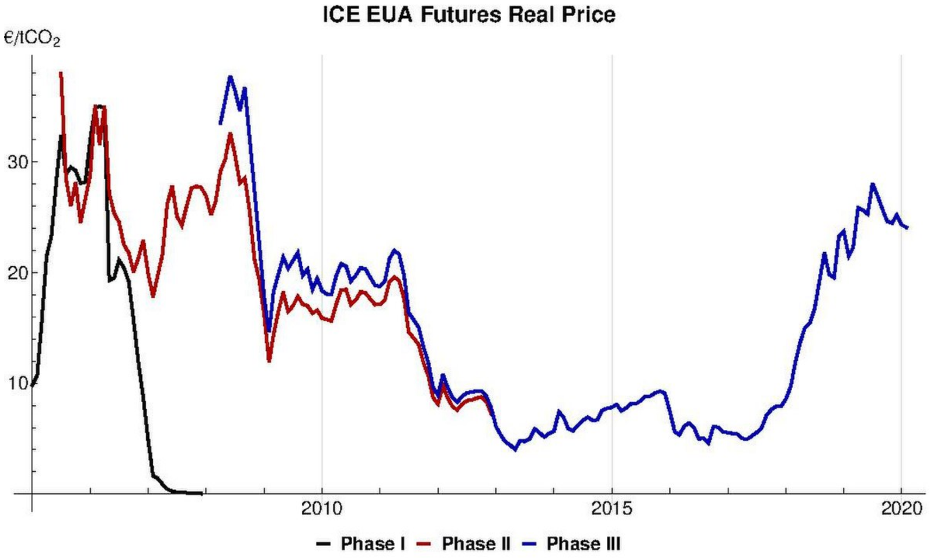
Phase II (2008-12)

- Inclusion of EEA countries (NO, IS, LI) & aviation inside EEA
- Auctioning for power sector and product benchmarking for the other sectors

Phase III (2013-20)

- Move from free allowances to auctioning (particularly for energy)
- Linear reduction factor (LRF) for cap of 1.74% per year
- Introduction of market stability reserve (MSR) in 2019 to address low prices, remove surplus certificates and stabilise prices

EUA prices during Phases I-III



Source: Wikipedia

Phases of ETS

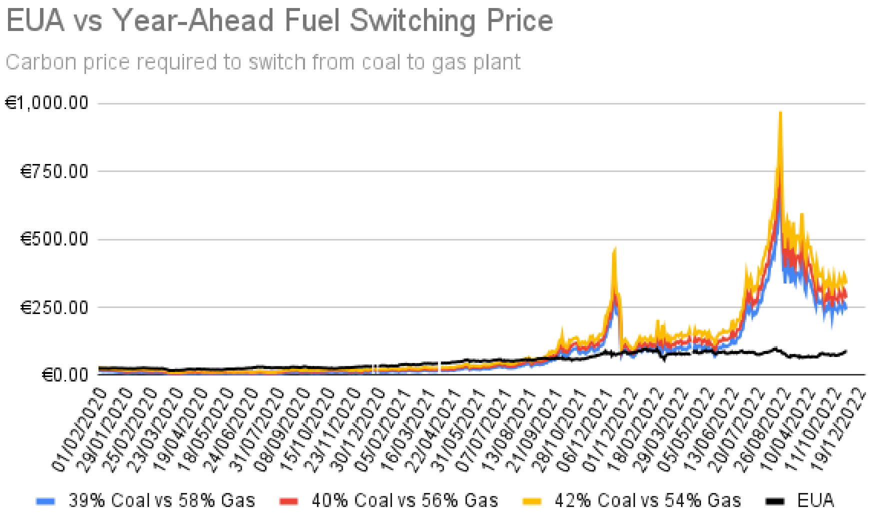
Phase IV (2021-2030)

- Linear reduction factor (LRF) raised to 2.2% per year
- LRF rises to 4.3% for 2024-7 and 4.4% for 2028-30
- New 2030 GHG target of -55% will require 62% reduction compared to 2005 (previous 40% GHG target required only -43%)
- Domestic maritime to be included: 40% from 2024, 70% in 2025, 100% in 2026
- Waste incineration to be included by 2028
- Gradual phase out of free allowances by 2034 as Carbon Border Adjustment Mechanism (CBAM) phased in 2026-2034
- Some revenue flows to Innovation Fund and Social Climate Fund, while rest goes to member states who have to spend at least 50% on energy and climate-related activities (e.g. subsidies for green tech, energy efficiency)

ETS 2 for remaining sectors

- Starts 2027-8, applied to upstream fuel distributors (like German BEHG)
- Covers road transport, buildings and additional (small) industrial sectors
- Trading separate from original ETS ("ETS 1")
- Total reduction of 43% in buildings and transport by 2030 compared to 2005
- LRF: 5.1% from 2027, 5.4% from 2028
- Price stability mechanism: if price above 45 €/tCO_2, 20 million allowances will be released (2% of annual capacity)
- Exemption from ETS2 until 2030 if there is national scheme with higher price (e.g. Germany BEHG Preiskorridor 55-65 €/tCO_2, Sweden, etc.)

Carbon price and coal-gas spread 2020-2



Source: Carbon Reporter

Carbon price and coal-gas spread 2023

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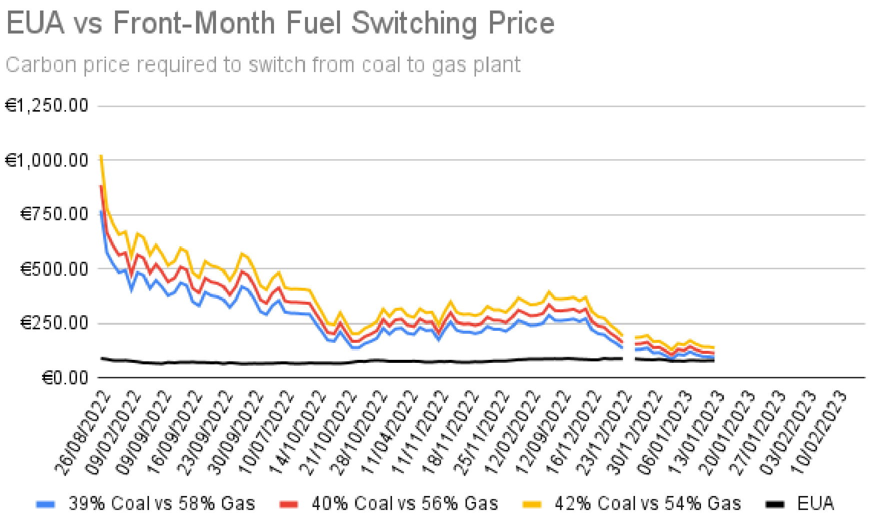
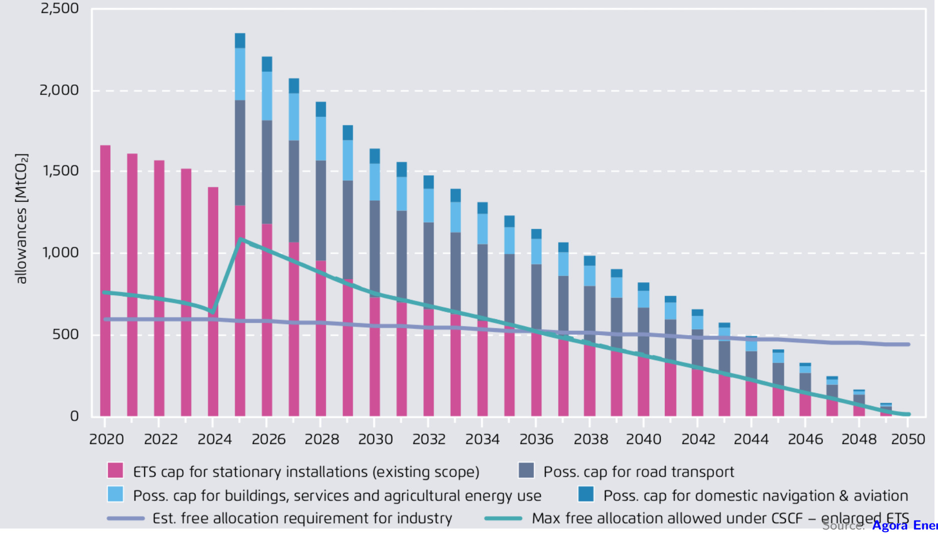


Source: **Carbon Reporter**

Future of ETS - all sectors

EU ETS emissions cap assuming ETS extension to buildings and transport:



Source: Agora Energiewende, 2020

Market Stability Reserve

Market stability reserve (MSR) is intended to address weakness of ETS: strong price fluctuations and **waterbed effect**. The waterbed effect is the effect whereby it makes little sense for individual countries or sectors to make additional reduction efforts, since this only makes EUA cheaper for others.

Market stability reserve operating since January 2019:

- addresses the surplus of allowances
- improves the system's resilience to shocks (recessions, pandemics, etc.)

It triggers adjustments to annual auction volumes in situations where the total number of allowances in circulation is outside a predefined range:

- Reducing allowances from future auction volumes if the EU ETS surplus exceeds 833 million allowances
- Adding allowances to future auction volumes provided the EU ETS surplus is below 400 million allowances

Carbon Border Adjustment versus Carbon Clubs

How to deal with the fact that European industries must pay for carbon emissions but their goods must remain competitive with imports? There is a danger of **carbon leakage**, i.e. carbon-intensive industries moving to countries without carbon pricing.

- **Free allowances** for industries with products at risk of carbon leakage. This was the solution in EU until now.
- **Carbon Border Adjustment Mechanism (CBAM)** that adds tariff on import of carbon-intensive products (like steel, electricity and ammonia) according to their emissions (based on benchmarking for each sector). This is the solution proposed by the European Commission in 2021.
- **Carbon Clubs** that allow free trading between partners with similar carbon reduction schemes. Has been **proposed** in October 2021 for US and EU trading clean steel and aluminium.

Future of ETS - all sectors

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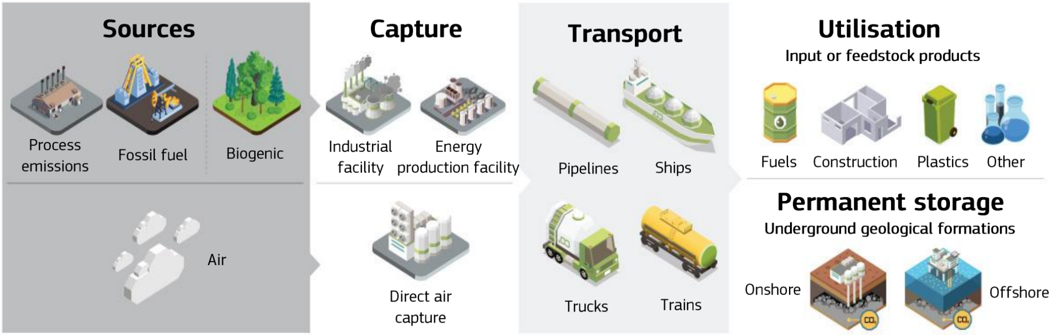
Currently being considered include:

- Extension to **agriculture** (i.e. an ETS 3; tricky because of monitoring of CH_4 from enteric fermentation (e.g. cows burping), N_2O from soil; politically sensitive)
- Merger of different ETS to a single system (to avoid distortions, e.g. CCU in industry then fuel used in residential heating where tax is lower)
- Regulation of **carbon dioxide removal** (CDR) and integration into the ETS
- **2040 target** of around 90% GHG reduction compared to 1990

Most scenarios show that in 2030-50 Europe will need carbon capture from point sources, following by CO_2 transport, usage in fuels and materials (carbon capture and usage, CCU) or long-term underground storage/sequestration (CCS). These options are collectively known as **carbon dioxide management**.



Source: COM: Industrial Carbon Management, 2024

Carbon dioxide removal (CDR)

E.g. afforestation, direct air capture and sequestration (DACS), bioenergy+CCS (BECCS)

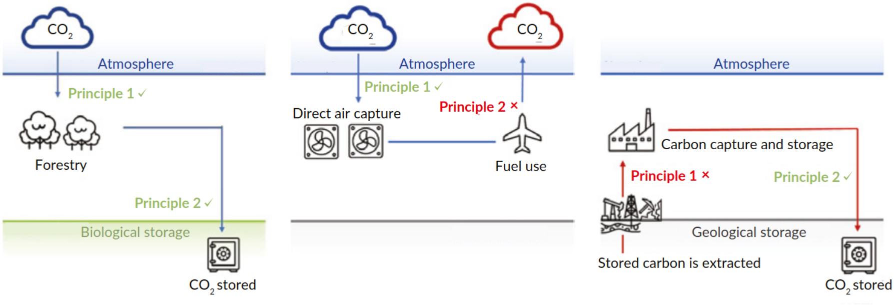
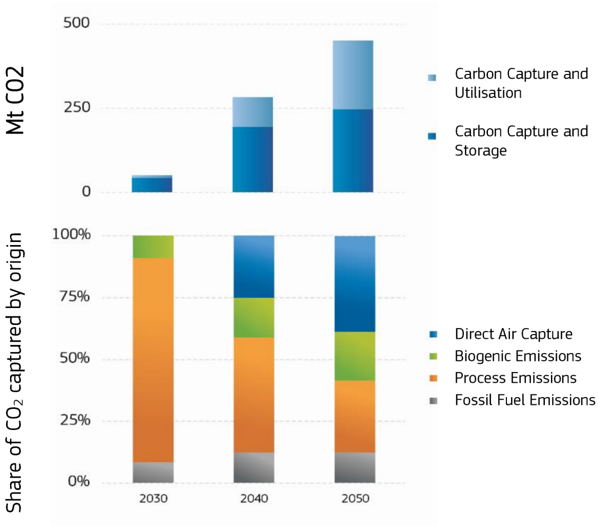


Figure 1.1. *To be defined as Carbon Dioxide Removal (CDR), a method must capture CO_2 from the atmosphere (Principle 1) and durably store it (Principle 2). An example of a method which satisfies both principles, and hence qualifies as CDR, is afforestation/reforestation (left). There are several approaches that satisfy only one of these principles, and hence are not CDR, but which count as Carbon Capture and Utilisation (e.g. Direct Air Capture to fuels (middle) or as fossil Carbon Capture and Storage (right). Source: Zero Emissions Platform (2020)[12].*

Source: State of CDR, 2023

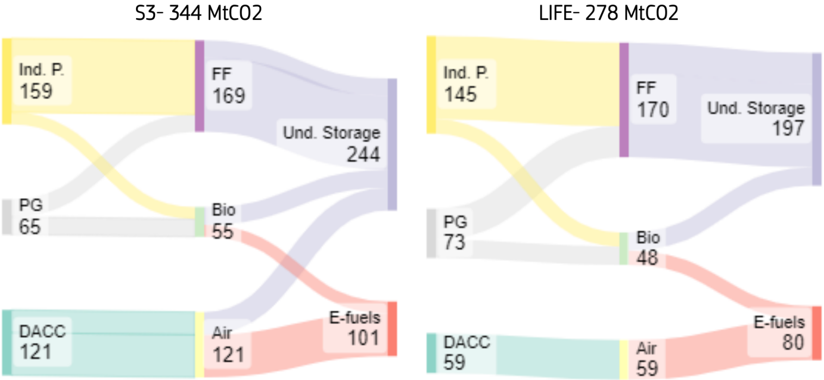
Carbon management in EU policy



- EU Commission's planning for 2030 has 50 $MtCO_2/a$ sequestration (in Net-Zero Industry Act), rising to $\sim$250 $MtCO_2/a$ in 2050
- 2050: around 450 $MtCO_2/a$ total capture from point sources and air
- 2050: around 200 $MtCO_2/a$ CCU
- 2050: around 100 $MtCO_2/a$ CDR
- NB: Neither DAC or BECCS have been demonstrated at scale!

Source: **COM: Industrial Carbon Management, 2024**

Carbon management in EU policy



Note: “Ind. P.” stands for Industrial processes and include fossil carbon from industrial processes as well as carbon of biogenic origin coming from the upgrade of biogas to biomethane. “FF” stands for “fossil fuels”. “PG” stands for “power generation”. “Bio” refers to CO2 produced by the combustion of biomass in power generation and produced during the upgrade of biogas into biomethane. “DACC” stands for “Direct Air Capture of CO2”, for underground storage (DACCS) or use in efuels.

Source: [European Commission 2040 target impact assessment, 2024]

Why a carbon tax on its own is not enough

If technology were static, all financing needs could be met, and all actors rational, a carbon tax might be sufficient. However there are several **market failures**.

- For cap-and-trade: **fluctuating prices** $\Rightarrow$ no investment certainty. Solution: price caps/floors, carbon contracts for difference.
- **New technologies** that are expensive but have cost reduction potential by scaling/learning, are not incentivised. Market failure: companies will not invest in hope of market share in 20-30 years. Solution: government investment incentives/subsidies.
- Consumers **don't perceive** or calculate benefits of low-carbon technologies. Market failure: bounded rationality. Solution: information campaigns, standards/norms.
- **Regressive impact:** poorer households pay a larger share of disposable income in carbon tax. Solution: carbon dividend, i.e. repayment of CO_2 revenues to citizens (Klimageld).
- **Financing gap:** poorer households cannot or will not finance investments of >€20,000. Solution: investment subsidies, interest-free loans, rental models for e.g. heat provision.

Carbon contracts for difference

Carbon contracts for difference (CCfD) are a government instrument to provide investment certainty for firms decarbonising, e.g. in cement or steel industry, particularly if their MAC is higher than the CO_2 price.

CCfD guarantee a strike price in €/tCO_2 for emissions reductions.

If the cap-and-trade price is below the strike price, the government pays the firm the price different in €/tCO_2 for each tonne of carbon dioxide avoided.

If the cap-and-trade price is above the strike price, the company pays the government the difference.

Further reading: "**Carbon contracts-for-difference**: How to de-risk innovative investments for a low-carbon industry?" by Richstein and Neuhoff (2022)

Why a carbon tax is still essential for efficient decarbonisation

Despite the need for an **instrument mix**, carbon pricing is still essential. It ensures:

- **General efficiency** - abatement options with lowest costs are chosen (avoids inefficient solutions where high cost options are prioritised over low-hanging fruit)
- **Efficiency across sectors** - if carbon is being capture here, used there and stored somewhere else, it is hard to incentivise correctly without a **single uniform carbon price** (e.g. if the carbon price is higher in industry than households, could avoid high price with CCU in industry to make synthetic methane then burn it in gas boiler at home - perverse!)
- We tax the problem **directly** in a **technology-neutral way**, rather than **choosing political favourites** (e.g. politicans choose solutions for interest groups) - important while in many areas the best technology is uncertain (e.g. steel, cement)
- It provides an **anchor price** for comparison with efficiency of other instruments (CCfDs, subsidies, financial help)