Integrated course „Energy Economics“ - Markets for CO_2 Emission Allowances

Chair of Energy Systems
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Outline

- External costs
- Quantification of external costs
- Greenhouse gas problem
- European Cap-and-Trade system

Kyoto Protocol

Greenhouse gases:

- Carbon dioxide (CO_2).
- Methane (CH_4), CO_2 equivalents: 23.
- Nitrous oxide (N_2O), CO_2 equivalents: 310.
- Hydrofluorocarbons (HFCs), CO_2 equivalents: 140–11 700.
- Perfluorocarbons (PFCs), CO_2 equivalents: 6500–9200.
- Sulphur hexafluoride (SF_6), CO_2 equivalents: 23 900.

Sector and source categories:

- Energy
- Industrial processes
- Solvents and other product uses
- Agriculture
- Waste

+ Impact of Land-Use, Land-Use Change and Forestry (LULUCF)

Kyoto Protocol: Flexible Mechanisms

Cost-effective options for reducing emissions or removing CO_2 in other countries

- **Clean Development Mechanism**
  - Project-based reduction of CO_2 emissions between non-Annex 1 countries and Annex 1 countries
  - Emission reductions must be additional (compared to baseline).
  - Independent certification
- **Joint Implementation Mechanism**
  - Project-based reduction of emissions between two Annex 1 countries
- **International Emissions Trading**
  - Emissions trading among Annex B countries
  - Not in use

Emission Allowances: Terminology

AAU: Assigned Amount Unit or Kyoto unit. An AAU permit to emit 1 t of CO_2 or 1 t CO_2 equivalent of greenhouse gases.

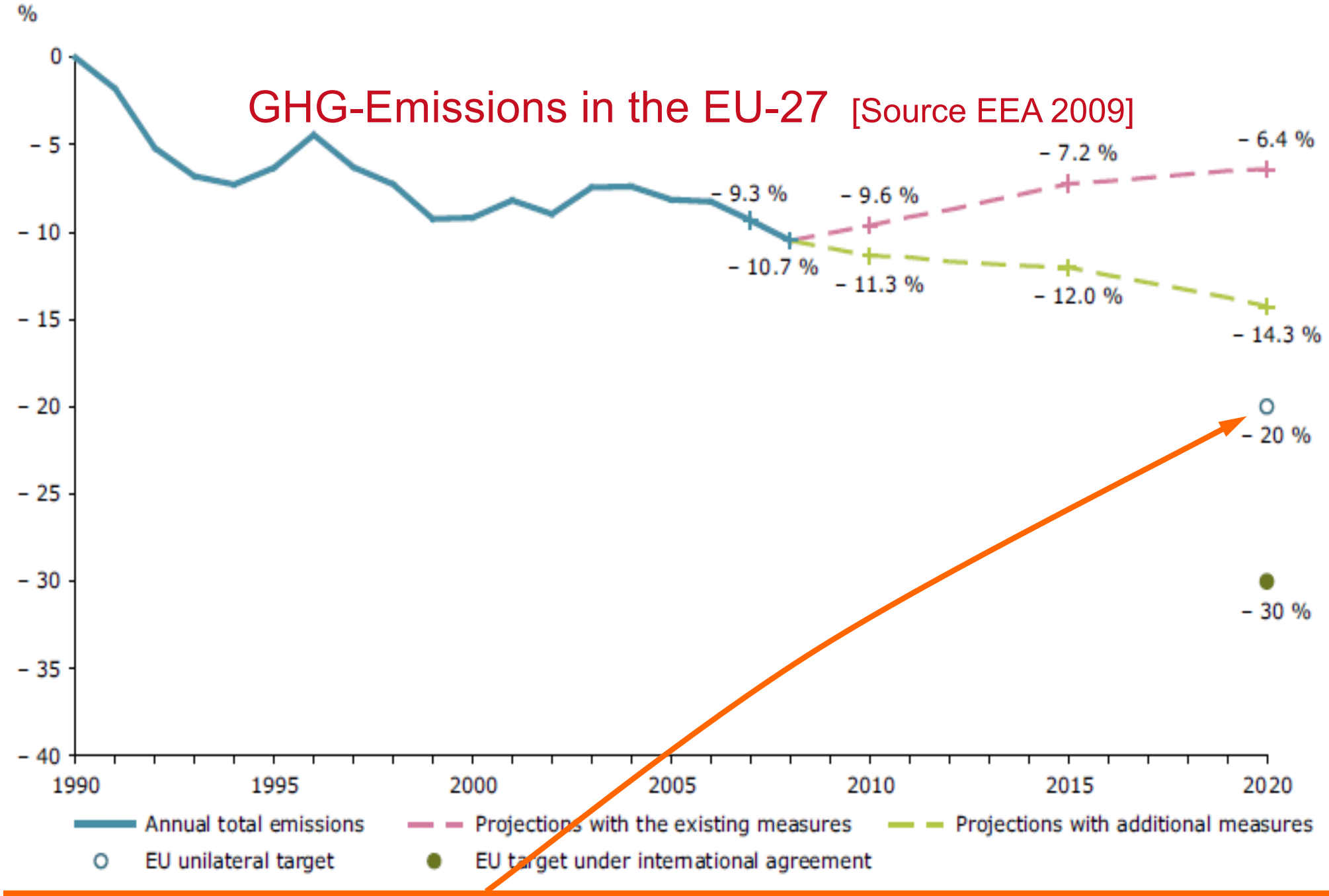
ERU: Emission Reduction Unit. An ERU is a certified emission reduction of 1 t of CO_2 resulting from a Joint Implementation project.

CER: Certified Emission Reduction. A CER is a certified emission reduction of 1 t of CO_2 resulting from a CDM project.

EUA: EU Allowance. An EUA permit operators of an industry installation or electricity generation unit to emit 1 t of CO_2 under the EU emissions trading system.

EUAA: EU Aviation Allowance. An EUAA permit airlines to emit 1 t of CO_2 under the EU emissions trading system.

GHG-Emissions in the EU-27 [Source EEA 2009]

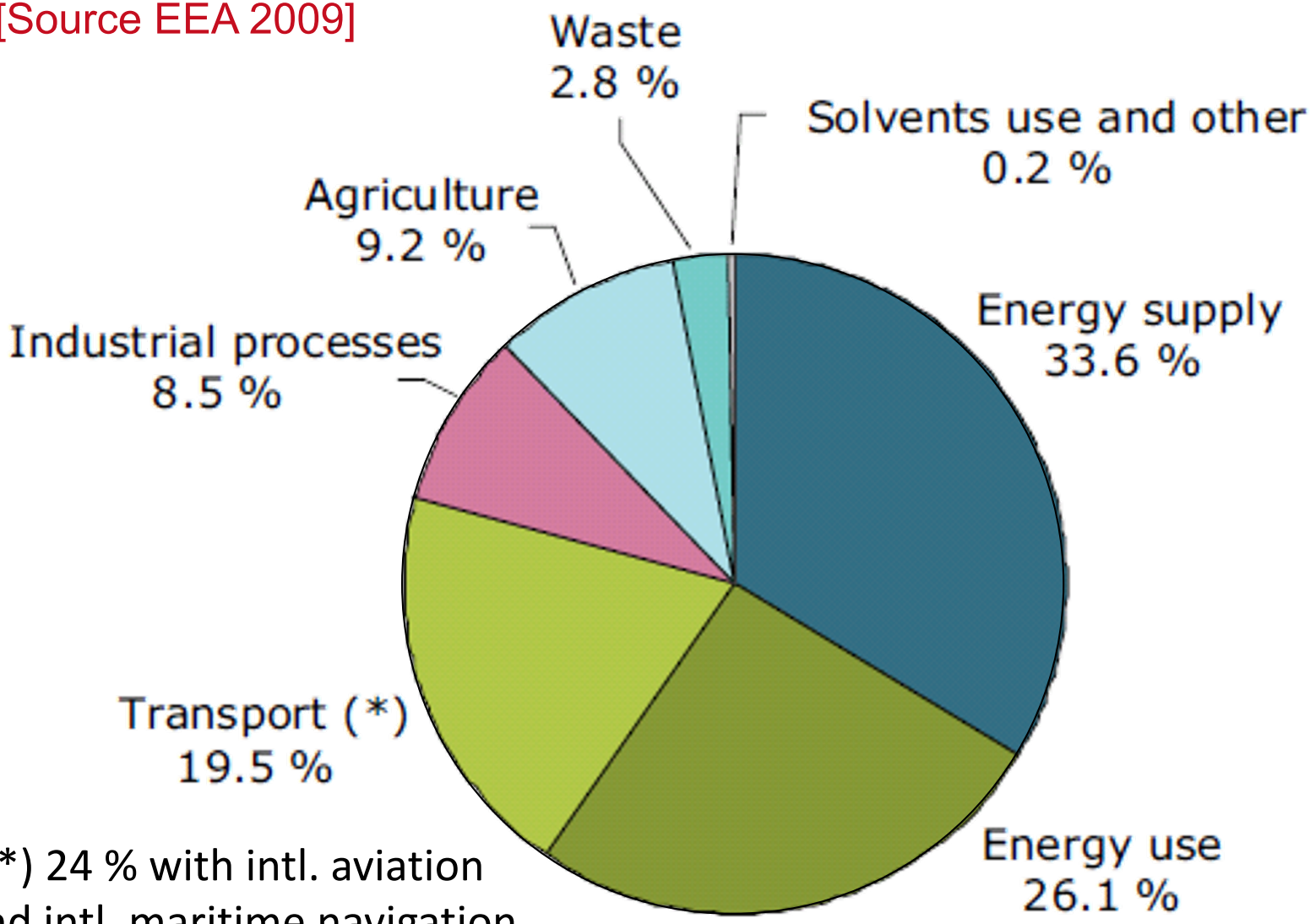


Unilateral target: -20% in 2020 compared to 1990

Source: European Environment Agency EEA 2009

EU-27 Composition of GHG Emissions 2007

[Source EEA 2009]



(*) 24 % with intl. aviation and intl. maritime navigation

EU Emission Trading System (ETS)

Technische Universität Berlin

For tax issues all EU member states must agree, but majority vote is sufficient for ETS system

Mandatory "CO_2 Cap and Trade" system for

- Installations of power, refinery, steel, glass, cement industries (2071 mio t CO_2 verified emissions in 2005)
- airline business (after 2011)

EU wide annual cap of tradable CO_2 Allowances (EUA)

Almost free allocation of emission rights in the first two trading periods 2005/7 and 2008/12 → Windfall profits

System is intended to become the prototype for a global "cap and trade" system

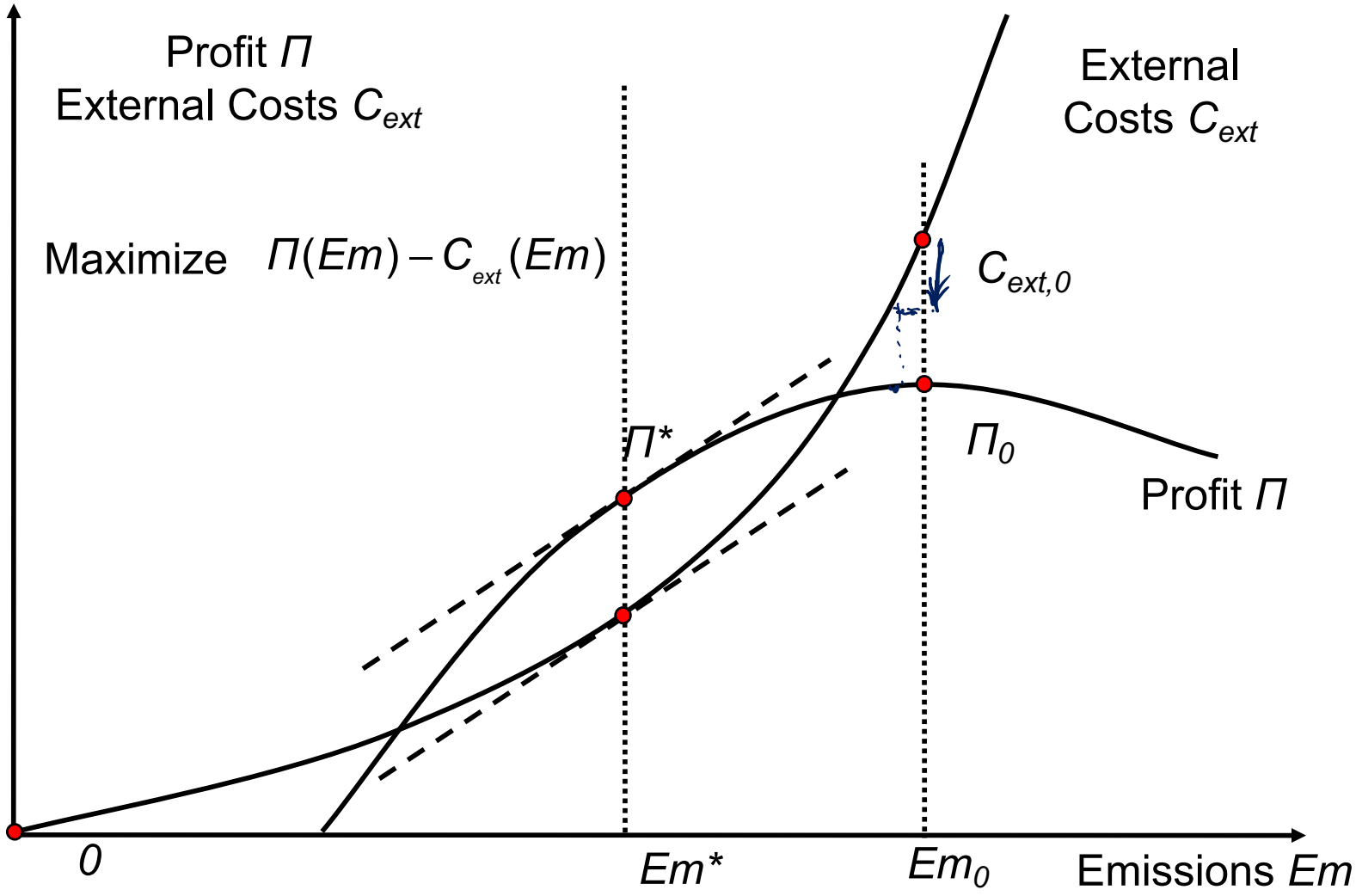
Task 1) External costs and internalisation

a) Explain the term externality in the context of GHG emissions.

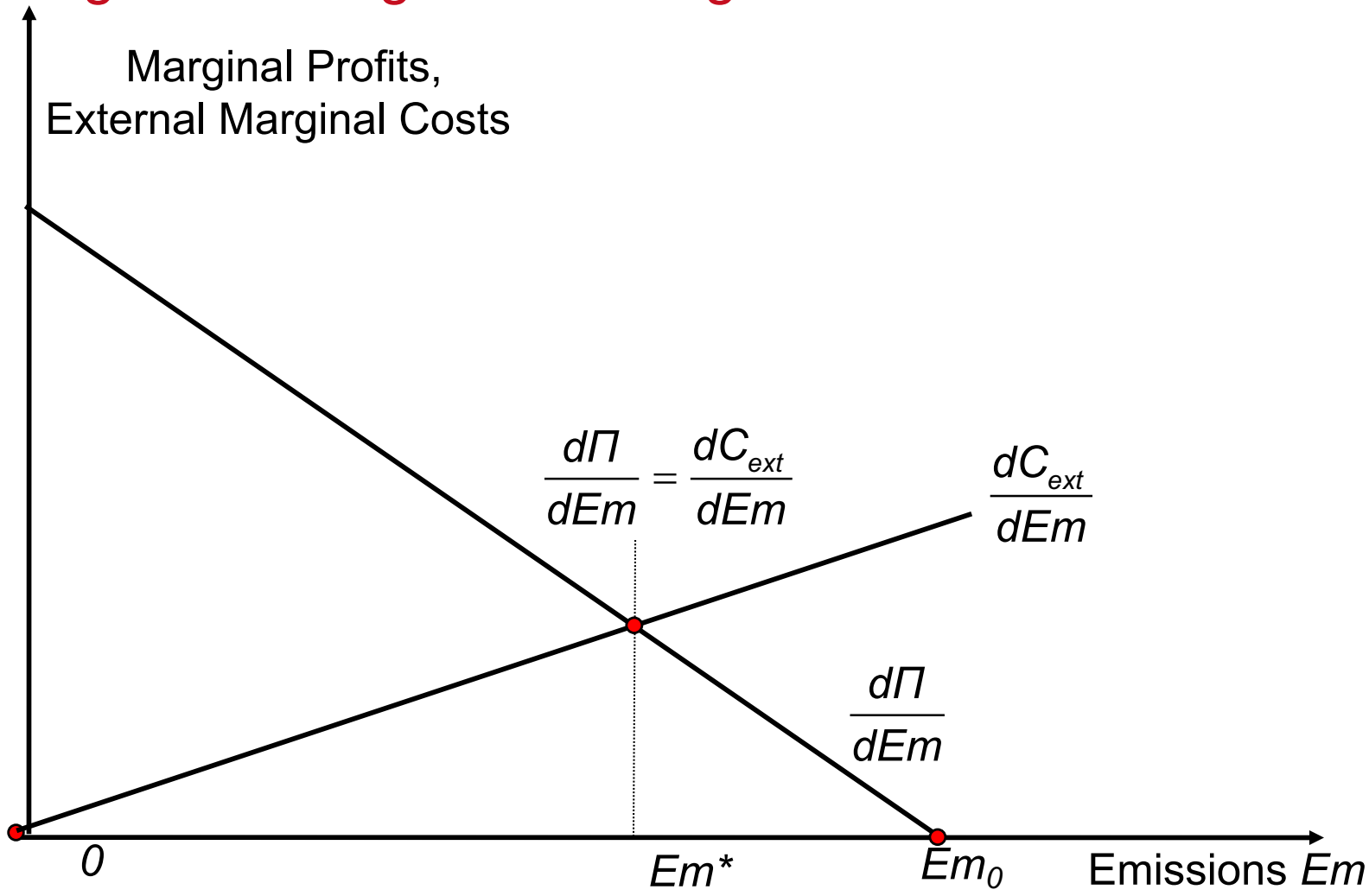
b) Why does the externatily of GHG emissions lead to insufficient energy markets?

c) Which policy instruments can correct this market failure in energy markets?

Optimal Emmision Levels



Marginal Damages and Marginal Abatement Costs



Task 1) External costs and internalisation

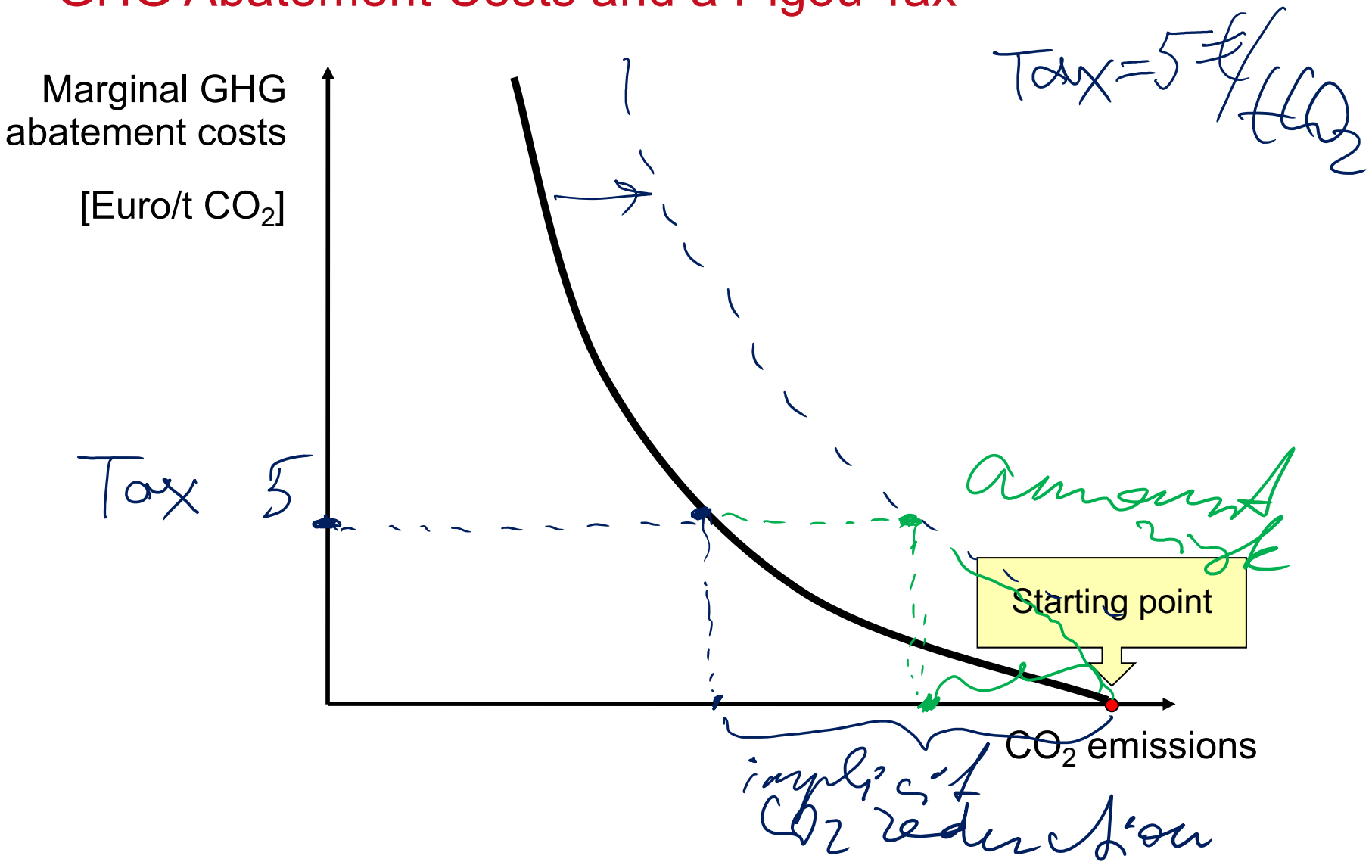
a) Explain the term externality in the context of GHG emissions.

b) Why does the externatily of GHG emissions lead to insufficient energy markets?

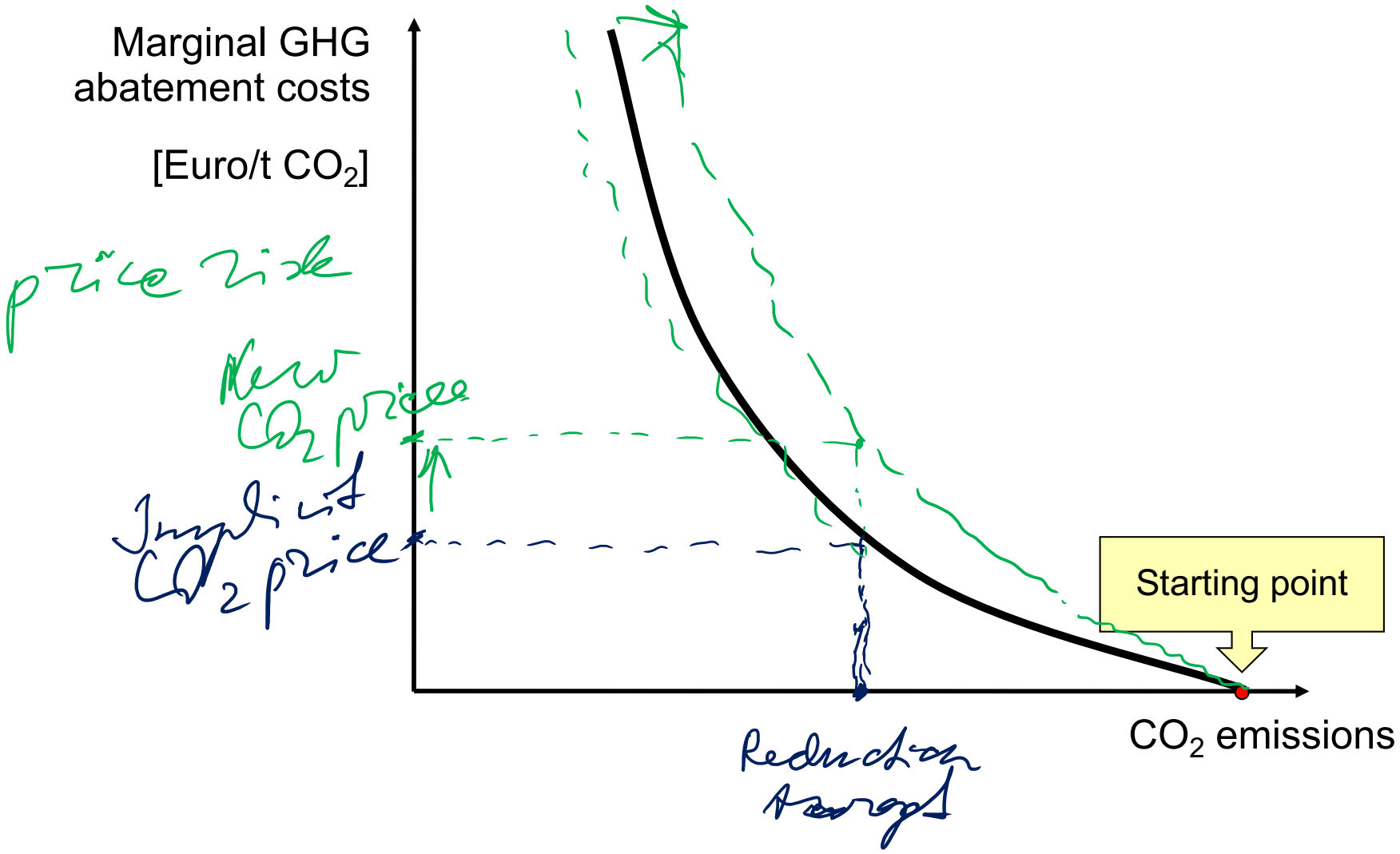
c) Which policy instruments can correct this market failure in energy markets?

d) Explain the quantity risk and price risk in context of these policy instruments.

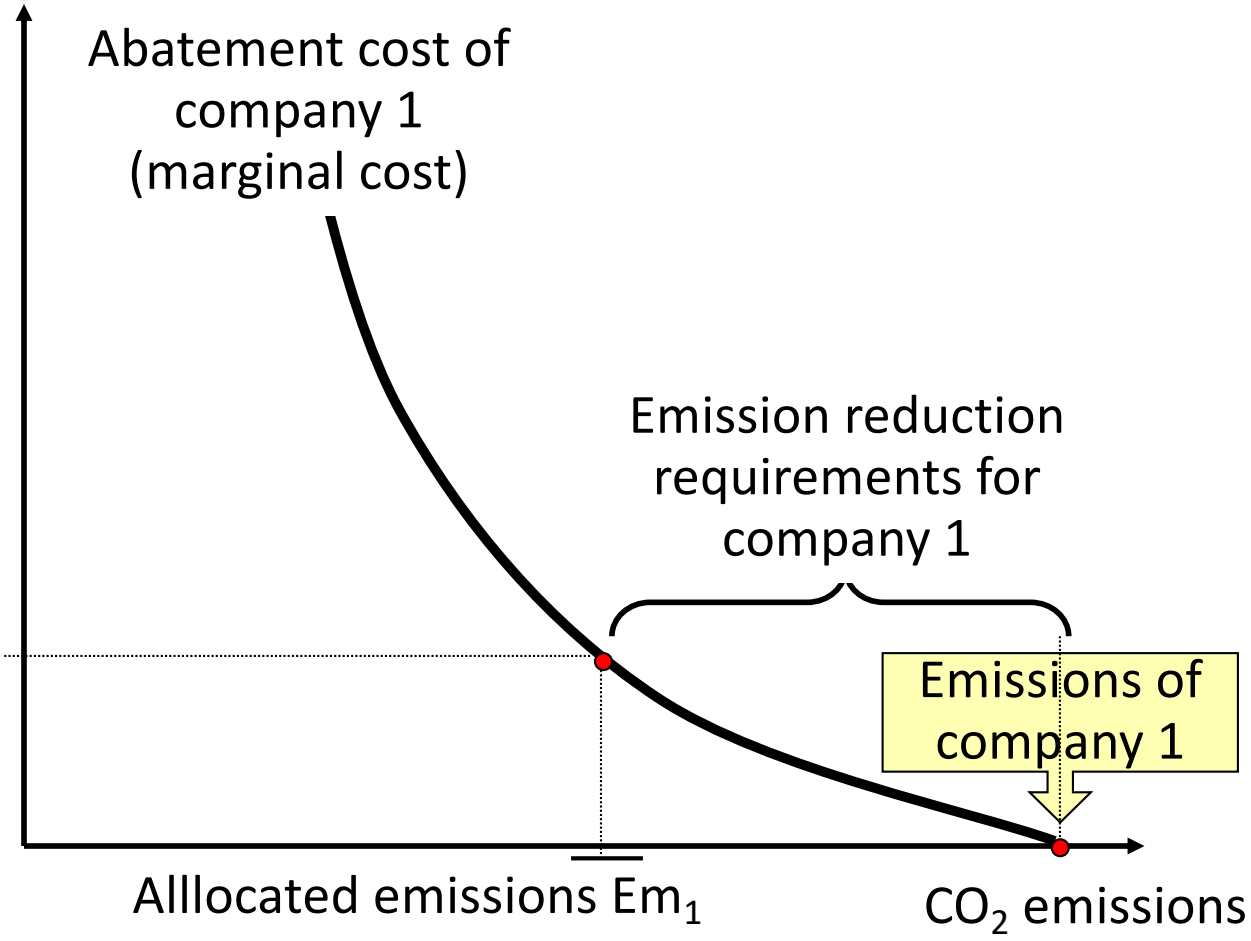
GHG Abatement Costs and a Pigou Tax



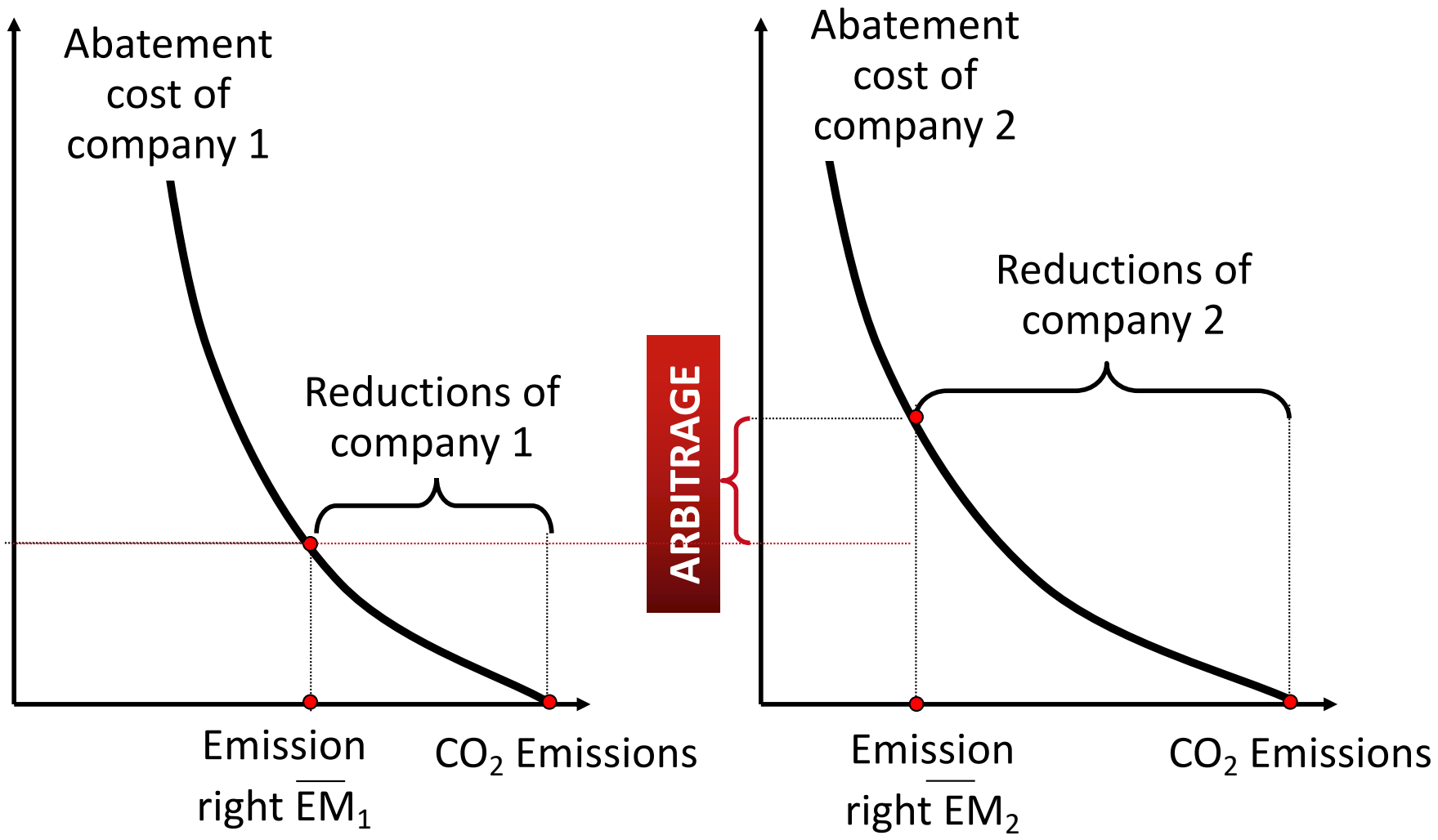
GHG Abatement Costs under Cap and Trade



Emission Allowances and Abatement Cost



Trade of Emission Allowances



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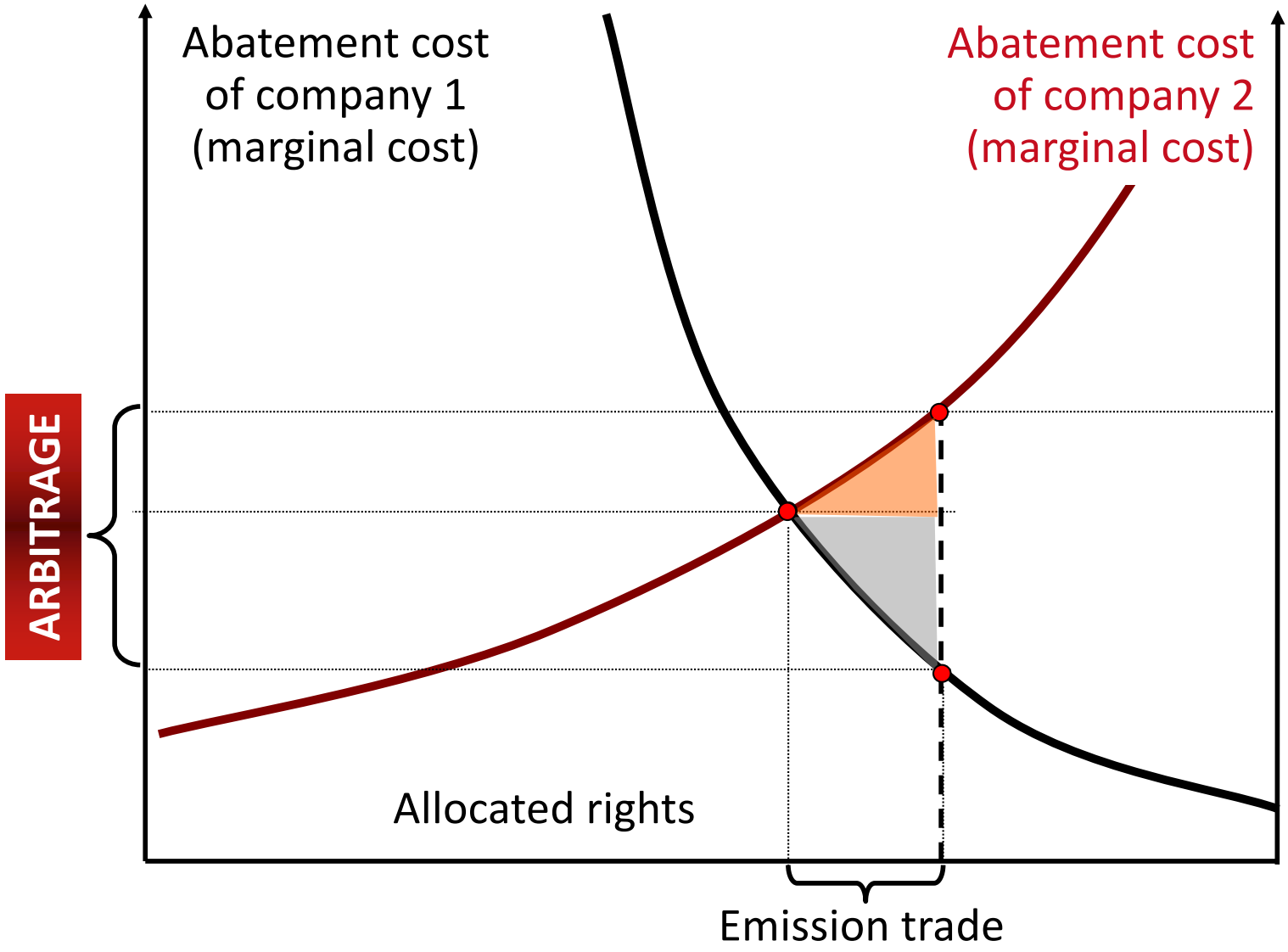

Trade of Emission Allowances

Effects of the trade:

- The given emissions target can be attained at a lower cost.
- At a given cost, a more ambitious emissions target can be achieved.

Designing Emissions Trading System

Trading period length:

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

Allocation of emissions allowances:

- Grandfathering – free allocation → windfall profits

  CO_2 prices are opportunity costs of power plant operators

- Auctioning

  Government redistributes the auctioning revenues.

Exercise in „Energy Economics“
- Markets for CO_2 Emission Allowances

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Task 1) CO_2 Reduction in Lummerland

The island of Lummerland wants to reduce its CO_2-emissions by 100 000 tons per year. The industry on the small island consists basically of two main types: castle construction and production of steam engines. Both industries have different CO_2-reduction goals with different abatement costs.

Industry A: Castle construction (incl. energy-intensive cement production)

CO_2-reduction goal: **40 000 tons per year**

CO_2-abatement costs per year:

$\boldsymbol{f_A(x) = 0.02x^2 + 0.002x^3}$

x: CO_2−amount per year [1000 t/a]

$f_A(x)$: abatement costs per year [1000 €/a]

Industry B: Production of steam engines (incl. energy-intensive steel melting)

CO_2-reduction goal: **60 000 tons per year**

CO_2-abatement costs per year:

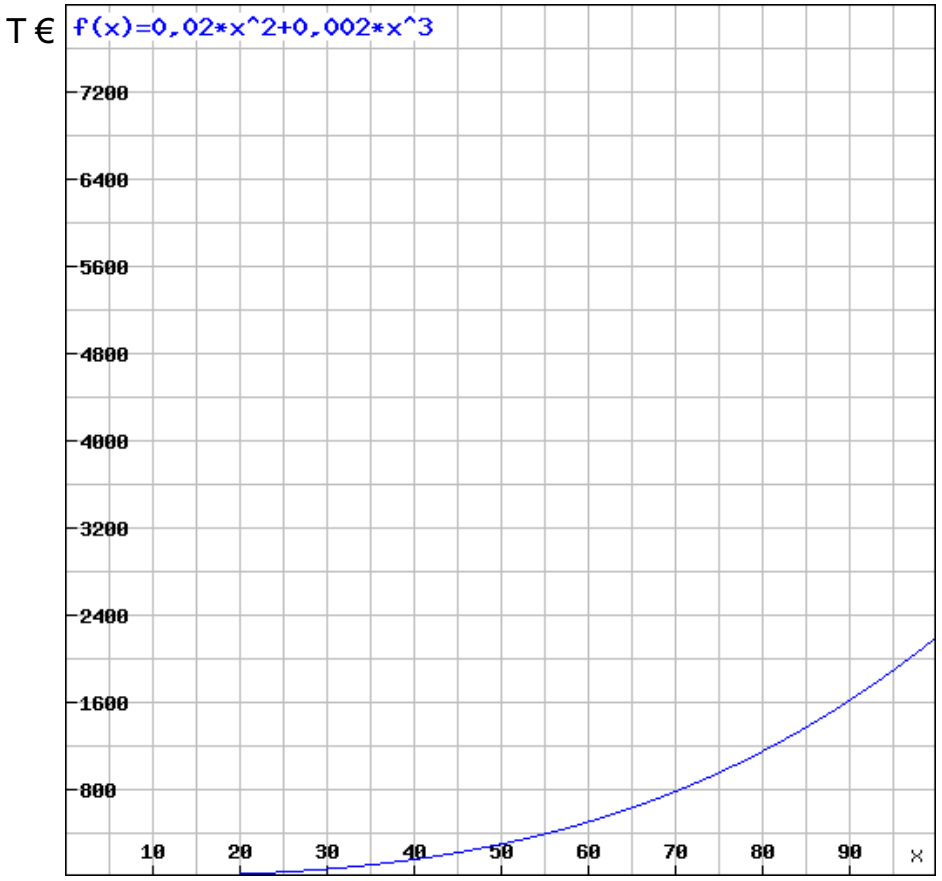
$\boldsymbol{f_B(x) = 5x + 0.2x^2 + 0.003x^3}$

x: CO_2−amount per year [1000 t/a]

$f_A(x)$: abatement costs per year [1000 €/a]

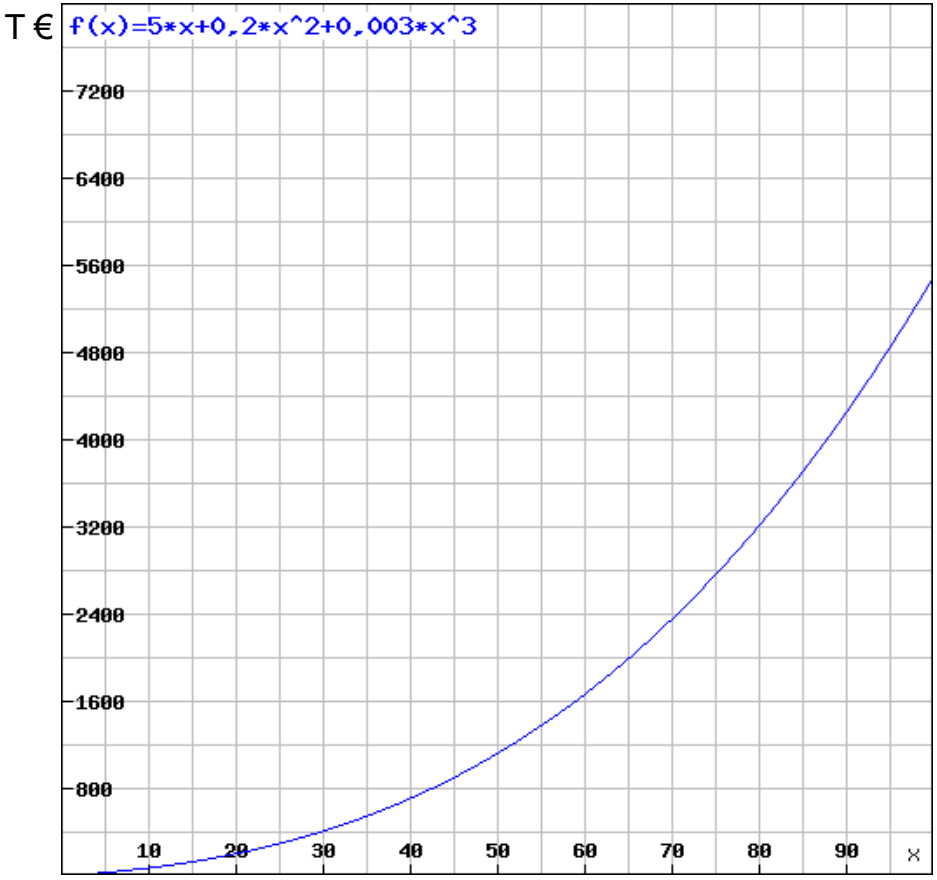
CO_2 Reduction in Lummerland

Industry A's annual CO_2 abatement costs



CO_2 reduction amount p.a. [1000 t CO_2]

Industry B's annual CO_2 abatement costs



CO_2 reduction amount p.a. [1000 t CO_2]

Industry A: Castle construction (which requires energy-intense cement production)

CO_2-reduction goal: **40 000 tons per year**

CO_2-abatement costs per year:

$$f_A(x) = 0.02x^2 + 0.002x^3$$

x: CO_2-amount per year [1000 t/a]

$f_A(x)$: abatement costs per year [1000 €/a]

CO_2 Reduction in Lummerland

a) What are the abatement costs per ton CO_2 for Industry A?

$$C_A = f_A(40) = 0{,}02 \cdot 40^2 + 0{,}002 \cdot 40^3$$

$$= 40^2 (0{,}02 + 0{,}002 \cdot 40)$$

$$= 1600 \cdot 0{,}1 = 160 \text{ (Tsd.)} \rightarrow 160.000 \text{ €/a}$$

$$C_A = \frac{160.000 \text{ €/a}}{40.000 \text{ t/a}} = 4 \text{ €/t}CO_2$$

Industry B: Production of steam engines (with high energy consumption for steel melting)

CO_2-reduction goal: **60 000 tons per year**

CO_2-abatement costs per year:

$f_B(x) = 5x + 0.2x^2 + 0.003x^3$

x: CO_2-amount per year [1000 t/a]

$f_A(x)$: abatement costs per year [1000 €/a]

CO_2 Reduction in Lummerland

b) What are the abatement costs per ton CO_2 for Industry B?

$C_B = f_B(60) = 5 \cdot 60 + 0{,}2 \cdot 60^2 + 0{,}003 \cdot 60^3 =$

$\rightarrow 1668000 \frac{€}{a}$

$C_B = \frac{1668000 €/a}{60.000 t/a} = 27{,}8 € / t CO_2 a$

CO_2 Reduction in Lummerland

c) In order to lower the costs for CO2 abatement, the government of Lummerland introduces a new emissions trading mechanism. What is the theoretical volume traded?

Find the volume at which the marginal abatement costs of both industries are equal. Given functions are for annual abatement costs as a function of the annual amount of CO_2 reduction.

$$\frac{d f_A(x_1)}{d x_1} = \frac{d(0{,}02 x_1^2 + 0{,}002 x_1^3)}{d x_1} = 0{,}04 x_1 + 0{,}006 x_1^2$$

$$\frac{d f_B(x_2)}{d x_2} = \frac{d(5 x_2 + 0{,}2 x_2^2 + 0{,}003 x_2^3)}{d x_2} \rightarrow$$

$$= 5 + 0{,}4 x_2 + 0{,}009 x_2^2$$

$x_1 + x_2 = 100$

$x_2 = 100 - x_1$

Total required reduction for both industries is 100.000 tons.

$$\frac{df_A(x_1)}{dx_1} = \frac{df_B(100 - x_1)}{dx_1}$$

$$0{,}04 x_1 + 0{,}006 x_1^2 = 5 + 0{,}4(100 - x_1) + 0{,}009(100 - x_1)^2$$

$$x_1 = 66.123 \text{ t } CO_2$$

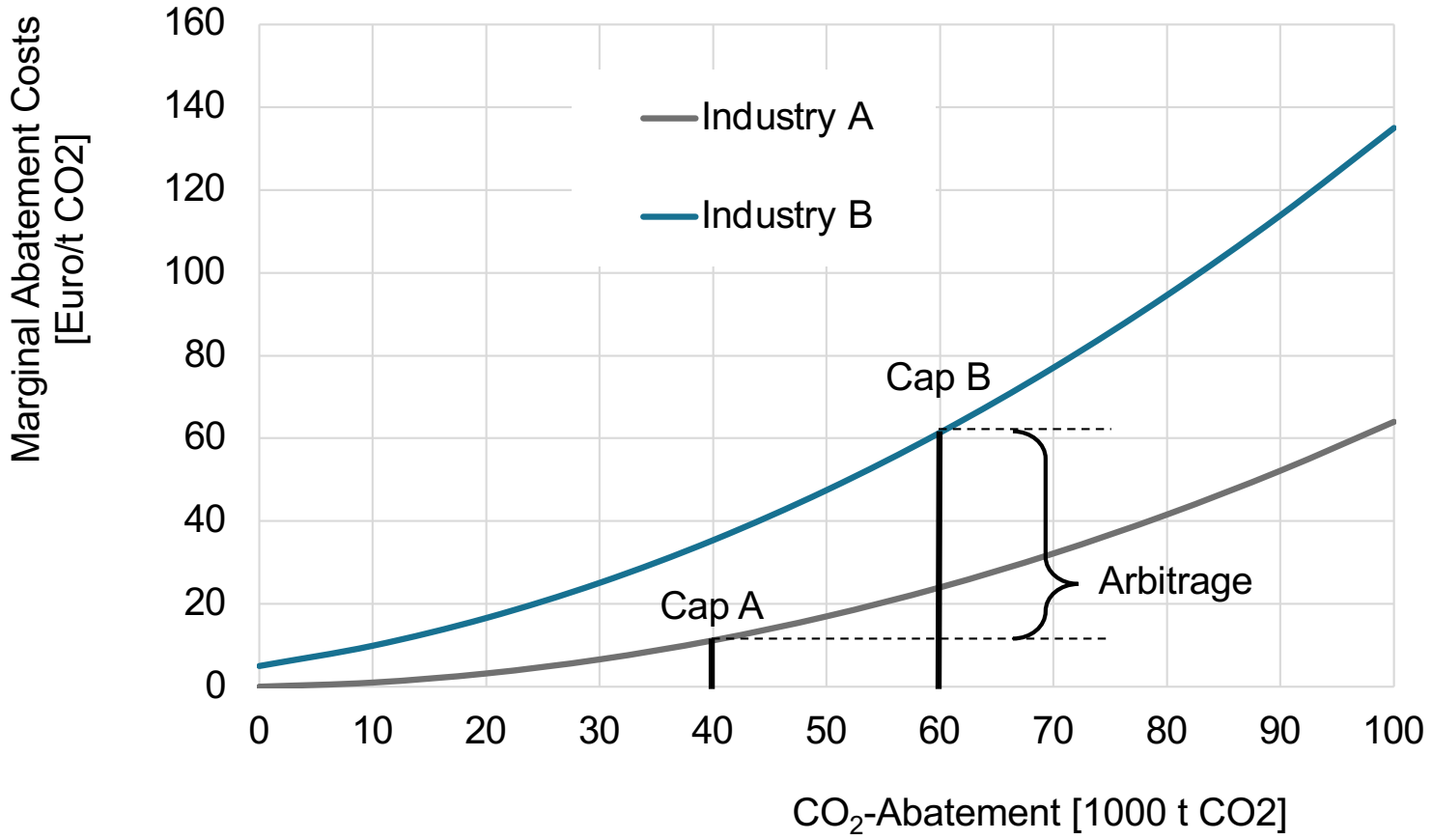
($x_2 = 680.547 > 100$; $0 \leq x_1 \leq 100$)

Second root does not meet the condition (just a matematical solution).

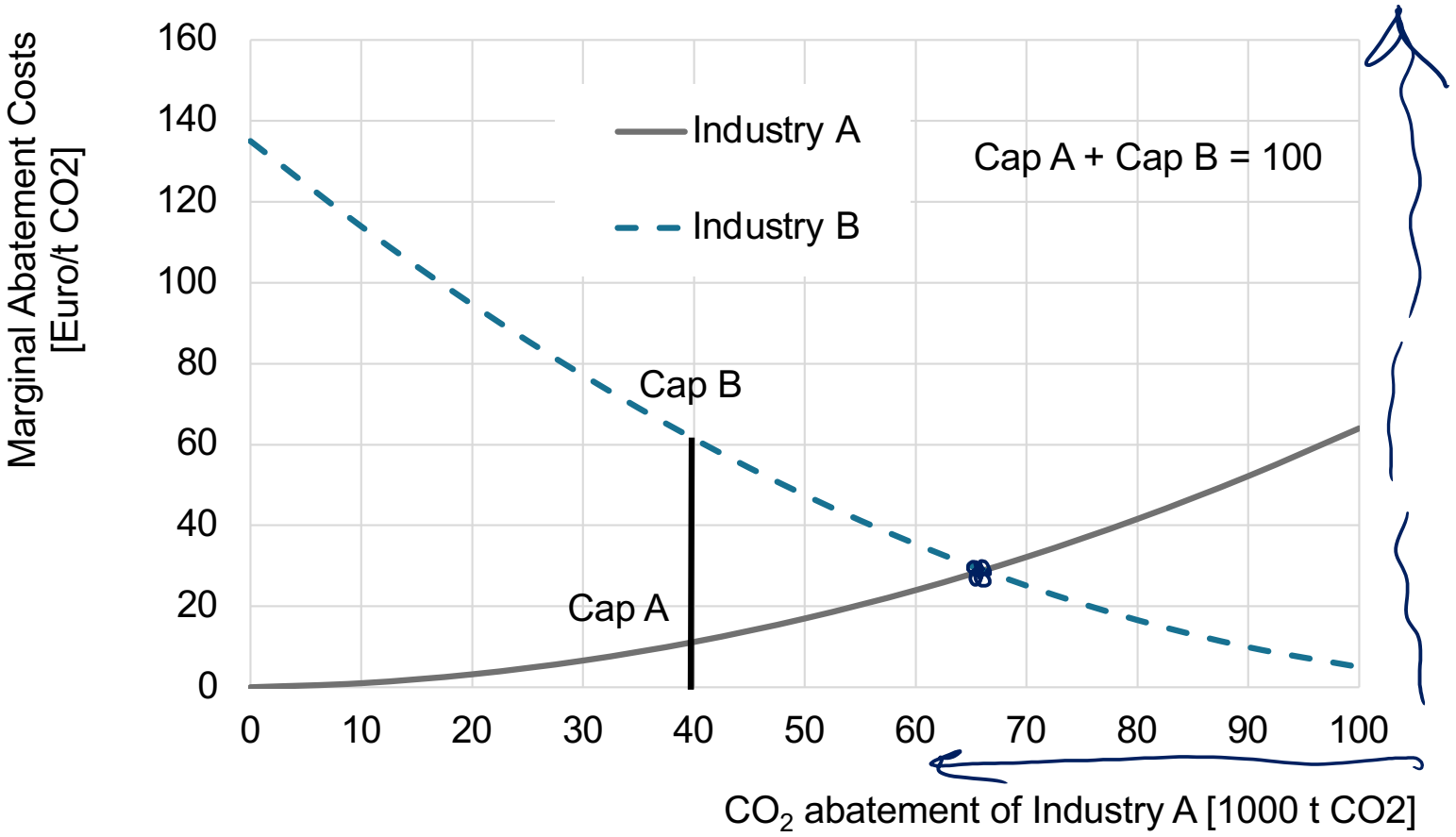
Trading volume $= (66.123 - 40.000)\,t = 26.123\,t$

Under perfect market conditions 66.123 t CO_2 will be abated by industry A.
The difference between industry A's abated amount and its reduction target will be traded.

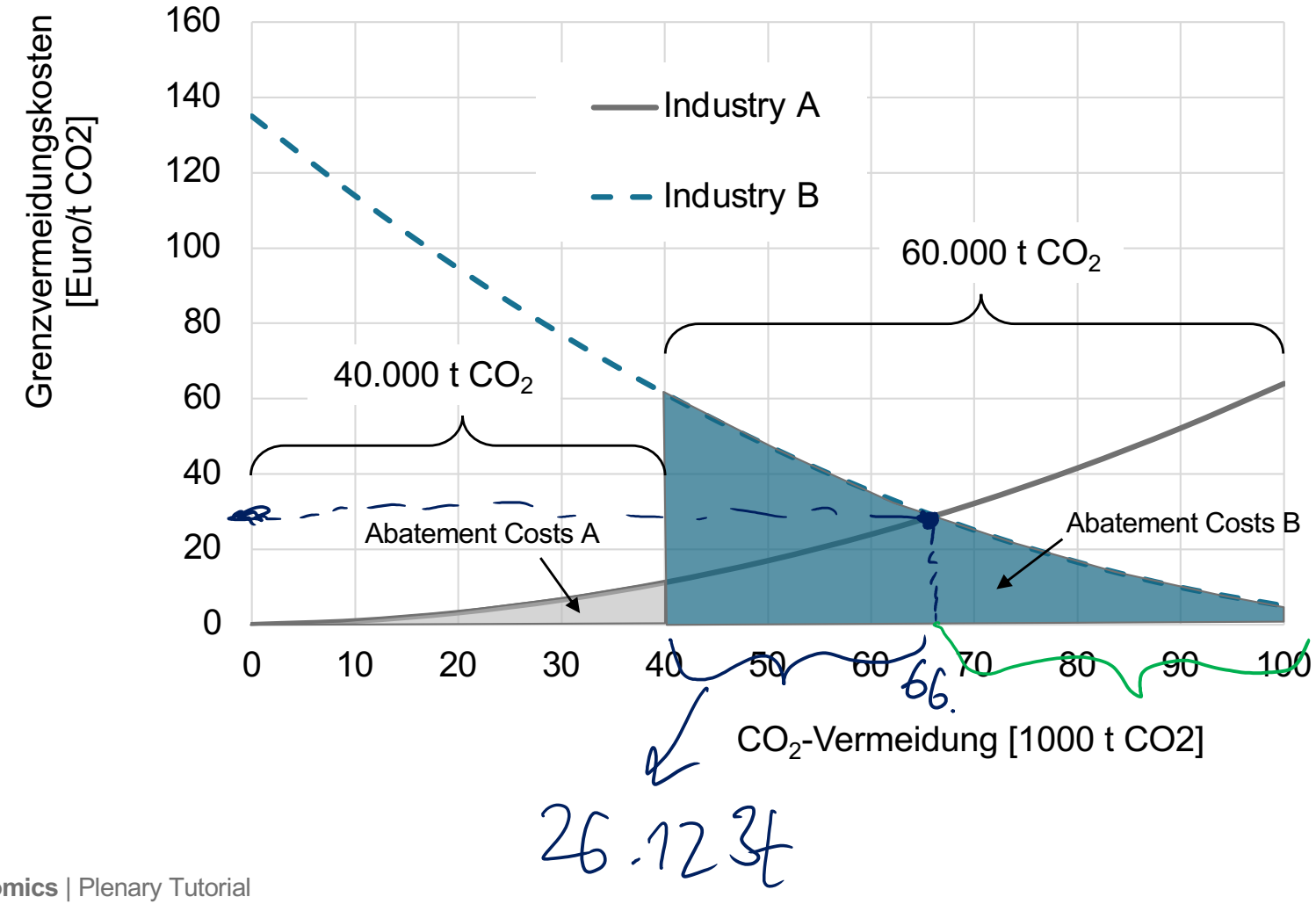
CO_2 Reduction in Lummerland



CO_2 Reduction in Lummerland



CO_2 Reduction in Lummerland



CO_2 Reduction in Lummerland

d) What is the system price in the emissions trading system?

$$\frac{d f_A(66.123)}{dx} = 0{,}04(66.123) + 0{,}006 \cdot (66.123)^2 =$$

$$= 28{,}88 \; €/t \cdot CO_2$$

CO_2 Reduction in Lummerland

e) What are the new overall abatement costs per ton CO2 for Industry B?

traded volume 26.123 t CO_2/a

own reductions (60.000 t CO_2 − 26.123 t CO_2) = 33.877

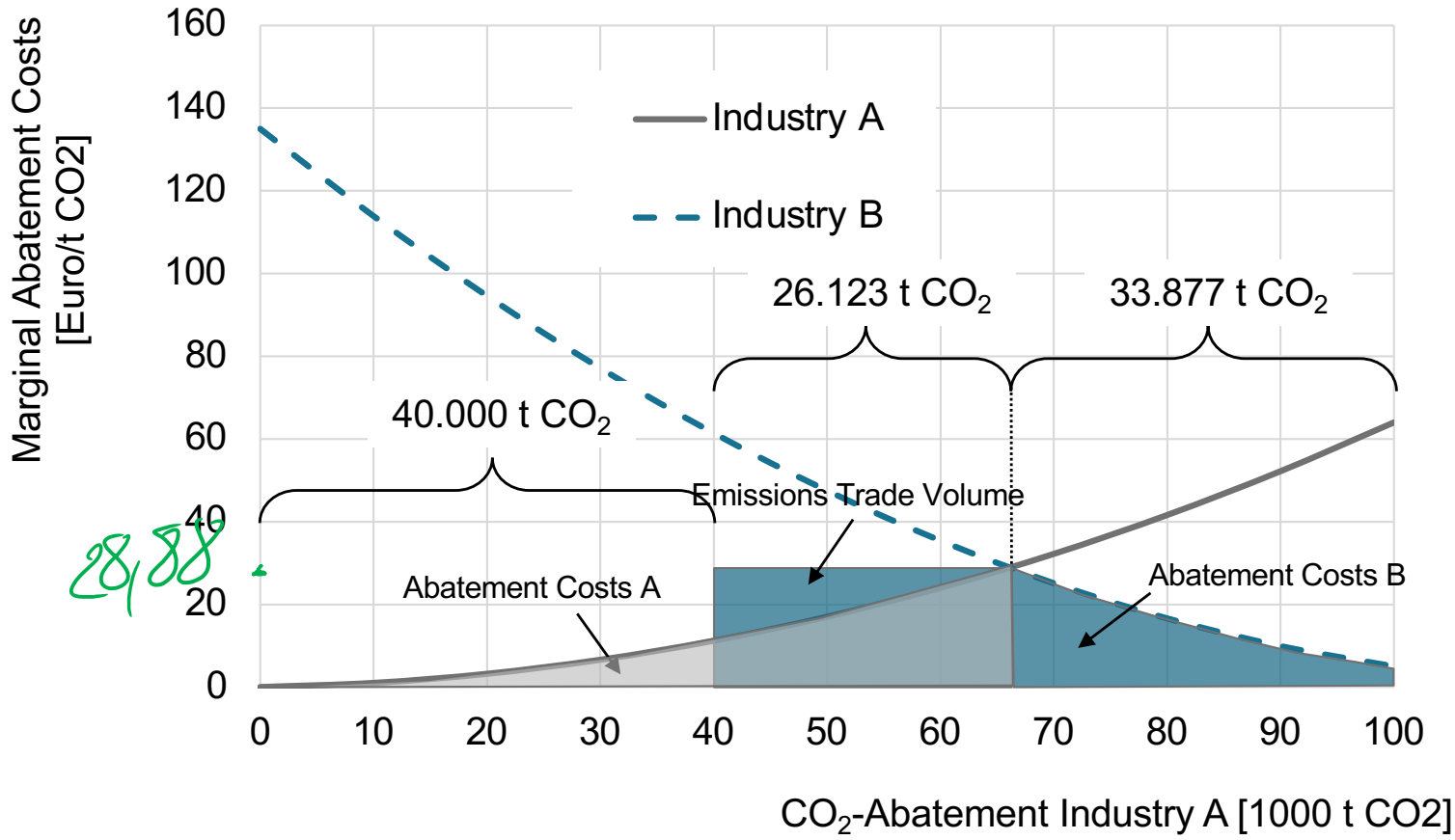
C_B = 26.123 t CO_2 · 28,18 €/t CO_2 +

+ (5 · 33.877 + 0,2 · 33.877^2 + 0,003 · 33877^3) · 1000 =

= 1 269 984,4 €/a

average C_B $\frac{1\,269\,984{,}4\ €/a}{60.000\ t\,CO_2}$ = 21,17 €/t CO_2 · a

CO_2 Reduction in Lummerland



EU Emissions Trading System

28 EU member states + Norway, Island and Liechtenstein

40% of EU emissions

4% of the world's GHG emissions (approx. 2 billion GHG as of 2014)

EU Emissions Trading System

A quantitative limit is put on the aggregate annual amount of emissions for all plants participating in ETS (cap).

- a single EU-wide cap
- declining by 1,74% annually

Emission allowances are issued in an amount corresponding to the cap.

EUA (EU Allowance): An EUA permits operators of an industry installation or electricity generation unit to emit 1 t of CO_2 under the EU emissions trading system.

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

Each regulated operator must surrender every year the amount of EUA corresponding to the amount of its emissions. (→ 100 €/t CO_2)

Trends in Emissions and Economic Activity

Source: Ellerman / Marcatonini / Zaklan (2016)

Conventional Economic Theory

EUA price = abatement cost of the last project that is necessary to meet the cap (marginal abatement cost)

For understanding the EUA price, the distribution of the marginal abatement cost for the “Kyoto period” has to be quantified.

GHG Abatement Costs [Source: McKinsey&Co. 2007]