Introduction to Environmental Economics and Sustanaible Growth

The economics of the European Union Emission Trading System (EU-ETS)

1) Global warming in a snapshot

2) Quantity regulation: static approach

3) Intertemporal regulation

4) Genesis of the EU-ETS

5) Quantity regulation: Intertemporal trading

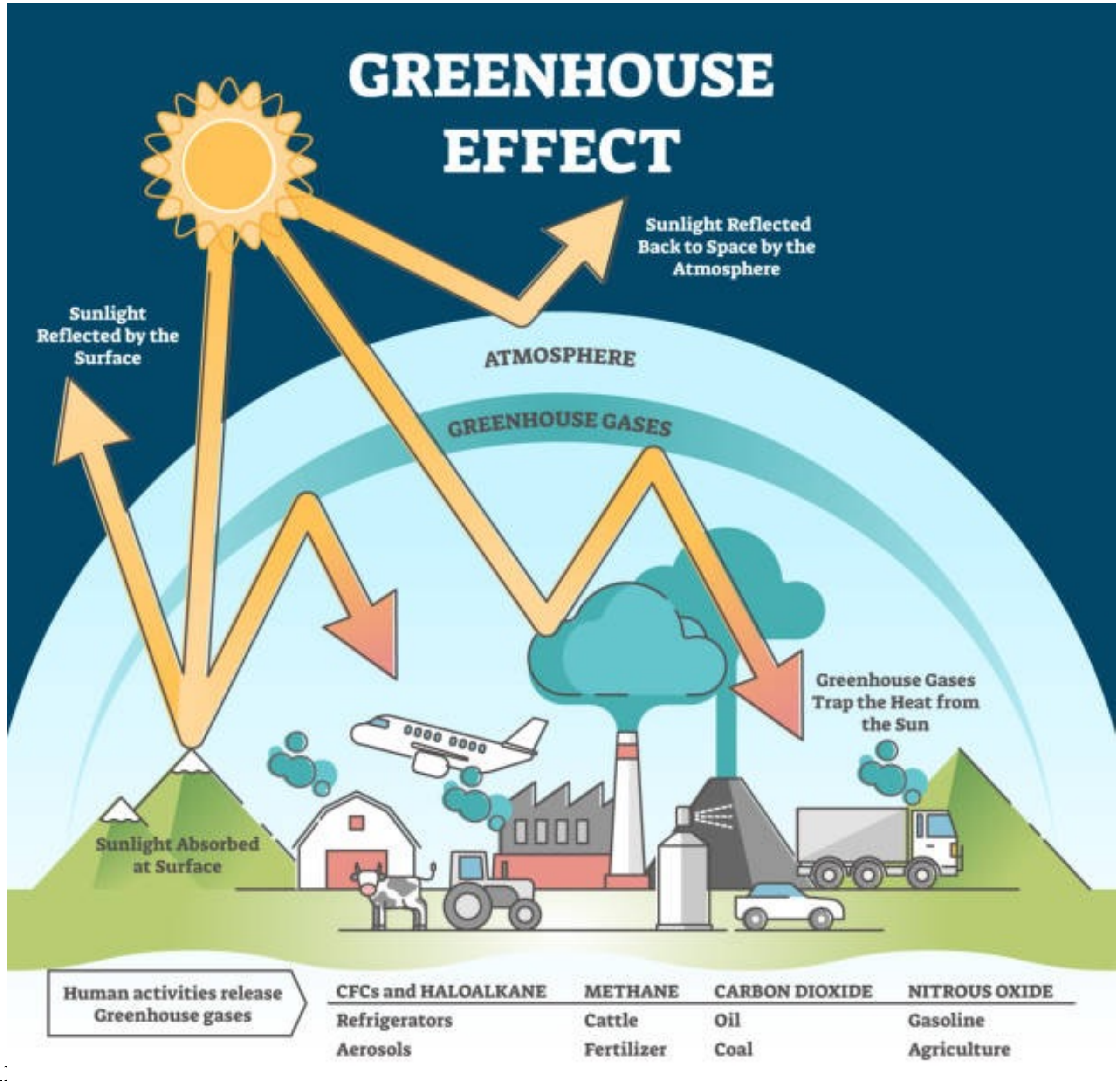
6) The EU-ETS at almost 20 years old

7) Beyond the EU-ETS

1) Global warming in a snapshot

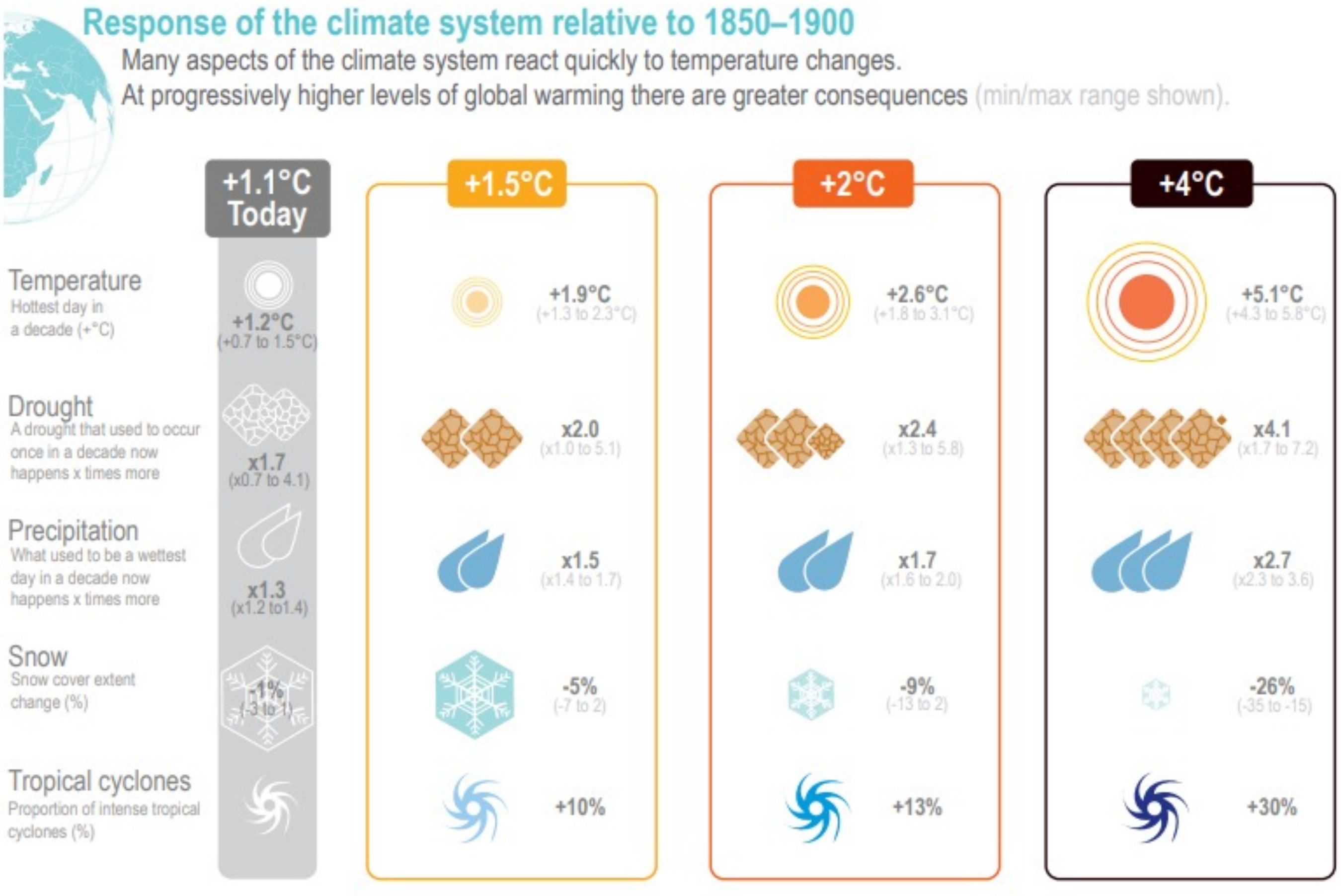
- Climate economics are based on the identification of climate change as the result of economic activity
  - Warning on global warming was given by the network of scientists created in 1988 under the dual supervision of the World Meteorological Organization and the United Nations Environment Program
  - Global warming is attributed to the increase in anthropogenic greenhouse gas emissions.
  - This pollution is said to be global because regardless of where greenhouse gases are emitted in the world, they contribute in the same way to global warming.
    - This is the reason why an international coordination of policies to challenge global warming is considered as crucial
      - But is still quite "in progress"
    - international coordination is not, however, incompatible with the leadership role played by certain countries or groups of countries
      - May be explained with a cooperative game theory approach
    - The European Union has notably taken the lead through the inception of the oldest and largest ETS dedicated to greenhouse gas emissions.

1) Global warming in a snapshot



1) Global warming in a snapshot

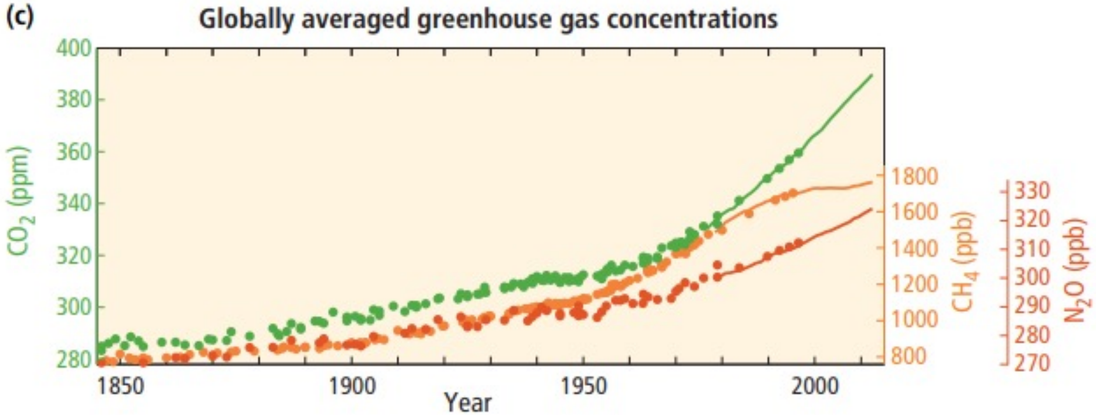
- The consequences of global warming are multifaceted

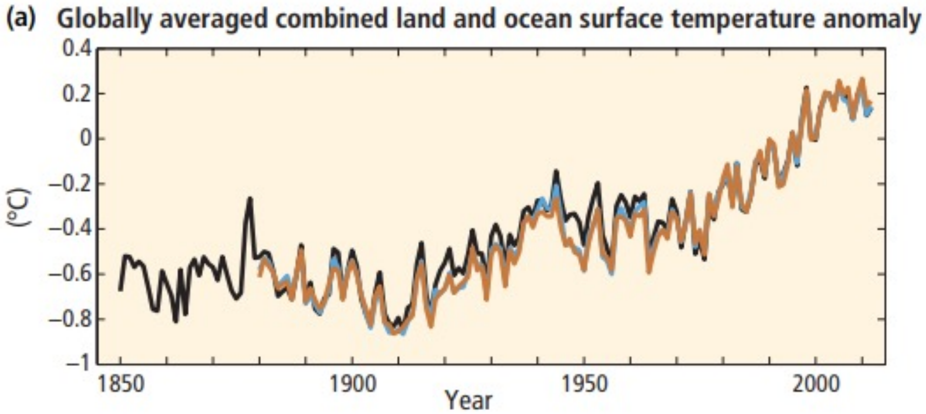


Source: IPCC « Climate Change 2021, The Physical Science Basis »

1) Global warming in a snapshot

- The concentration of greenhouse gases in the atmosphere has increased since the end of the 19th century
- In parallel, the average temperatures on the surface of the globe have also increased.





Source: IPCC
« Climate Change 2014, Synthesis Report »

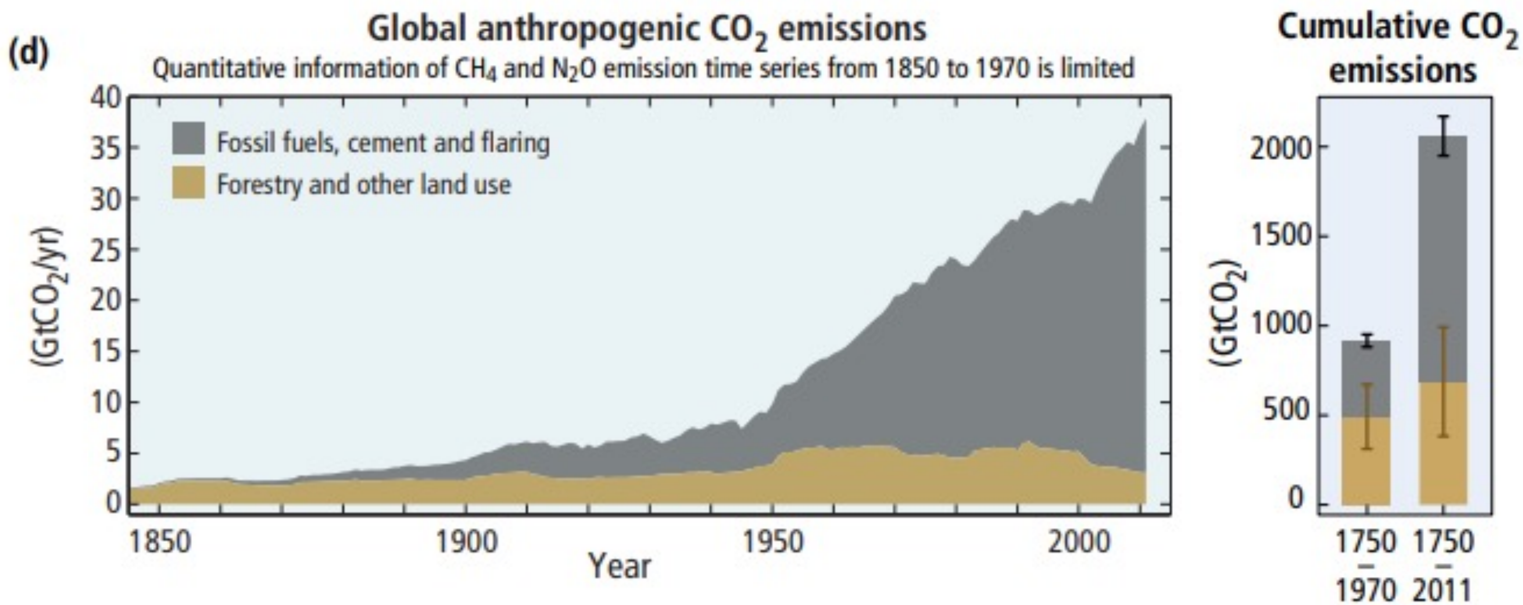
[AR5 Synthesis Report - Climate Change 2014 (ipcc.ch)](www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf)

The full synthesis of the 6th Assessment Report will be released in March 2023
The volume on the physical science basis is already available

https://www.ipcc.ch/report/ar6/wg1/

1) Global warming in a snapshot

- Human activity has contributed to the emission and then to the concentration of greenhouse gases in the atmosphere
  - These emissions are said to be "anthropogenic" by contrast to natural emissions
  - One of these main gases (but not the only one) is carbon dioxide, whose anthropogenic emissions have been linked to the use of fossil fuels since the beginnings of the industrial revolution.



Source: IPCC « Climate Change 2014, Synthesis Report »

1) Global warming in a snapshot

- Anthropogenic emissions associated with an activity can be direct or indirect

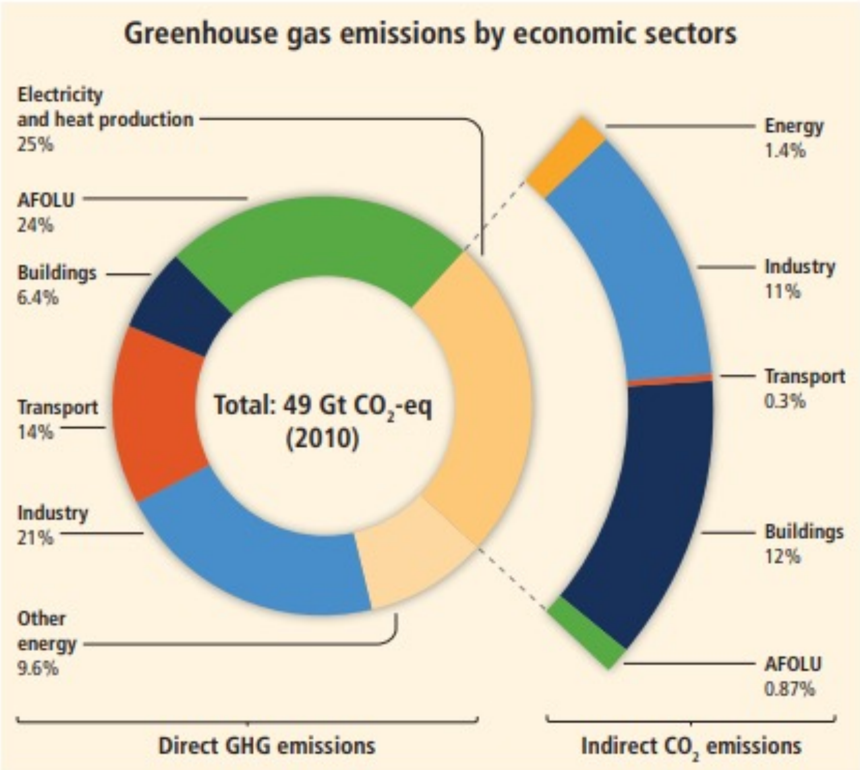
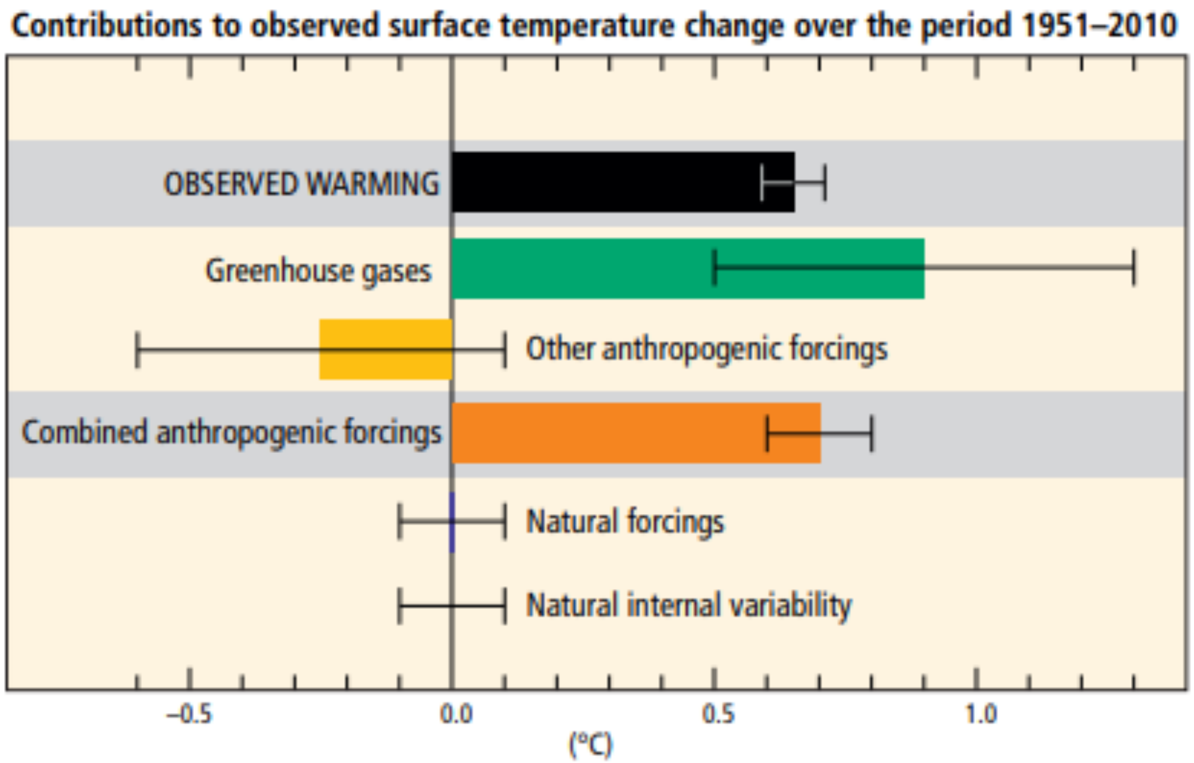


Figure 1.7 | Total anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) from economic sectors in 2010. The circle shows the shares of direct GHG emissions (in % of total anthropogenic GHG emissions) from five economic sectors in 2010. The pull-out shows how shares of indirect CO_2 emissions (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. 'Other energy' refers to all GHG emission sources in the energy sector as defined in WGIII Annex II, other than electricity and heat production *{WGIII Annex II.9.1}*. The emission data on agriculture, forestry and other land use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the sub-sectors of forestry and other land use (FOLU) as described in Chapter 11 of the WGIII report. Emissions are converted into CO_2-equivalents based on 100-year Global Warming Potential (GWP_{100}), taken from the IPCC Second Assessment Report (SAR). Sector definitions are provided in WGIII Annex II.9. *{WGIII Figure SPM.2}*

Source: IPCC « Climate Change 2014, Synthesis Report »

1) Global warming in a snapshot

- Scientific studies establish a link between anthropogenic emissions and global warming

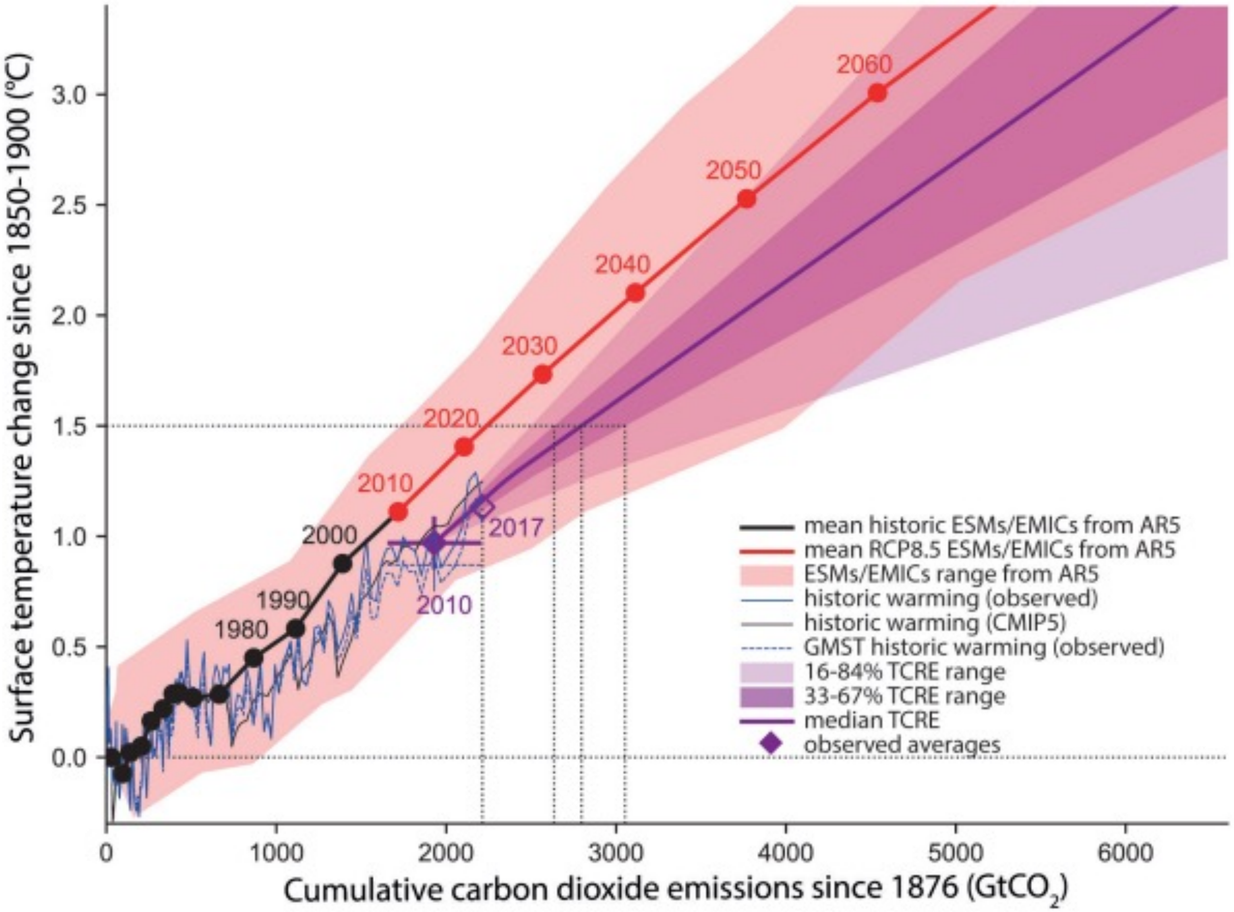


Source: IPCC « Climate Change 2014, Synthesis Report »

1) Global warming in a snapshot

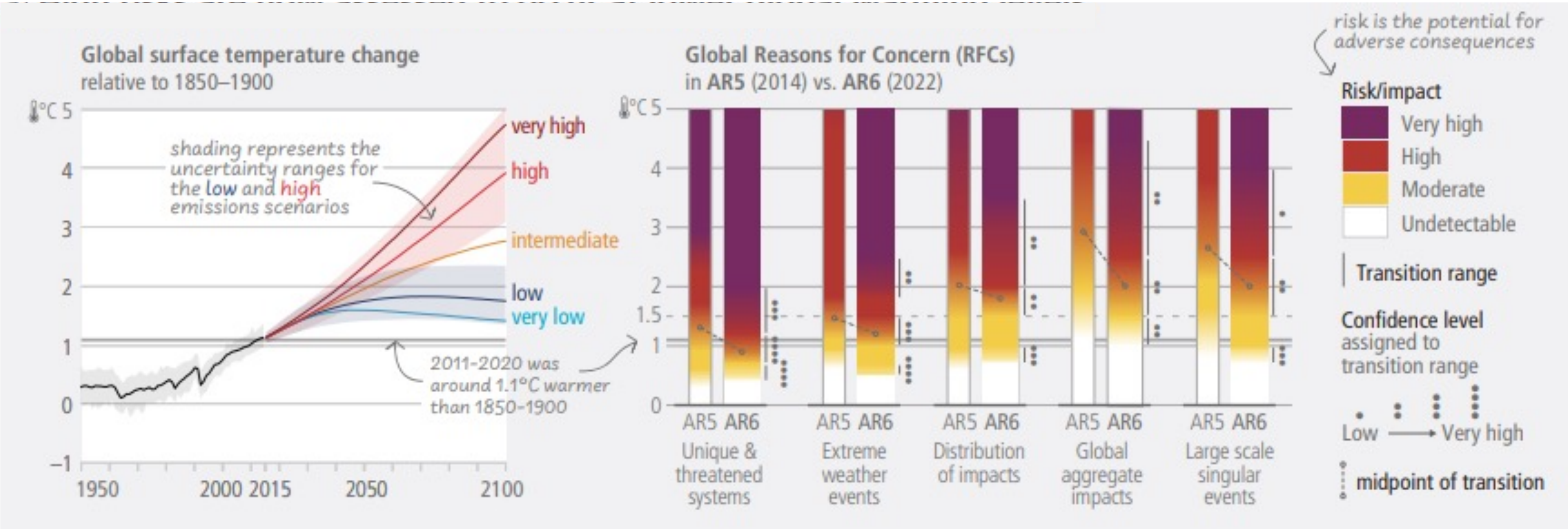
- Global warming is highly correlated with GHG cumulative emissions

Source: IPCC, 2018: Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 616 pp. https://doi.org/10.1017/9781009157940.



1) Global warming in a snapshot

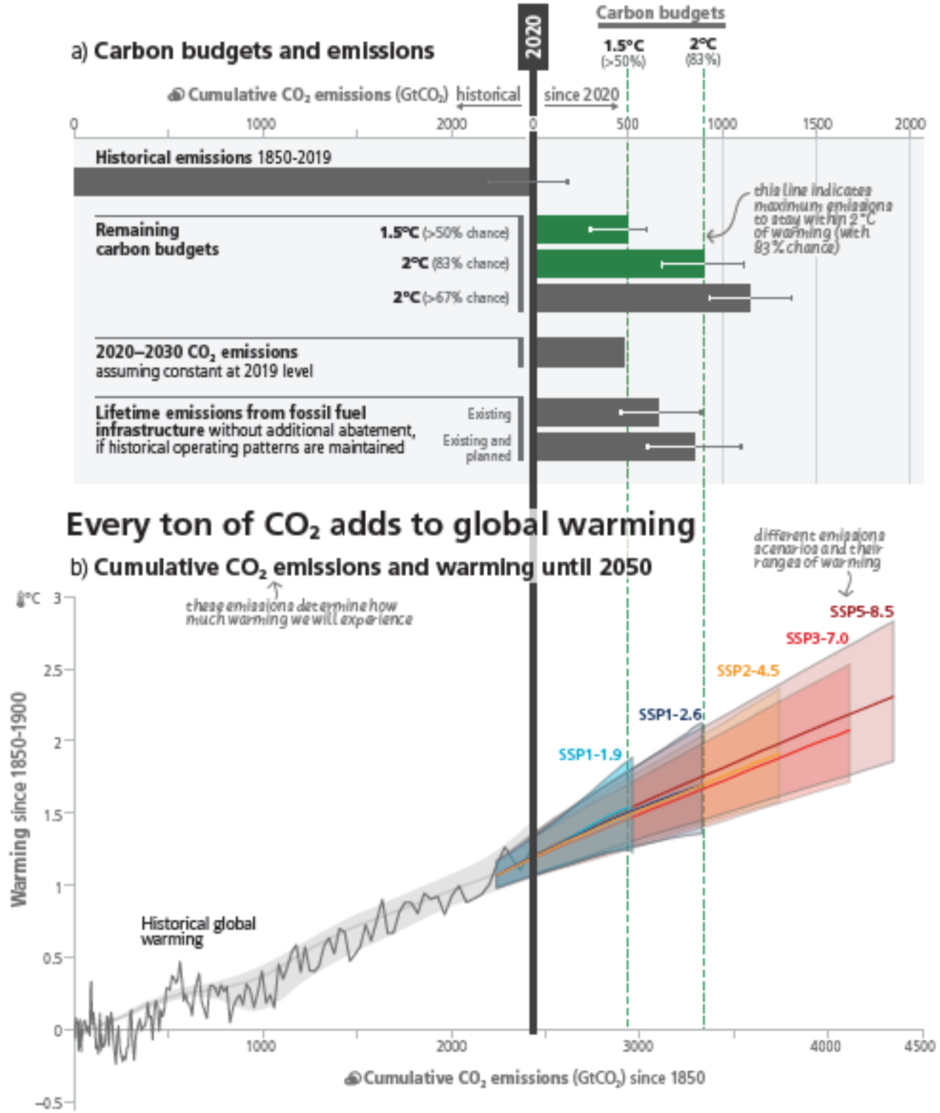
- Adverse consequences become more likely above **1.5°C or 2.0°C** of global warming
  - These levels of global warming are considered as **tipping points** above which drastic changes and damages would occur



Source: IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.

1) Global warming in a snapshot

- From these tipping points in terms of global warming it is possible to deduce how much GHG emissions we can still emit
  - This is the **carbon budget approach**
  - example for a 1.5°C and 2.0°C threshold (IPCC AR6 and updates)



Source: IPCC « Climate Change 2023, Synthesis Report » Figure 3,5, page 83

1) Global warming in a snapshot

2) Quantity regulation: static approach

3) Intertemporal regulation

4) Genesis of the EU-ETS

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6) The EU-ETS at almost 20 years old

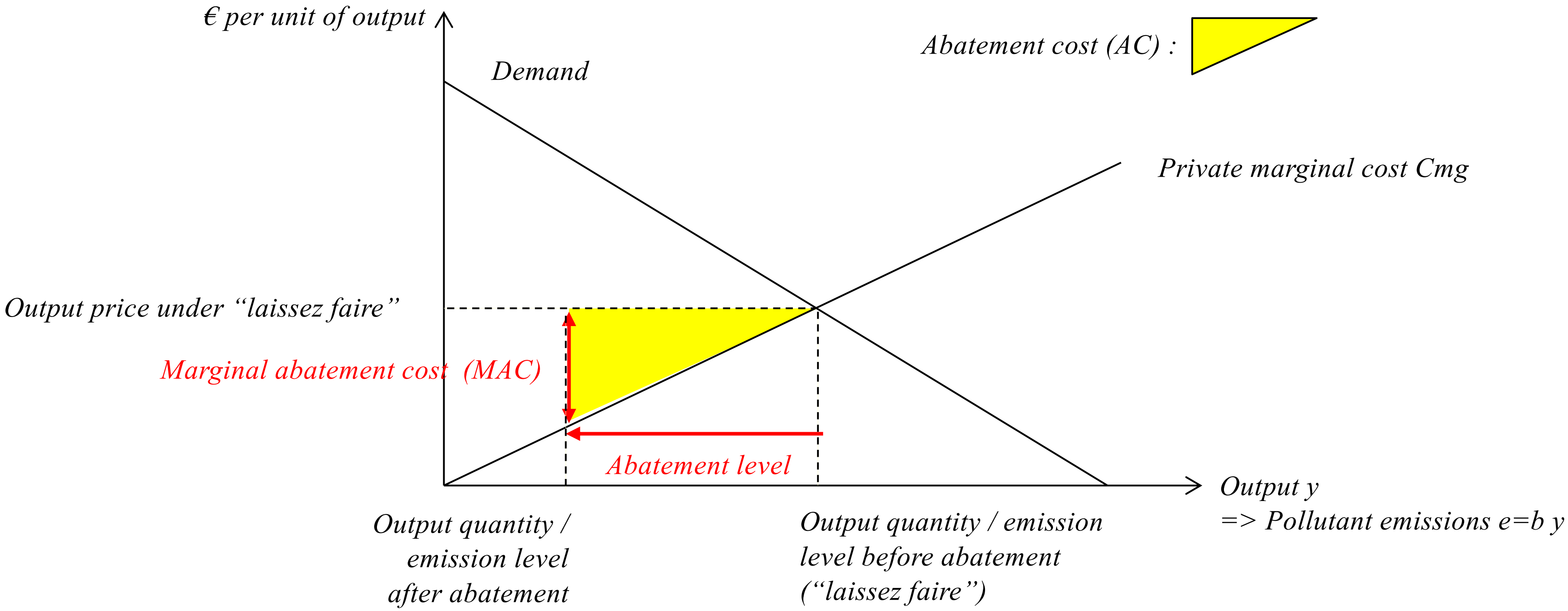
7) Beyond the EU-ETS

2) Quantity regulation: static approach

- A first step to analyze climate economics is to consider GhG emissions as a pollution of global commons and to adapt standard/static regulation instruments
  - Carbon tax in the spirit of Pigou (price regulation)
    - Implemented in several countries, sometimes in complement to an Emission Trading System (ETS)
    - See e.g.
      - Criqui, P., Jaccard, M. and T. Sterner, (2019). "Carbon Taxation: A Tale of Three Countries", *Sustainability*, Vol. 11, pp. 1-21.
  - Emission Trading System (quantity regulation)
    - Among which the EU-ETS is the older and wider in terms of regulated emissions (at least until the inception of the national wide Chinese ETS in July 2021).
  - There is not a clear cut advantage of one compared to the other
    - For a more in depth discussion see e.g.
      - Goulder, L. H. and A. R. Schein, (2013). "Carbon Taxes versus Cap and Trade: A Critical Review", *Climate Change Economics*, Vol. 4, n°3, pp. 1-28.
  - Thereafter, we focus on an ETS system, which is the basis of the EU climate policy

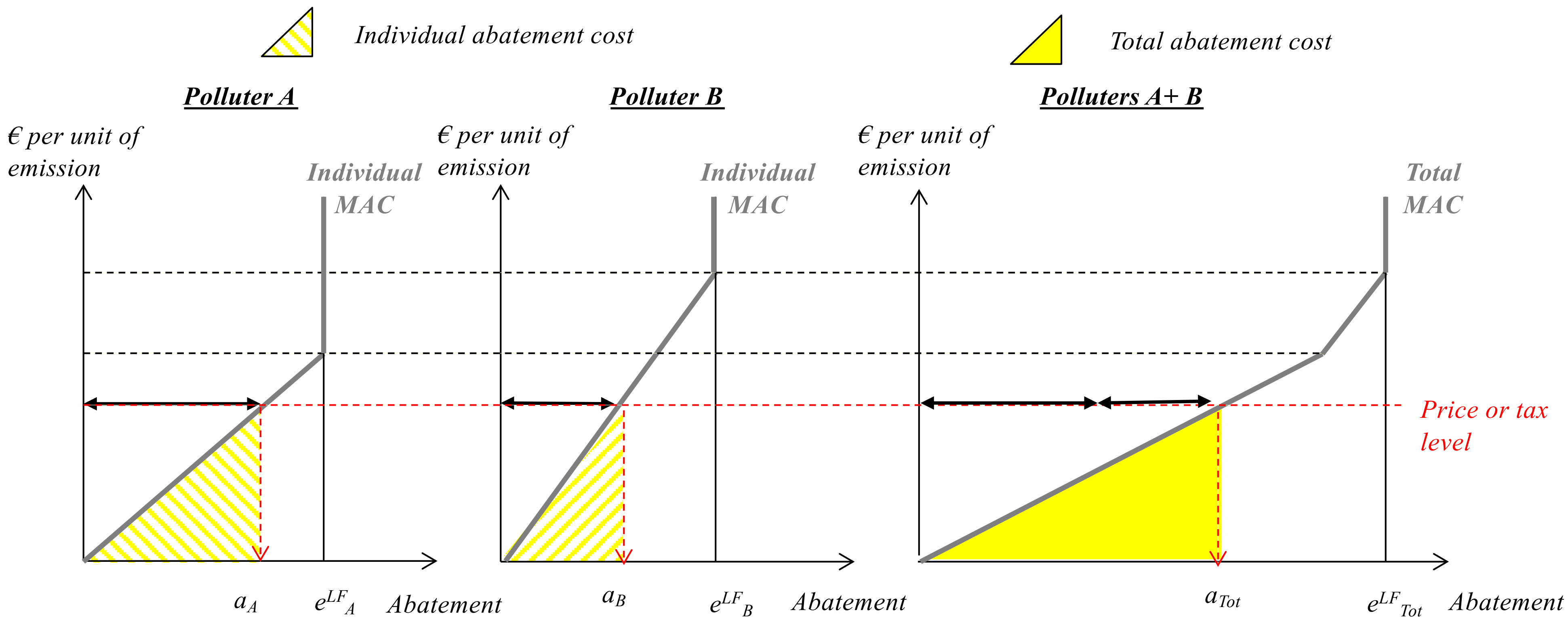
2) Quantity regulation: static approach

- Prior discussing the quantity regulation of polluting emissions it is worthwhile discussing the concept of Marginal Abatement Cost (MAC)
  - The « laissez faire » situation is used as a starting point, and **the marginal abatement cost is defined as the marginal profit of polluting firms forgone to reduce/abate emissions by one unit more**



2) Quantity regulation: static approach

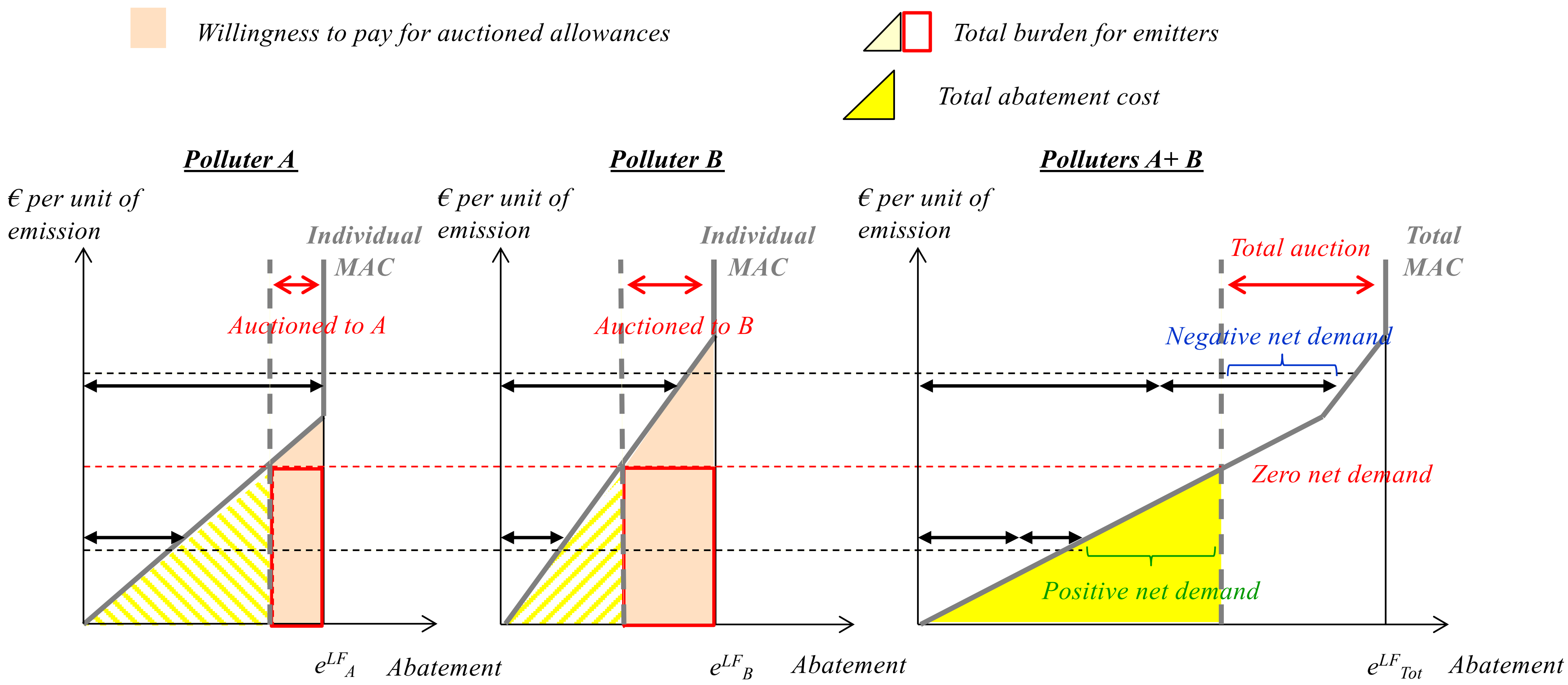
- The aggregate marginal abatement cost is the "horizontal sum" of individual MACs
  - The aggregated MAC is used to determine the optimal tax or cap but it hides heterogeneity across individual MACs, which requires flexibility in the regulation



2) Quantity regulation: static approach

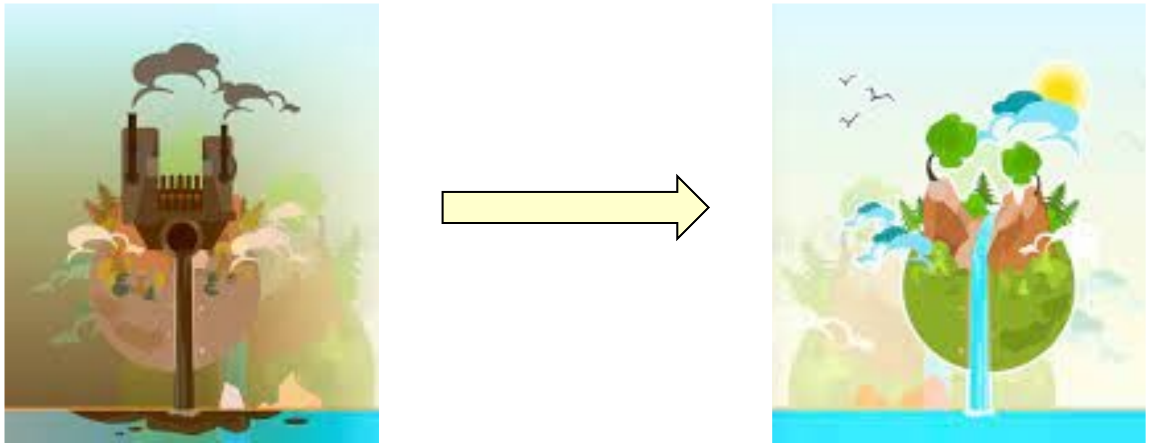
- Quantity regulation thanks to an **<u>ETS with auctionning of allowances</u>**
- A cap is first fixed for total emissions, the price signal results from the auctioning of allowances
  - In case of exogenous shocks on baseline emissions, the total cap is always just reached but the price signal changes
    - This is neutral (at least in short term) for the environment…
    - … but detrimental in the long run as it can deter investments in clean technologies (by creating uncertainty on their rate of return)
- The burden of the system is quite similar to that with a tax and auction revenues may also be recycled in different ways (=> possible **double dividend**)
  - This burden may be alleviated by combining with free allocation of allowances up to a benchmark and auctioning only the allowances in excess of the benchmark
  - Quite similar to a tax rebate up to a benchmark level of emissions => the burden of the system does not distinguishes a Pigouvian tax and an ETS

2) Quantity regulation: static approach



2) Quantity regulation: static approach

- Details on the **double dividend**
  - The first dividend is the immediate one, corresponding to the correction of the pollution externality.
    - This is the one initially sought with the mechanism



  - The second dividend only appears on the condition that all or part of the taxes feeding public finances consist of distorting taxes.
    - See the course on "industrial economics" for a presentation of what are distortive taxes and their consequences in terms of loss of surplus

2) Quantity regulation: static approach

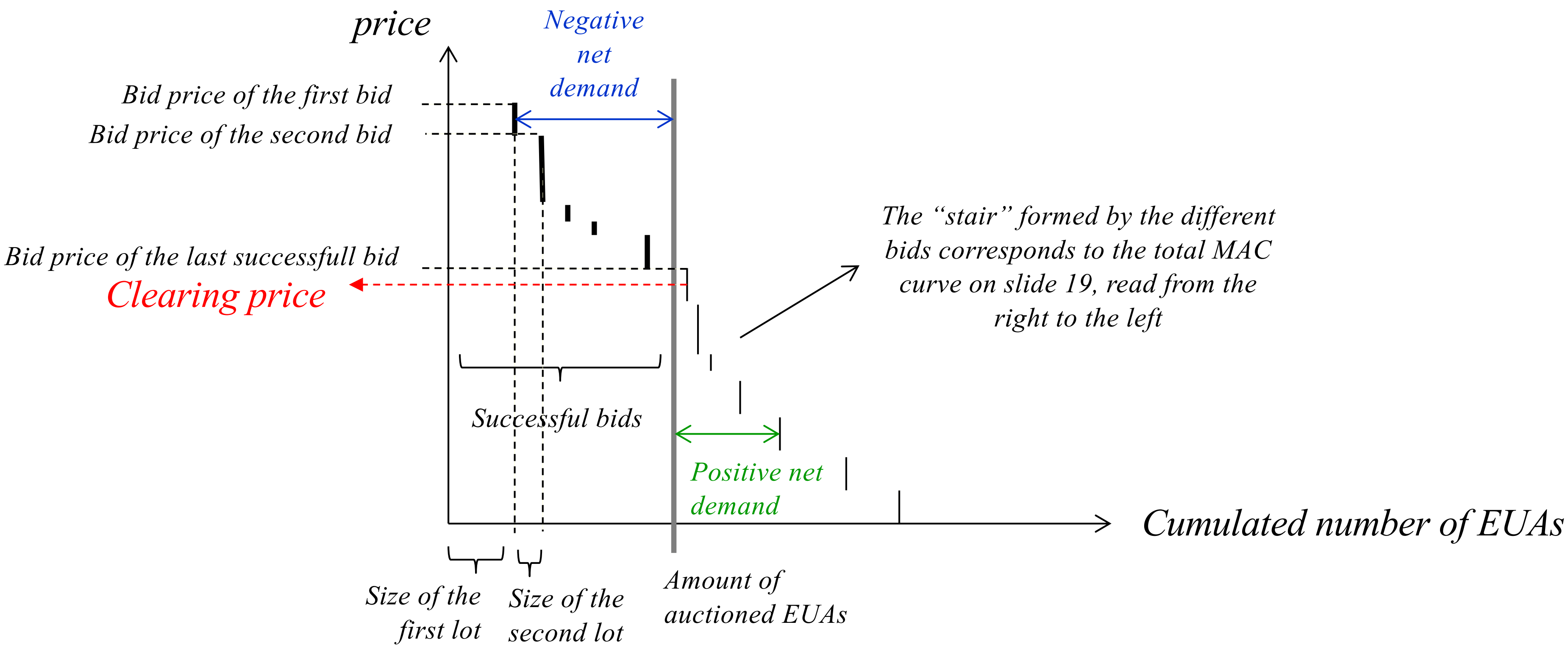
- **The second dividend is then the reduction in distortion (removal of the deadweight loss of surplus on the taxed market) obtained when the distorting tax is removed or lowered and the missing revenue is replaced by that of auctioning the allowances on the EU-ETS**
  - Remark: according to the logic of the double dividend, revenue from pricing pollution (from auctionning allowances in the case of the EU-ETS) **replaces** revenue from distorting taxation.
  - In this sense, **pricing the pollution does not add to existing taxation but is a substitute to it!**
- The idea of the second dividend dates back to
  - Pearce, D., (1991), "The Role of Carbon Taxes in Adjusting to Global Warming", *The Economic Journal*, Vol. 101, N° 407, pp. 938-948
- See also
  - Goulder, L. H., (1995), "Environmental Taxation and the Double Dividend: A Reader's Guide", *International Tax and Public Finance*, Vol. 2, pp, 157-183.

2) Quantity regulation: static approach

- In practice, the regulator asks polluters how much allowances they would like to buy at different price level (done electronically) and finally selects the price so as to make the total demand equal to the cap.
  - Quite similar to open market financing of the banking system by a central bank
    - Actually, an ETS with full auctioning of allowances is close in its functioning and spirit to the inter-banks market: allowances are created *ex nihilo* by the regulator like money by the central bank and their price may by indirectly controlled like the inter-banks interest rate
- How do auctions work on the EU ETS?
  - Participants bid by lots of 500 EUAs (=500 tCO2eq) and only authorized persons are entitled to place bids (bidder's representatives)
    - A bid specifies the number of lots and the price per allowance (in two decimal points)
  - Auction format:
    - Single round: Bids will be submitted during one given bidding window
    - Sealed bid: Bids will be submitted without seeing other participant's bids
    - Uniform price: All successful bidders will pay the same auction clearing price
  - For more details see the EEX platform in charge of auctions for the EU-ETS: https///www.eex.com

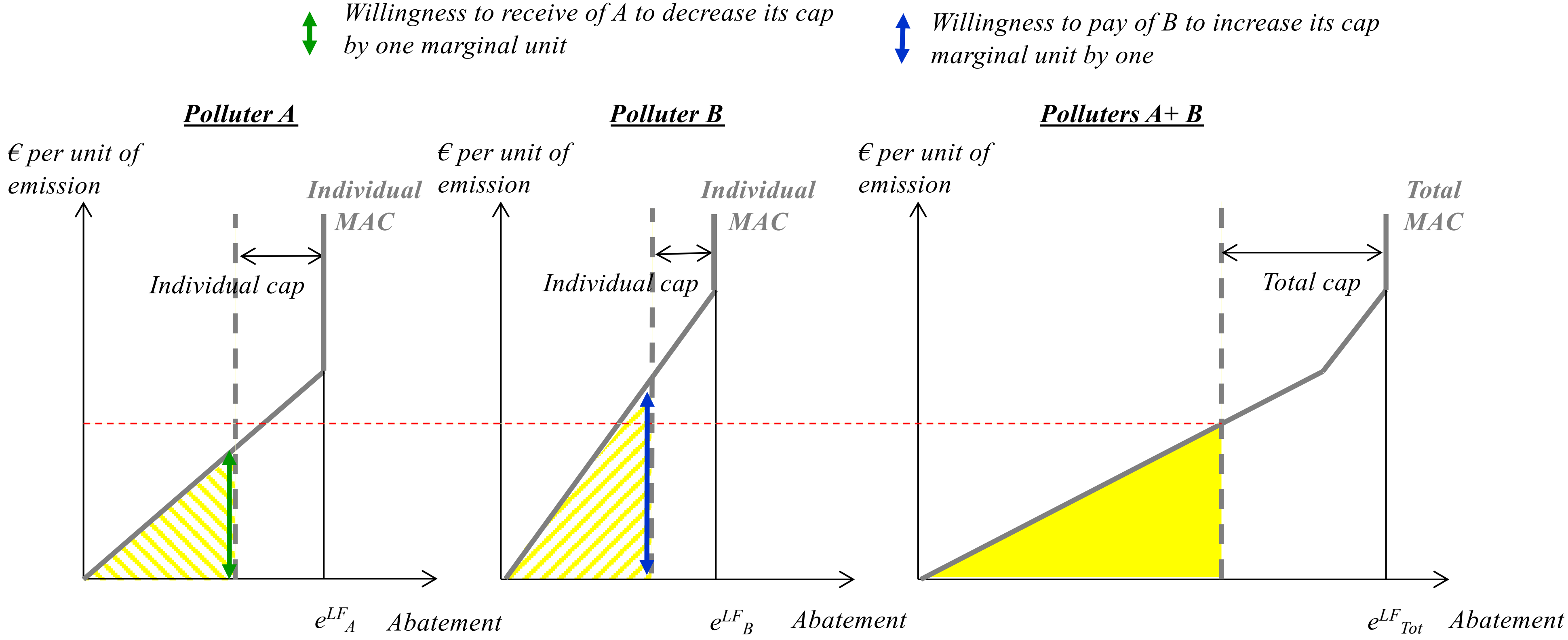
2) Quantity regulation: static approach

- The different bids are sorted in descending order of the price bid
- The auction clearing price is automatically determined as the price at which the sum of volumes bid matches or exceeds the volume of allowances auctioned



2) Quantity regulation: static approach

- Quantity regulation with **<u>fixed individual caps and free allocation</u>** (no trade)



2) Quantity regulation: static approach

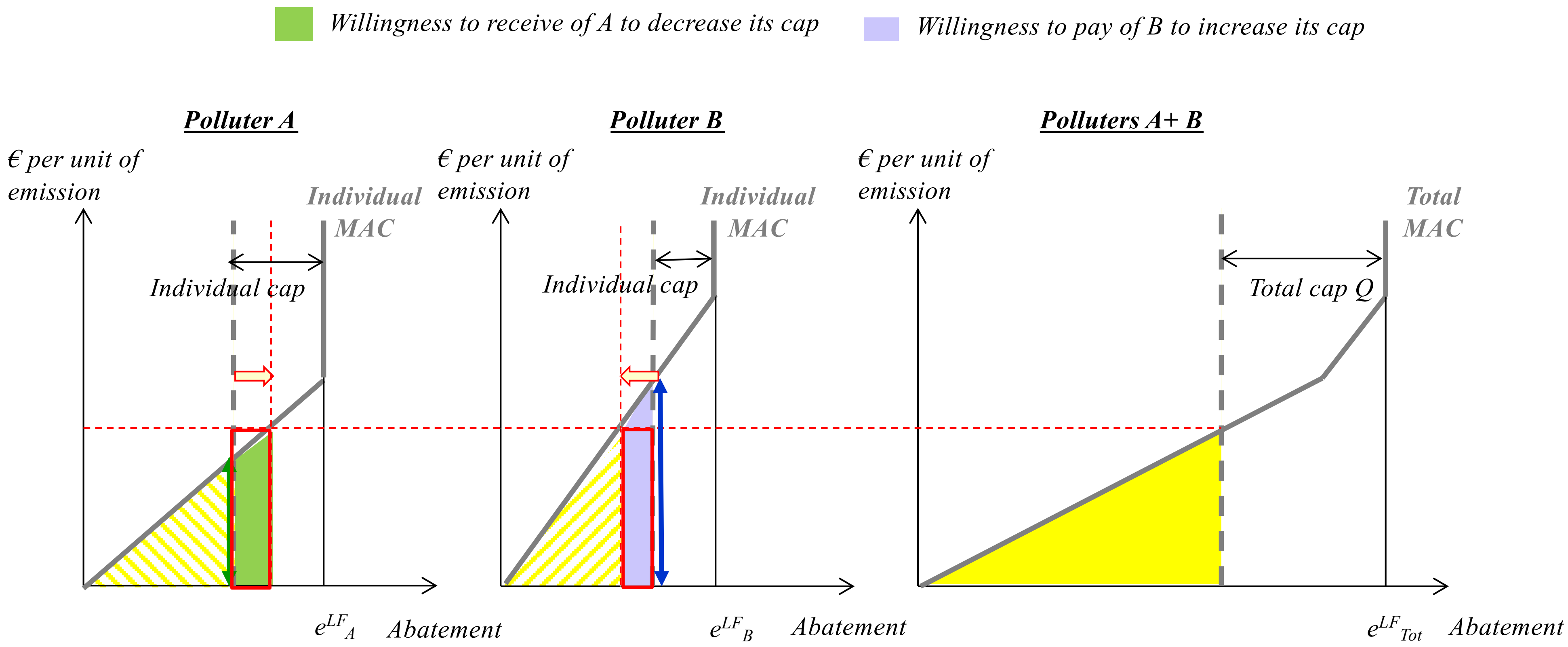
- The marginal abatement cost differs from one polluter to another one
  - **Cost efficiency is not satisfied**

- It may be win-win for polluters to change their individual caps without changing the total cap but they are not allowed to
  - Justifies not only capping but also allowing trading (see next case)

- The burden of the regulation is limited to the abatement cost but there is **no revenue to recycle**
  - Explains why this kind of regulation is generally attractive for businesses
  - Limits the risk of perverting the system to raise financial resources rather than to regulate the externality
  - This advantage may compensate the loss of cost efficiency if the individual caps do not significantly depart from the optimal abatement levels reached with a tax or an ETS with auctioning of allowances

2) Quantity regulation: static approach

- Quantity regulation with **cap and trade and free allocation of allowances**



2) Quantity regulation: static approach

- Win-win transfers of allowances are allowed
  - As a result, cost efficiency is satisfied
- The burden of the cap and trade system is limited to final abatement costs but there is no revenue to recycle
  - **=> more easily accepted by businesses**
  - combines cost effectiveness of a tax system or an ETS with auctioning on the one hand, limited risk of perversion to raise public funds on the other hand)
- But implies redistributive effects among firms covered by the ETS
  - **Redistributive effects are highly dependent on the allocation rule**

2) Quantity regulation: static approach

- Possible allocation rules:
  - *Equal allocation to each firm*:
    - generates monetary transfers from large firms to small firms
  - *Allocation based on an emission intensity benchmark*:
    - a benchmark is fixed for the ratio (emissions / production) at the sector level and each firm within the sector receives the product of this ratio by
      - its past production level (Western Carbon Initiative ETS – Californian carbon market)
      - or its realised production level (National wide Chinese ETS).
    - **In the last case there is a loss of efficiency**.
    - This allocation rule acts as a *bonus-malus* (feebate) mechanism where more environmentally efficient firms (with lower emission intensity than the benchmark) sell allowances to less efficient firms (with higher emission intensity than the benchmark)
  - *Grandfathering*:
    - allocated allowances are proportional (coefficient <1) to historical emissions observed before the inception of the ETS
    - Therefore it is supposed to limit the amount of trading and the redistributive effects

2) Quantity regulation: static approach

- The EU-ETS rule has progressively switched from grandfathering to benchmarking, auctions have been introduced and will become prevalent
  - Grandfathering was prevailing during **Phase 1 and Phase 2** of the EU-ETS
    - Phase 1 (2005-2007): 100% of free allocation based on grandfathering
    - Phase 2 (2008-2012): 90% of free allocation based on grandfathering, 10% of auctioned allowances
  - Auctioning became the default allocation rule in **Phase 3** (2013-2020)
    - In practice, only the power sector no longer received free allowances
    - The allocation rule for free allowances switched from grandfathering to benchmarking
      - Benchmarks have been computed at the sector level (more than 50) as the average carbon intensity of the 10% most efficient regulated installations.
      - They decrease at a yearly rate between 0.2% and 1.6%
      - The output level used to deduce the amount of allowances is computed based on the recent activity of the installation, and is readjusted if the average output for the last two years varies by more than 15%
      - Supposed to generate incentives to adopt a carbon efficient technologies
  - Free allocation is reduced to 30% of allowances at the beginning of **Phase 4** (2021-2030) with a planned phasing out in 2030
    - The phasing out is progressive.
    - Only sectors at risk of carbon leakage still receive 100% of free allowances, except if they are concerned by the CBAM (see Chapter 5)

2) Quantity regulation: static approach

- Any cap and trade or taxation system requires a Monitoring Reporting Verification (MRV) process
- Specific case of the EU-ETS
  - ***M**onitoring*
    - Firms can choose between two methodologies
    - 1) calculation-based methodology where standard coefficients are applied
    - 2) measurement-based methodology which relies on continuous measurement with standard tools
    - An efficient firm may prefer a measurement-based methodology that reveals its true performance => acts as a screening device
  - ***R**eporting*
    - Firms have to fully document their monitoring process and communicate their estimated emission level to the regulation authority in due time
  - ***V**erification*
    - The declared emissions are verified by independent (no conflict of interest) tierce organizations which themselves have to receive accreditation by national non profit authorities
    - Verifiers can not verify a same installations more than five successive years
    - Accreditation consists in checking that verifiers have the required skills and also in checking a representative sample of verification cases

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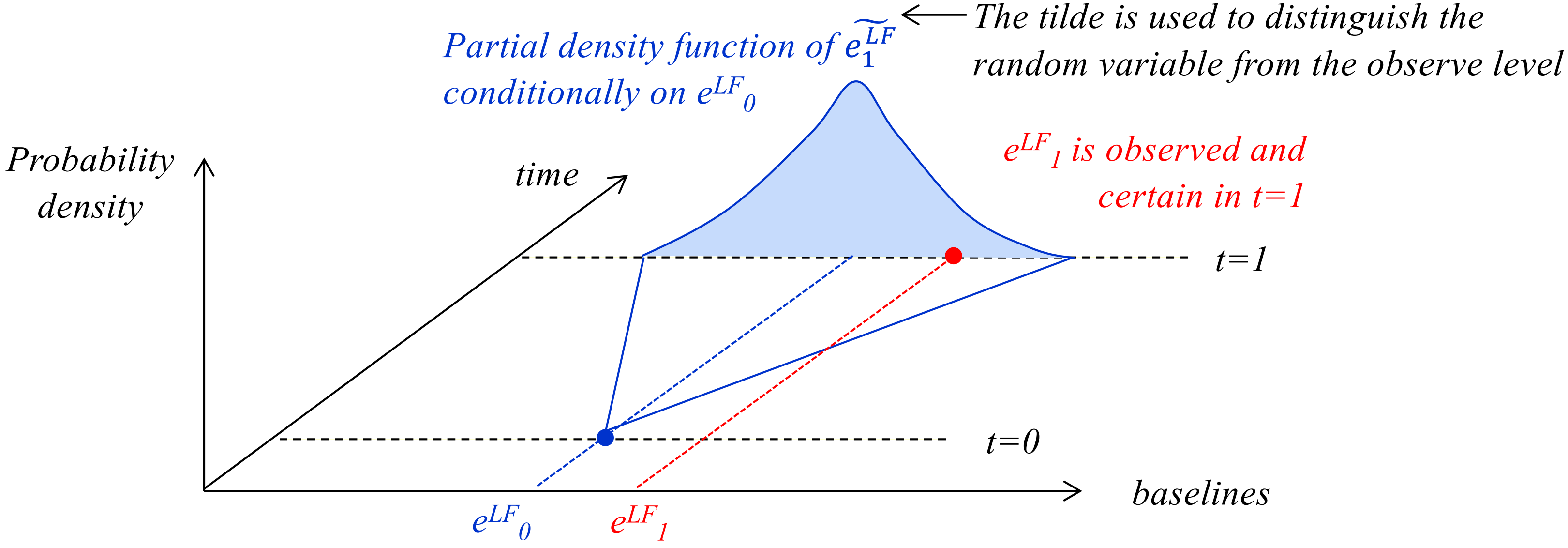
3) Intertemporal regulation

- So far, we have only presented a static analysis
  - But it is the cumulated emissions of GhG that generate global warming and damages
  - Carbon emissions actually generates a stock externality and their regulation has thus to be analysed in a dynamic setting
- Simple dynamic setting
  - Consider a two periods problem ("present": $t=0$ and "future": $t=1$)
  - At time $t=0$, the current baseline emissions ($e^{LF}{}_{0}$) are known but the future baseline emissions ($e^{LF}{}_{1}$) are uncertain
    - Economic agents nevertheless know their probability distribution conditionally on $e^{LF}{}_{0}$ and are able to make their choice according to expectations conditionally on $e^{LF}{}_{0}$
    - These expectations are referred to as $E_0[.]$
  - At time $t=1$, the current baseline emissions ($e^{LF}{}_{1}$) are observed and known with certainty

3) Intertemporal regulation

- Illustration of the simple dynamic setting
  - Introducing this kind of stochastic dynamics aims at better understanding price fluctuations (see Section 6 and comments on the observed price trajectory of the EU-ETS)



3) Intertemporal regulation

- Total abatement costs at time $t=0$ and $t=1$ are respectively denoted $AC_0(a_0)$ and $AC_1(a_1)$ and depend on the total abatement level a_0 and a_1 at the date under consideration
  - The respective marginal abatement costs are denoted $MAC_0(a_0)$ and $MAC_1(a_1)$
- Emissions cumulate as time goes so that the stock at time $t=0$ is

$$S_0 = e_0^{LF} - a_0$$

- And the stock at time $t=1$ is

$$S_1 = S_0 + e_1^{LF} - a_1$$

Or equivalently

$$S_1 = e_0^{LF} + e_1^{LF} - a_0 - a_1$$

- Total damages at time $t=0$ and $t=1$ are respectively denoted $D_0(S_0)$ and $D_1(S_1)$ and depend on the total stock S_0 and S_1 at the date under consideration
  - The respective marginal damages are $Dmg_0(S_0)$ and $Dmg_1(S_1)$

3) Intertemporal regulation

- Let consider first the social planner problem: minimise the discounted and expected sum of damages and abatement costs
- The corresponding (dynamic programming) problem may be written as
  - A key feature is that a_1 only affects the total cost in $t=1$ and may be determined at that period of time (dynamic programming principle)

a_0 is chosen optimally at $t=0$ knowing that a_1 will also be chosen optimally at $t=1$ conditionally on the observed value of e_1^{LF} and on a_0

a_1 is chosen optimally in $t=1$ conditionally on the observed value of e_1^{LF} and on a_0

$$\min_{a_0} \underbrace{\underset{\substack{\downarrow \\ \text{Abatement in} \\ t=0}}{AC_0(\boldsymbol{a_0})} + D_0(\underbrace{e_0^{LF} - \boldsymbol{a_0}}_{\substack{\text{Emissions in} \\ t=0}})}_{\substack{\text{Total cost in the} \\ \text{“present” } (t=0)}} + \underbrace{\frac{1}{1+\rho}}_{\substack{\text{Discount} \\ \text{factor}}} \underbrace{E_0\left[\min_{a_1}\left\{\underset{\substack{\downarrow \\ \text{Abatement in} \\ t=1}}{AC_1(\boldsymbol{a_1})} + D_1\left(\underbrace{\widetilde{e_1^{LF}} - \boldsymbol{a_1}}_{\substack{\text{Emissions in} \\ t=1}} + \underbrace{e_0^{LF} - \boldsymbol{a_0}}_{\substack{\text{Emissions in} \\ t=0}}\right)\right\}\right]}_{\substack{\text{Expected total cost in the} \\ \text{“future” } (t=1)}}$$

3) Intertemporal regulation

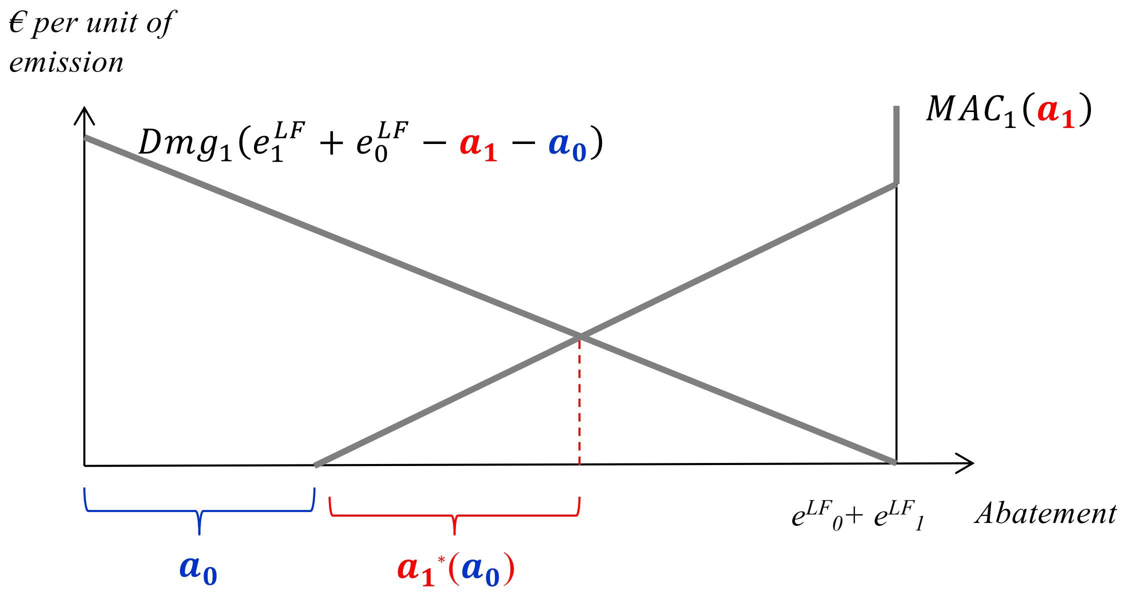
- The second period problem is almost identical to a static problem
  - The abatement level a_1 is determined so as to equalise its marginal abatement cost and the associated (with respect to a_1) marginal damage
  - … except that the marginal damage also depends on the first period abatement level a_0
    - At period $t=1$, a_0 works as a cost-free abatement that shifts MAC_1 to the right

relation **A**

$$MAC_1(\boldsymbol{a_1}) = Dmg_1(e_1^{LF} - \boldsymbol{a_1} + e_0^{LF} - \boldsymbol{a_0})$$

The optimal abatement level $\boldsymbol{a_1}^*(\boldsymbol{a_0})$ at the second period is obtained conditionally on the abatement level $\boldsymbol{a_0}$ at the first period

Except if MAC_1 is very steep, $\boldsymbol{a_1}^*(\boldsymbol{a_0})$ ***is strictly positive***



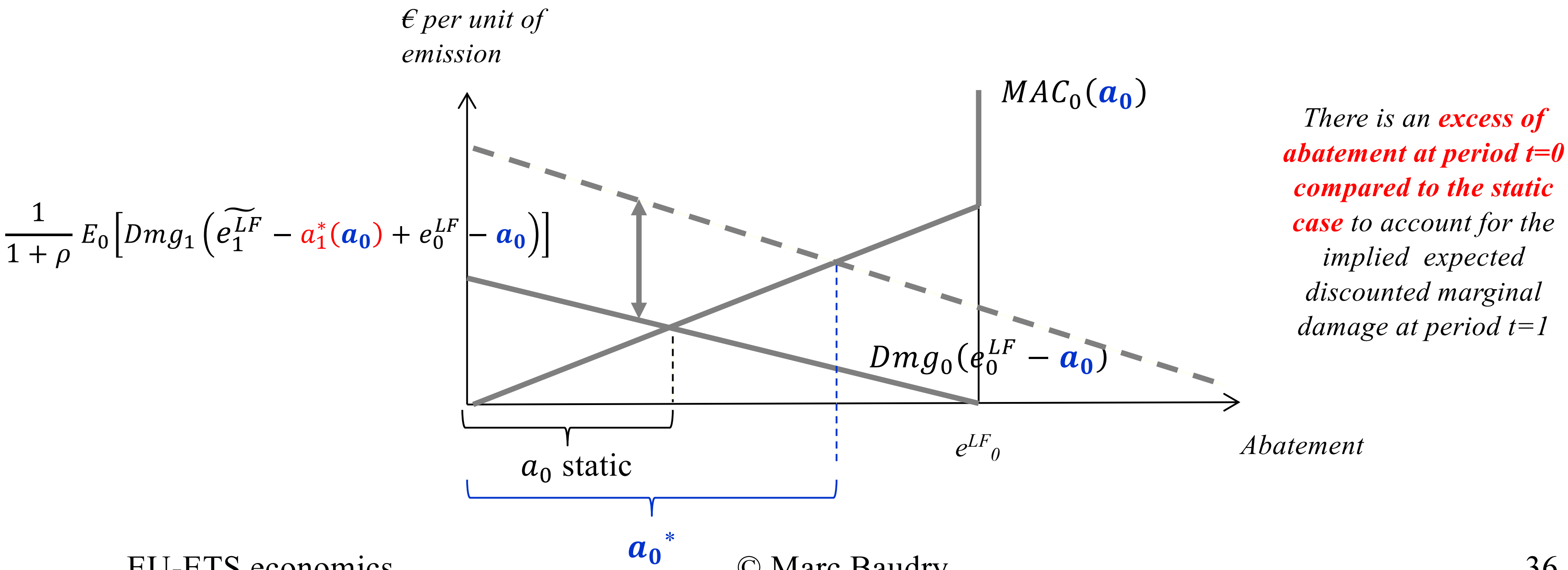
3) Intertemporal regulation

- The first period problem is also almost identical to a static problem
  - Except that the abatement level a_0 is determined so as to equalise its marginal abatement cost and the associated (with respect to a_0) expected discounted sum of marginal damages over the two periods

relation **B**

$$\boxed{MAC_0(\boldsymbol{a_0}) = Dmg_0(e_0^{LF} - \boldsymbol{a_0}) + \frac{1}{1+\rho} E_0\left[Dmg_1\left(\widetilde{e_1^{LF}} - \boldsymbol{a_1} + e_0^{LF} - \boldsymbol{a_0}\right)\right]}$$

    – The abatement level $\boldsymbol{a_1}$ for the second period can then replaced by the optimal level $\boldsymbol{a_1}^*(\boldsymbol{a_0})$ at the second period conditionally on the abatement level $\boldsymbol{a_0}$ at the first period



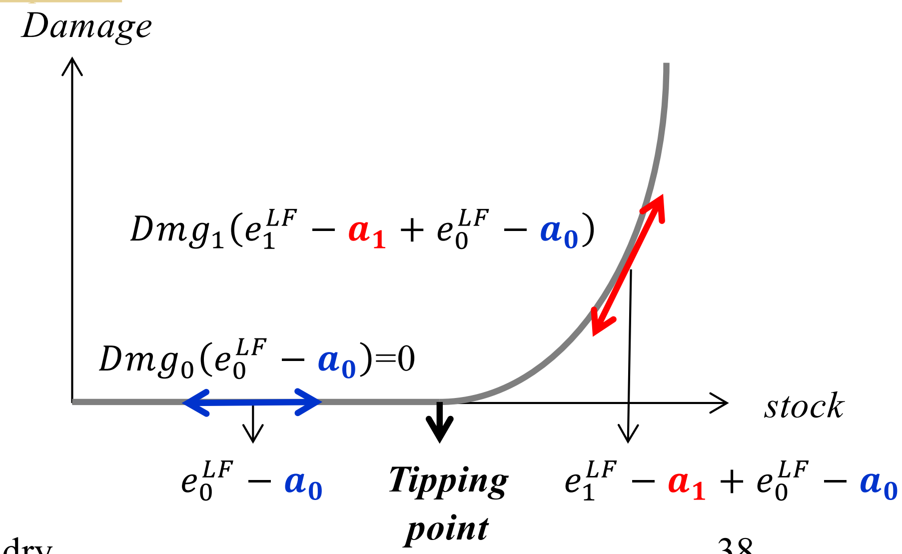
3) Intertemporal regulation

- In the presence of a stock externality, the short term optimal abatement level is higher *ceteris paribus* (i.e. with identical damage and abatement cost curves at period $t=0$) than with a flow externality
- Nevertheless, it is optimal to spread the abatement effort between the short term and the long term
  - Unless additional assumptions on the damage and abatement cost curves and/or on the discount rate and/or on the probability distribution of future baselines are introduced, it is not possible to rule out the possibility that the abatement level in the long term ($t=1$) will be higher than in the short term ($t=0$)
- The difference between baseline emissions and the optimal abatement level defines the **optimal cap to be put on emissions** at each period
  - There is no objective reason for the optimal cap to be time invariant
- According to relation **A** and **B** it is also possible to characterise the **optimal intertemporal Pigouvian tax**
  - At each period, the optimal Pigouvian tax is such that the marginal abatement cost just equals the tax and thus polluters abate the optimal level of emissions
  - => it is given by the right hand side of relations **A** (at $t=0$) and **B** (at $t=1$)
  - There is no objective reason for the optimal tax to be time invariant

3) Intertemporal regulation

- A peculiar case of interest is that of a **tipping point in the stock of pollutant**
  - It is particularly relevant in the case of Greenhouse Gases
  - As long as the stock of GhG in the atmosphere remains below a threshold value, a smooth climate change occurs
  - Above the threshold value, global warming implies a dramatic climate change
  - IPCC assessments suggest that tipping points could be reached between 1°C and 2°C of global warming
    - The remaining global carbon budget for 2°C was **1,046 GtCO2** at the start of 2021.
    - See https:// www.ipcc.ch/sr15/chapter/chapter-2/

- This peculiar case can be schematized by considering that the damage (and marginal damage defined by the slope) is nil below the tipping point and increases very rapidly beyond
  - Assume that the tipping point is unlikely to be reach in the short term but is a long term risk



3) Intertemporal regulation

- Short term and long term abatement levels are then driven by the sole long term marginal damage
  - Indeed, relations **A** and **B** now reads

$$MAC_1(\boldsymbol{a_1}) = Dmg_1(e_1^{LF} - \boldsymbol{a_1} + e_0^{LF} - \boldsymbol{a_0})$$

$$MAC_0(\boldsymbol{a_0}) = \frac{1}{1+\rho} E_0\left[Dmg_1\left(\widetilde{e_1^{LF}} - \boldsymbol{a_1} + e_0^{LF} - \boldsymbol{a_0}\right)\right]$$

Let $\boldsymbol{a_0}^*$ *and* $\boldsymbol{a_1}^*$ *denote the optimal abatement levels*

  - The optimal Pigouvian tax (or equivalently the equilibrium price of allowances) τ_0* and τ_1* at respectively period $t=0$ and period $t=1$ induces that polluters equate their marginal abatement costs to this tax (or price) at the optimal abatement levels:

$$\tau_1^* = MAC_1(a_1^*)$$

$$\tau_0^* = MAC_0(a_0^*)$$

$$E_0[\boldsymbol{\tau_1^*}] = (\mathbf{1} + \boldsymbol{\rho})\, \boldsymbol{\tau_0^*}$$

=> The optimal carbon tax/price is expected to increase at the same rate than the social discount rate

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4) Genesis of the EU-ETS

5) Quantity regulation: Intertemporal trading

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7) Beyond the EU-ETS

4) Genesis of the EU-ETS

- Faced with the issue of global warming, the European Commission initially adopted a strategy very much centered on the concept of Pigouvian taxation
  - More specifically the European Commission proposed an EU-wide carbon energy tax in 1992.
    - It failed due to the opposition of some Member States to delegate any power of taxation to the European level
      - There was a fear that it led to other taxing initiatives and leak fiscal autonomy to the Commission
    - The carbon tax proposal was formally withdrawn in 1997
  - Concomitantly, during the Rio Earth Summit in 1992, the existence of climate change and human responsibility for this phenomenon were officially recognized.
    - From this recognition emerges the **goal of stabilizing atmospheric concentrations of greenhouse gases and implementing policies to achieve this**.
  - This led to the Kyoto protocol signed in December 1997.

4) Genesis of the EU-ETS

- The negotiations for the Kyoto protocol constituted a key stage for the establishment of the EU-ETS.
- The European Union wanted to adopt the principle of binding emission ceilings for developed countries.
- This principle was accepted by other parties, but with the counterpart of favoring flexible policy instruments.
  - The concept of flexibility was pushed by the United States
  - It was inspired by the experience with **the sulfur dioxide (SO_2) trading system** implemented under the framework of the Acid Rain Program of the 1990 Clean Air Act in the U.S.
    - This early ETS had progressively emerged in the US as a mean to tackle the acid rain problems which was acceptable by businesses or, at least, **more acceptable than Pigouvian Taxation** (see Section 2 for a discussion of this point)
  - For a more comprehensive presentation of the history of ETS see
    - Calel, R. (2013). "Carbon markets: a historical overview", *WIREs Climate Change*, Vol. 4, pp. 107-119.

4) Genesis of the EU-ETS

- The Kyoto Protocol provided for a mechanism of tradable permits between Annex 1 countries (essentially developed countries that had historically contributed early to carbon emissions)
- The European Union was initially unfavorable to it because the allocation of permits on the basis of national emissions in 1990 suggested strong rents for certain countries (Russia given its post-Soviet transition)
  - This is the so called **"hot air" problem**
- In order to prepare for this international market, the European Union decided to start by creating its own ETS which, in time, was to be coupled with the international ETS.
  - The international carbon market did not took place, in part because of the slow pace of ratification of the Kyoto treaty and the refusal of ratification by the US Senate
  - By contrast, the EU-ETS started with a pilot phase (Phase 1, 2005-2007) and then came into force in 2008 (Phase 2, 2008-2012; Phase 3, 2013-2020; Phase 4, 2021-2030).
  - For a comprehensive history of the ETS genesis see
    - Convery, F. J. (2009). "Origins and Development of the EU-ETS", *Environmental and Resource Economics*, Vol. 43, pp. 391-412.

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5) Quantity regulation: intertemporal trading

- In Chapter 2, it has been highlighted that tradeable allowances where more cost efficient than individual fixed caps on emissions in the case of quantity regulation
  - This is referred to as **spatial flexibility** in the sense that the trading of allowances occurs at the same period of time between polluting sites located at different places (they contribute to pollution whatever their location).

    Fankhauser, S. and C. Hepburn (2010.b). "Designing Carbon Markets. Part II: Carbon Markets in Space", *Energy Policy*, Vol. 38, pp. 4381-4387.

  - **Temporal flexibility** refers to the case where it is more cost efficient to let each polluter transfer allowances from one period to the other and practice
    - **Banking of allowances** when allowances are saved for future use
    - **Borrowing of allowances** when allowances are used before their receipt

    Fankhauser, S. and C. Hepburn (2010.a). "Designing Carbon Markets. Part I: Carbon Markets in Time", *Energy Policy*, Vol. 38, pp. 4363-4370.

  - Temporal flexibility implies that polluters are facing an intertemporal allowance budget constraint instead of a per period allowance constraint.

5) Quantity regulation: intertemporal trading

- Temporal flexibility makes sense when only the cumulated stock of pollutant emissions at a given time horizon matters or when a tipping point of the stock should not be crossed.
  - This is typically the context of the "carbon budget" approach
    - No matter when the greenhouse gas emissions take place and what is the time path of the stock, what matters is that the stock does not cross the threshold leading to a global warming of more than 2°C.
  - In alternative configurations, the stock at each period of time generates a damage and the time path of the stock matters
    - Indeed (see Section 3) there is a tradeoff between damages at the different periods, and thus between the corresponding stock of pollutant reached at these periods => there is an optimal cap per period
  - We thereafter focus on the context of a "carbon budget" in a simplified two periods problem and consider that the social planner has determined the optimal final stock to be reached at the last period
  - The heterogeneity of firms' discount rate play a key role

5) Quantity regulation: intertemporal trading

- Firms are characterized by heterogeneous discount rates which reflect their differences in terms of risk and access to financing.

  - The portfolio choice theory in finance implies that investors will demand risk premiums on the rate of return of investments offered by firms to compensate for known differences in the riskiness of their projects.

  - Moreover, in order to provide a credible signal of their solvency to lenders, firms are led to finance a minimum part of their investments with equity. This share increases with the prior belief in their insolvency.

  - These different elements define their **Weighted Average Cost of Capital (WACC)**, i.e. the opportunity cost of one Euro invested in their projects.

5) Quantity regulation: intertemporal trading

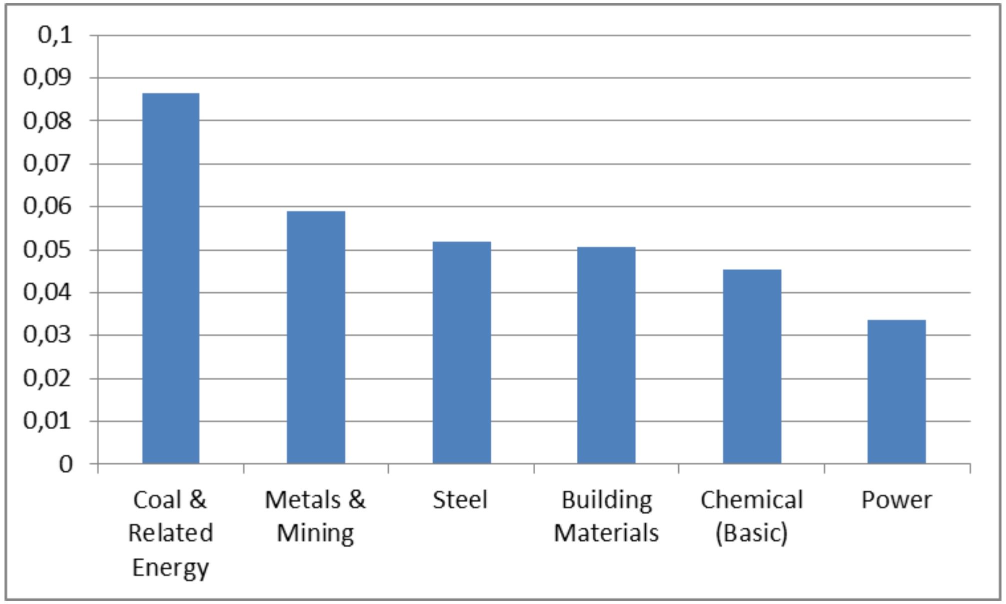
- Firms make their intertemporal choices on the basis of their WACC which is used as their discount rate

  - There may be wide differences in terms of WACC between sectors but also within a sector at the European level
  - For heterogeneity **between sectors**, see data collected by the NYU Stern Business School
    https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datacurrent.html#discrate
  - For heterogeneity **within a sector**, see e.g. the Diacore report (pages 48-54) that presents WACC estimates for wind power

    http://www.idaea.csic.es/sites/default/files/DIACORE_Final_Report.pdf

5) Quantity regulation: intertemporal trading

- Weighted Average Cost of Capital (rate level) by sectors in Western Europe, 2021
  - Selected sectors covered by the EU-ETS



  - Source: https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datacurrent.html#discrate

5) Quantity regulation: intertemporal trading

DIA-CORE Final Report

DiaCore

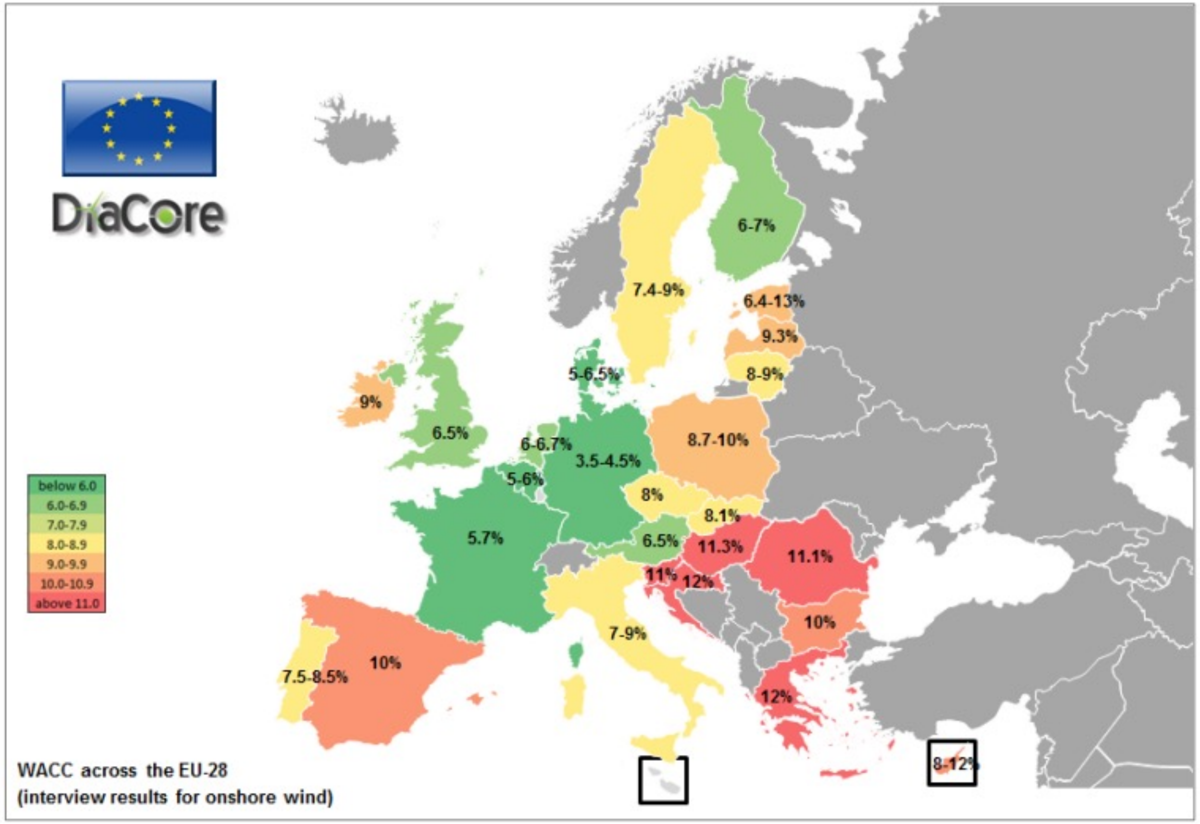


Figure 32: WACC estimations onshore wind – approximation based on interviews

5) Quantity regulation: intertemporal trading

- In a two period setting with temporal flexibility, each firm $i \in \{1, \dots, N\}$ is not constrained to balance its emissions with the same amount of allowances at each date.
- **There is <u>banking of allowances</u> if the firm holds more allowances than its emission level at the end of period *t=0*.**
- **There is <u>borrowing of allowances</u> if the firm holds less allowances than its emission level at the end of period *t=0* .**
  - Net banking levels (banking if >0, borrowing if <0) of a firm at each period are

$$nb_0 = q_0 + x_0 - (\underbrace{e_0^{LF} - a_0})$$

Allowances granted for free — ***Net purchases of allowances*** — *Emissions (baselines minus abatement)*

$$nb_1 = nb_0 + q_1 + x_1 - (\underbrace{e_1^{LF} - a_1})$$

  - In addition, **net borrowing is not possible at the end of the second period** because the firm has to certify that it has not less allowances than it has emitted during the two periods AND, **net banking at the end of the second period** if worthless because allowances can not be sold latter
  - => $\boldsymbol{nb_1 = 0}$ and net purchases are adjusted to settle the position of the firm i.e. $x_1 = (e_0^{LF} - a_0) + (e_1^{LF} - a_1) - nb_0 - q_1 - q_0 - x_0$

5) Quantity regulation: intertemporal trading

- The two periods problem of the firm consists in minimising the discounted expected sum of abatement cost and allowances net of allowance purchases
  - Firms are price takers on the ETS
  - They have rational expectations of the future price of allowances (which is stochastic due to uncertainty about future baseline emissions)
- This two periods problem reads

Abatement cost at t=0

$$\min_{\{a_0,x_0\}} \Big\{ AC(a_0) + +p_0 x_0$$

Net purchase of allowances at t=0
(the firm buys if x>0 and sells if x<0)

Discount factor
r_i : WACC of firm i

$$+\frac{1}{1+r_i} E_0 \left[\min_{a_1} \{ AC(a_1) + p_1 x_1 \} \right] \Big\}$$

Only the total cap on emissions matters

The abatement decision for t=1 is made at t=1 once the realised value of the baseline e_1^{LF} is observed (dynamic programming principle)

Abatement cost at t=1

Net purchase of allowances at t=1

$$= (e_0^{LF} - a_0) + (e_1^{LF} - a_1) \boxed{- q_1 - q_0} - x_0$$

Because net banking at t=1 is worthless and amounts to 0

5) Quantity regulation: intertemporal trading

- Each firm $i \in \{1, \dots, N\}$ has a different discount rate r_i corresponding to its WACC
- For the seek of simplicity, it is assumed that net purchases of allowances by each firm are bounded : $x_i \in [-\bar{x}, \bar{x}]\ \forall i$
  - Reflects transaction costs, like the risk of inquiry by the regulator if too short or too long positions are adopted by regulated firms (fear of market "manipulation"…).
- The first order condition for the optimal abatement at date *t=1* reads

$$MAC_1(a_1) = p_1$$

Market clearing at t=1 requires that $\sum_{i=1}^{N} x_{1i} = 0$ which, together with the expression of x_{1i} and the FOC characterising a_{1i} for each firm i implicitly defines the equilibrium price p_1 as a function of observed baselines at t=0 and t=1, abatements at t=0 and net purchases at t=0.

- The first order condition for the optimal abatement at date *t=0* reads

$$MAC_0(a_0) = \frac{1}{1 + r_i} E_0[p_1]$$

*Abatement at the first period are driven by expectations at the second period => **expectation as regards the future of the ETS play a key role in current choices***
=> Sensitive to time inconsistency in climate policy and to discretionary rules

5) Quantity regulation: intertemporal trading

- The first order condition for the optimal net purchases (and thus banking/borrowing) at date $t=0$ reads

$$x_{0i} = \begin{cases} \bar{x} & if \quad p_0 - \dfrac{1}{1+r_i}E_0[p_1] < 0 & \Leftrightarrow & r_i < (E_0[p_1] - p_0)/p_0 \\ any\ x \in [-\bar{x}, \bar{x}] & if \quad p_0 - \dfrac{1}{1+r_i}E_0[p_1] = 0 & \Leftrightarrow & r_i = (E_0[p_1] - p_0)/p_0 \\ -\bar{x} & if \quad p_0 - \dfrac{1}{1+r_i}E_0[p_1] > 0 & \Leftrightarrow & r_i > (E_0[p_1] - p_0)/p_0 \end{cases}$$

A firm buys (sells) allowances if its own discount rate is lower than the expected growth rate of the price of allowances

If the firm buys (sells) allowances, this favours banking (borrowing). Net banking is thus highly influenced by the firm's discount rate (WACC)

- Market clearing at the first period implies that $\sum_{i=1}^{N} x_{0i} = 0$

5) Quantity regulation: intertemporal trading

- => Market clearing at $t=0$ is satisfied if and only if the expected growth rate of the price equals the median of the discount rates of firms
  - Indeed, by definition of the median there are as many firms with a lower discount rate than firms with a higher discount rate so that the count of firms which bank $\bar{x}$ each just equals the count of firms that borrow $\bar{x}$ each
  - Thus $E_0[p_1] = p_0(1 + r_{median})$

    The price of allowances is expected to grow at a constant rate corresponding (in this simplified case) to the median discount rate of firms

  - We are let with the determination of p_0 :
    - The equilibrium current price of allowances is the minimum value of p_0 that makes the abatement levels at $t=0$ and $t=1$ (which are increasing in p_0) sufficiently high to guarantee that the sum of emissions over all firms and all periods does not exceed the total cap
- These key properties of an ETS with temporal flexibility and a stock externality date back to

  Leiby, P. and J. Rubin (2001). "Intertemporal Permit Trading for the Control of Greenhouse Gas Emissions", *Environmental and Resource Economics*, Vol. 19, pp. 229-256.

- Previous literature had focus on a similar condition in the case of flow externalities

  Rubin, J. R. (1996), "A Model of Intertemporal Emission Trading, Banking and Borrowing", *Journal of Environmental Economics and Management*, Vol. 31(3), pp. 269–286

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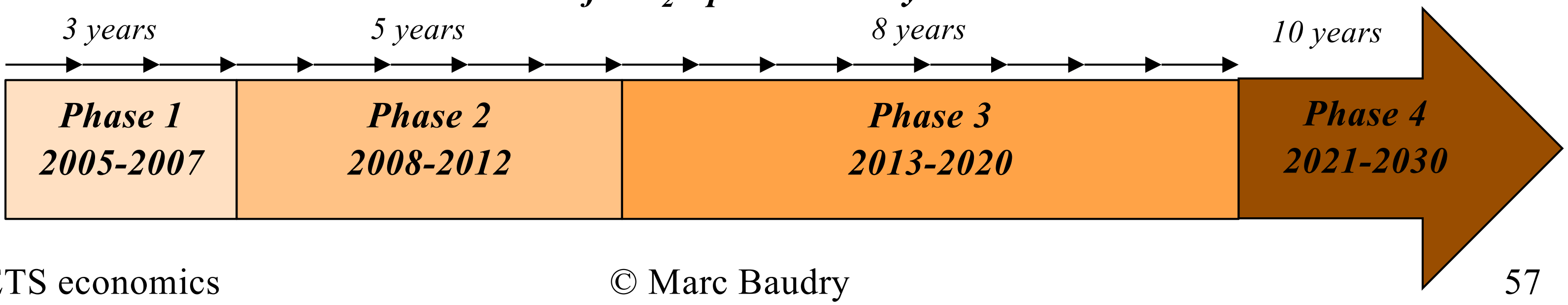
6) The EU-ETS at almost 20 years old

- The European Union Emission Trading System was launched in 2005
  - It has been divided in several trading periods (or phases) with a specific total targeted abatement level for each period
  - In this sense, it may be thought of as a hybrid regulation system between
    - Regulating a pollution which main damage results from the cumulated stock at a given horizon and which should not exceed a tipping point=> temporal flexibility is allowed
      - Consistent with the EU climate neutrality by 2050
    - Regulating a pollution, the stock of which generates a damage at each period => the time paths of the stock matters, hence the end of phases emission goals
  - Phases last longer as knowledge, experience and policy stringency increase
    - https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en

The compliance period is one year: each year, firms have to surrender as many allowances as tonnes of CO_2 equivalent they have emitted



6) The EU-ETS at almost 20 years old

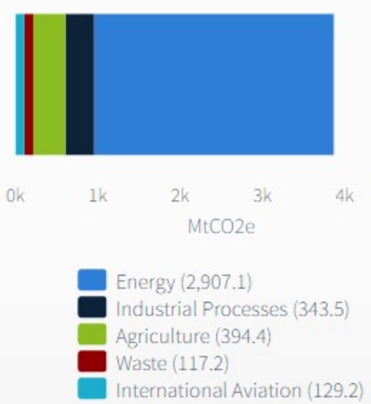
- About 40% of EU GHG emissions are covered by the EU-ETS

Overall GHG emissions (excluding LULUCF)

Emissions: 3,893.1 $MtC0_2e$ (2018*)

*Overall GHG emissions for the EU-27 that comprises all European Member States, which as of 2021 no longer includes the United Kingdom.

Overall GHG emissions by sector (in MtCO2)

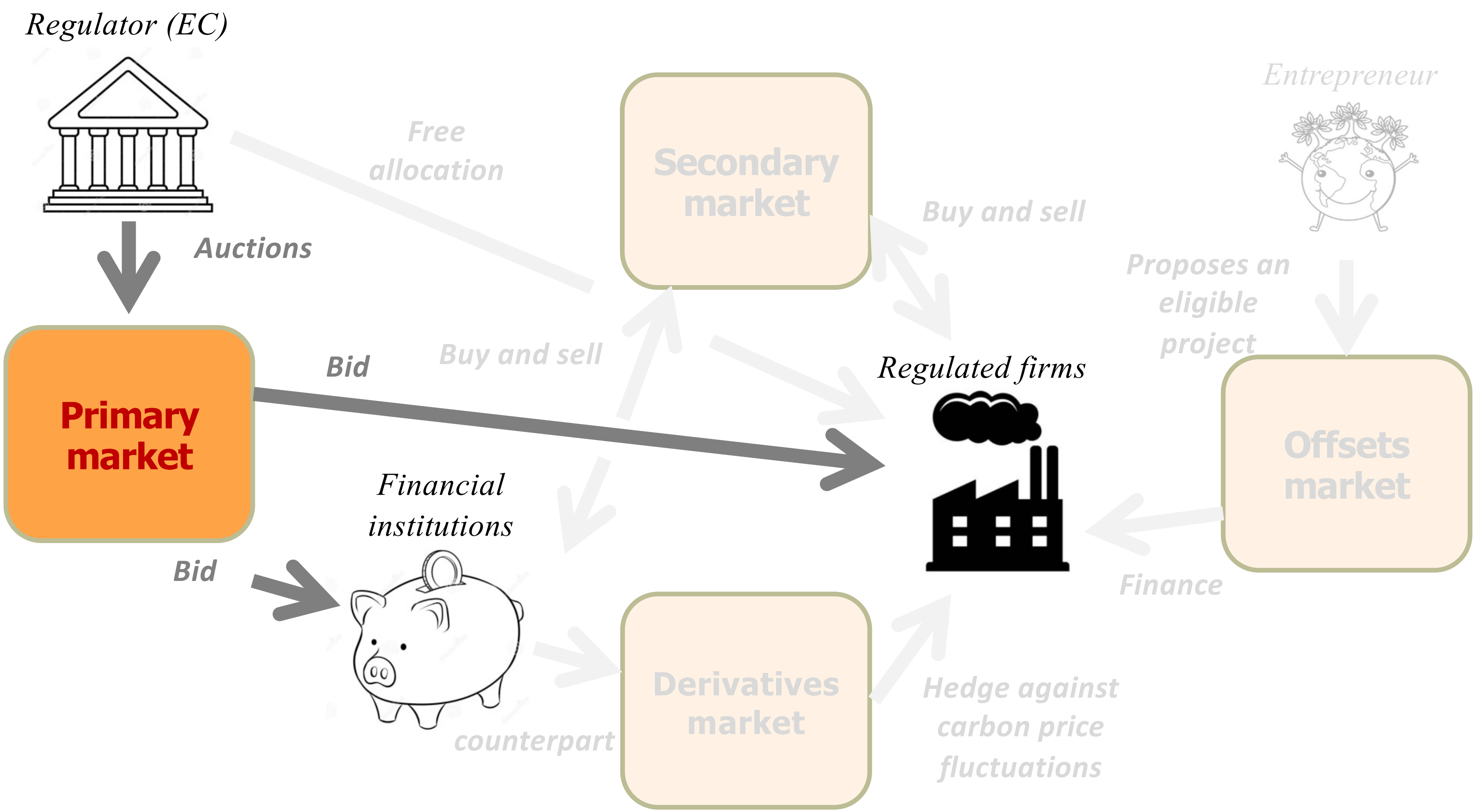


Covered emissions

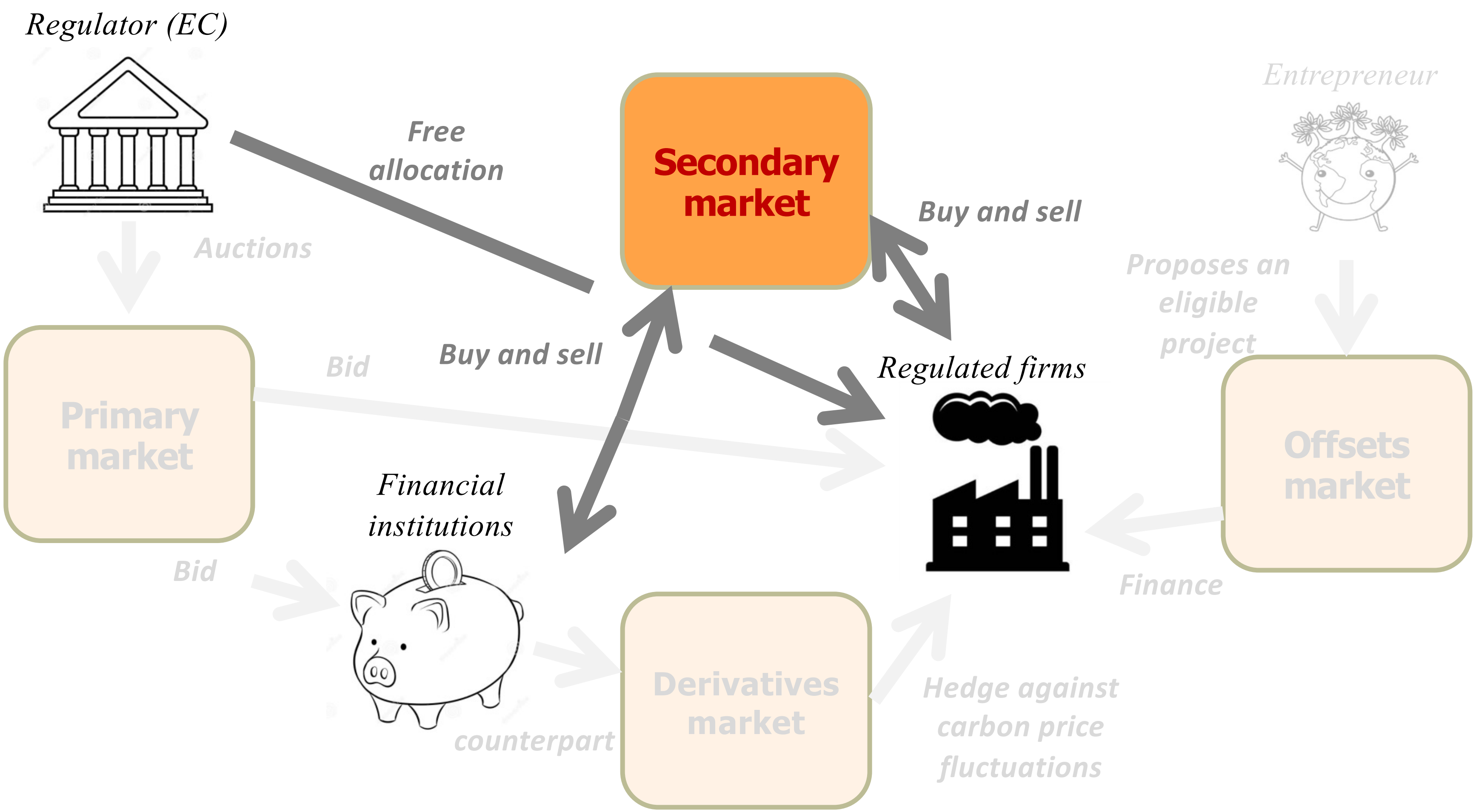
Source: [International Carbon Action Partnership (ICAP) - ETS Map (icapcarbonaction.com)]

6) The EU-ETS at almost 20 years old

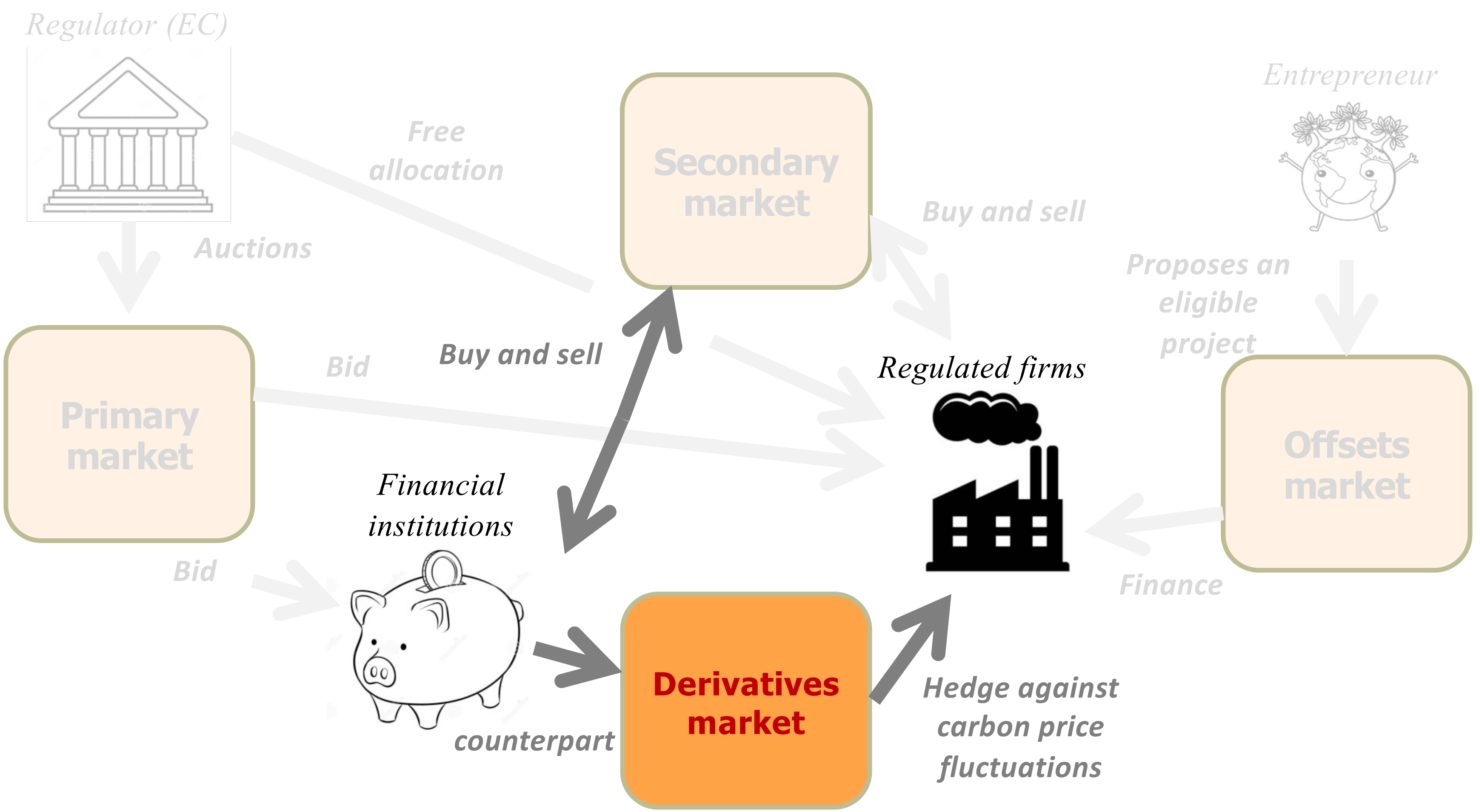
- The carbon market may encompass or involve four different markets



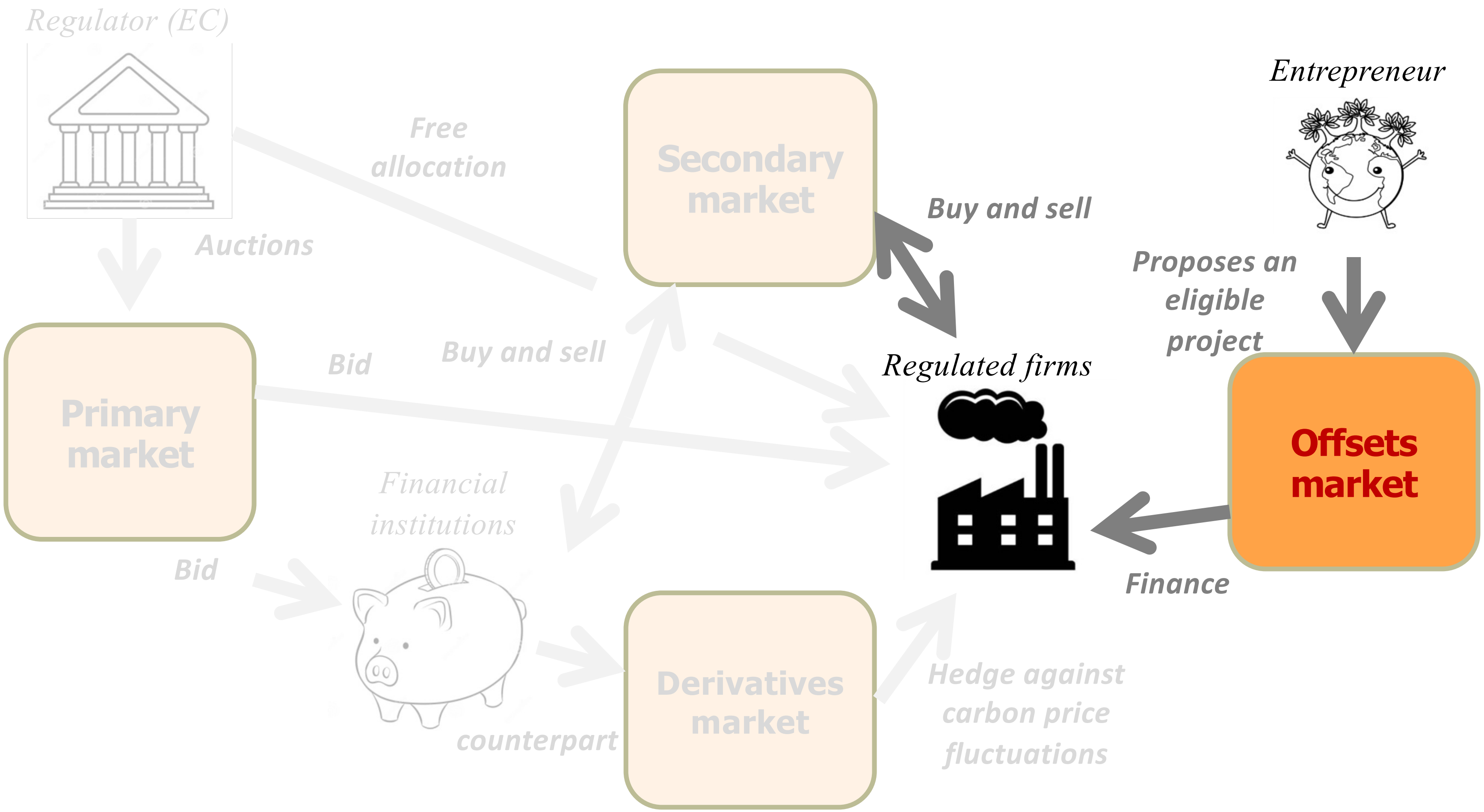
6) The EU-ETS at almost 20 years old



6) The EU-ETS at almost 20 years old



6) The EU-ETS at almost 20 years old



6) The EU-ETS at almost 20 years old

- The history of the EU-ETS is paved by important price shocks
  - European Union Allowances (EUA) spot price (€ per tonne)

Source (updated on the 2sd of February 2024): https://tradingeconomics.com/commodity/carbon

6) The EU-ETS at almost 20 years old

- Phase 1 (2005-2007)
  - This was a **3-years pilot** of 'learning by doing' to prepare for phase 2, when the EU ETS would need to function effectively to help the EU meet its Kyoto targets.
    - Banking within the 3-year period was allowed (time flexibility) in addition to trading between regulated sites (spatial flexibility)
    - Borrowing was (at first sight) not allowed to limit the risk that in case of a firm bankruptcy the emission debt is never compensated by corresponding future abatements
  - Key features:
    - Covered only **CO_2** emissions from **power generators** and **energy-intensive industries**
    - **Almost all** allowances were given to businesses **for free**
    - The penalty for non-compliance was **€40** per tonne (on top of the allowance price)
    - The amount of allocated allowances was decided on a national basis => incentives for national governments to over-allocate to their national regulated firms
  - Phase 1 succeeded in establishing:
    - a **price** for carbon
    - free **trade** in emission allowances across the EU
    - the **infrastructure** needed to monitor, report and verify emissions from the businesses covered.

6) The EU-ETS at almost 20 years old

- In the absence of reliable emissions data, phase 1 caps were set on the basis of estimates. As a result, the total amount of **allowances issued exceeded emissions** and, with supply significantly exceeding demand, in 2007 the spot price of allowances fell to zero (**phase 1 allowances could not be banked for use in phase 2**).

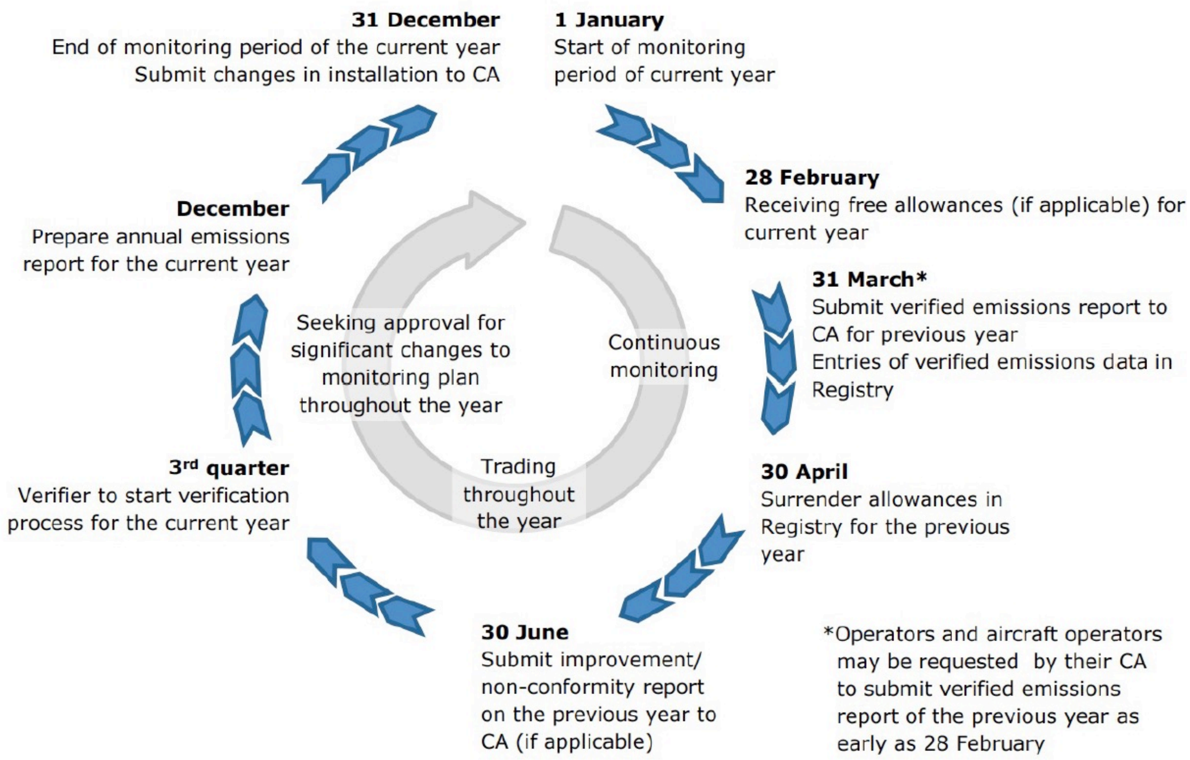
6) The EU-ETS at almost 20 years old

- Phase 2 (2008-2012)
  - Phase 2 coincided with the first commitment period of the Kyoto protocol, where the countries in the EU ETS had concrete emissions reduction targets to meet.
  - Key features:
    - **Lower cap** on allowances (some 6.5% lower compared to 2005)
    - **3 new countries** joined – Iceland, Liechtenstein and Norway
    - **Nitrous oxide** emissions from the production of nitric acid included by a number of countries
    - The proportion of **free allocation** fell slightly to around **90%**
    - Several countries held auctions
    - The penalty for non-compliance was increased to **€100** per tonne
    - Businesses were allowed to buy **international credits** totalling around 1.4 billion tonnes of CO_2-equivalent

      -> see CERs and ERUs
    - Union registry replaced national registries and the European Union Transaction Log (EUTL) replaced the Community Independent Transaction Log (CITL)
    - The aviation sector was brought into the EU ETS on 1 January 2012 (but application for flights to and from non-European countries was suspended for 2012)
      - Distinct allowances are granted for free to the aviation sector and can only been traded within this sector. Aviation companies can comply with either standard allowances (EUAs) or with these specific allowances (EUAAds) => partial linking

6) The EU-ETS at almost 20 years old

- Allowances can be banked from year to year AND from phase to phase (time flexibility)
- Theoretically, they can not be borrowed
    - However there is overlapping between the period where a site has to surrender allowances to comply with its emissions measured at year t and the period at which the site is granted free allowances for year t+1
    - => during this overlap, allowances granted for year t+1 can be borrowed to comply with regulation at year t!

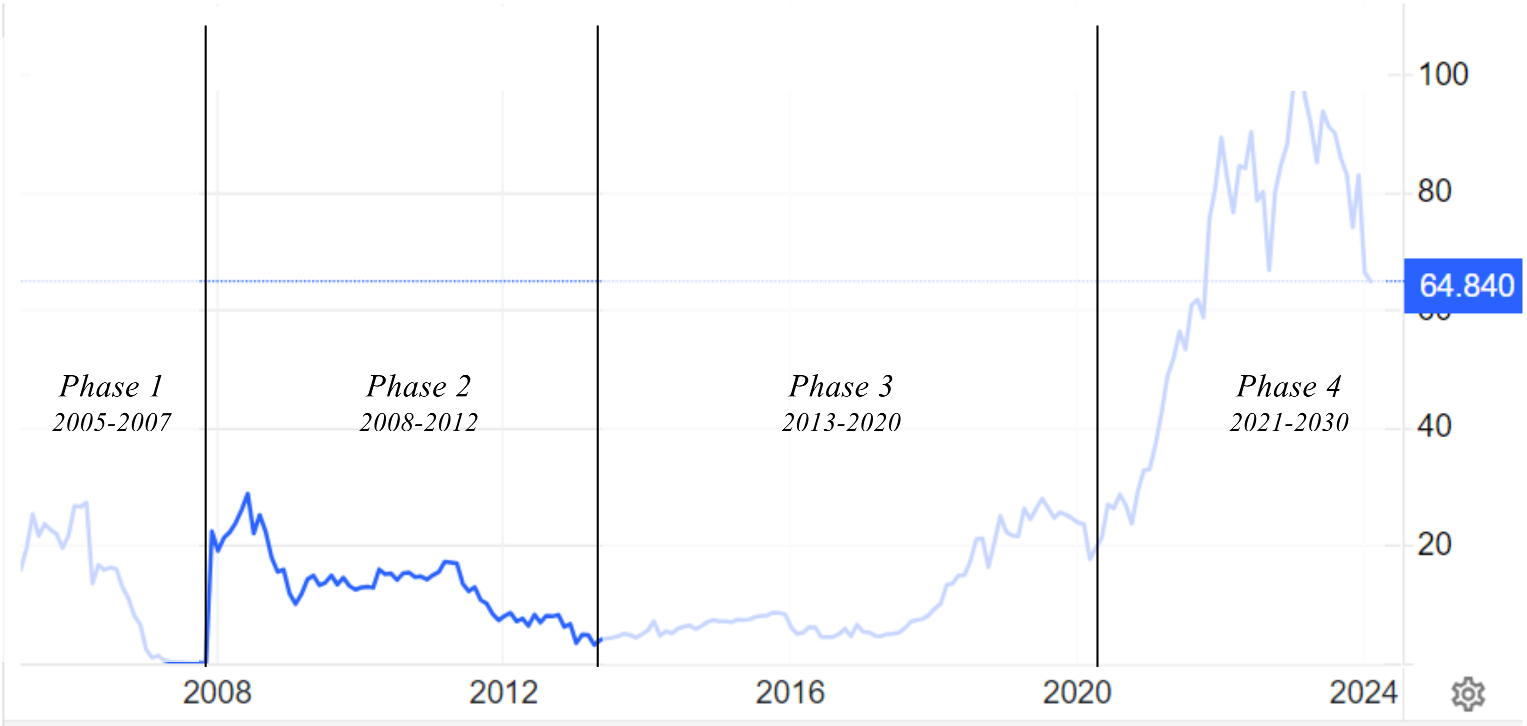


6) The EU-ETS at almost 20 years old

- Offsets: CERs and ERUs have been introduced, in addition to EUAs, in order to comply with two mechanisms set up under the Kyoto Protocol
- The Clean Development Mechanism (CDM)
  - allowed industrialized countries with a greenhouse gas reduction commitment (called Annex 1 countries) to invest in projects that were reducing emissions in developing countries as an alternative to more expensive emissions reductions in their own countries
  - Led to **Certified Emissions Reductions (CERs)** that were and could be used for compliance on the EU-ETS
  - Most CERs came form projects in China (China's development of wind power farms and, as a consequence, of wind power industry, dates back to this system)
- Joint Implementation (JI)
  - allowed industrialized countries to meet part of their required cuts in greenhouse gas emissions by paying for projects that were reducing emissions in other industrialized countries
  - Led to **Emissions Reductions Units (ERUs)** that were and could be used for compliance on the EU-ETS
- Both CERs and ERUs have contributed to making the supply of allowances on the EU-ETS uncontrollable and to lowering the spot price

6) The EU-ETS at almost 20 years old

- Because verified annual emissions data from the pilot phase was now available, the **cap on allowances was reduced** in phase 2, based on actual emissions.
- However, **the 2008 economic crisis led to emissions reductions that were greater than expected**. This led to a large **surplus of allowances and credits**, which weighed heavily on the carbon price throughout phase 2.

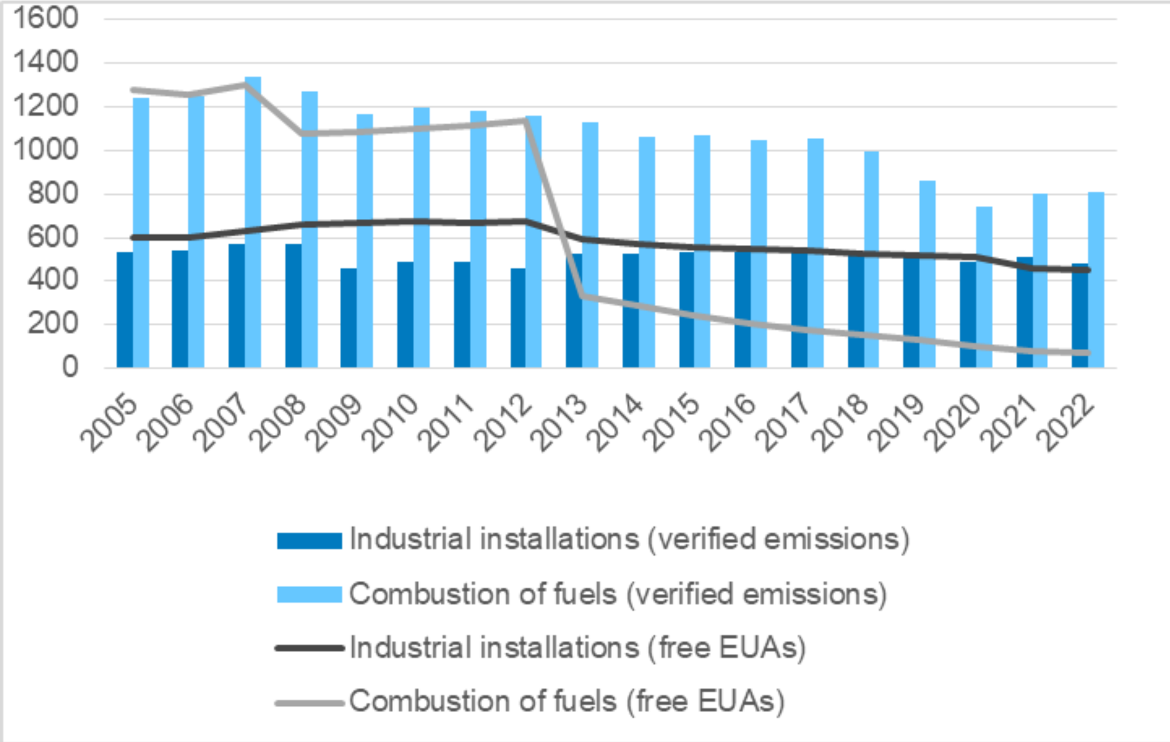


6) The EU-ETS at almost 20 years old

- Phase 3 (2013-2020)
  - The reform of the ETS framework for phase 3 (2013-2020) changed the system considerably compared to phases 1 and 2.
  - The main changes included:
    - a single, EU-wide cap on emissions in place of the previous system of national caps;
    - auctioning as the default method for allocating allowances (instead of free allocation);
      - In practice and because of the threat of a loss of competitiveness, only the power sector had to bid for all its allowances whereas the other sectors still received part of their allowances freely
    - harmonised allocation rules applying to the allowances still given away for free;
    - more sectors and gases included;
    - 300 million allowances set aside in the New Entrants Reserve to fund the deployment of innovative, renewable energy technologies and carbon capture and storage through the NER 300 programme.
  - CERs et ERUs issued during Phase 2 are still valid but the use of new credits obtained after 2012 is prohibited:
    - In relation with the fact that the Kyoto Protocol was initially planned up to 2012 and has been only extended (but not renewed) for the period 2013-2020.

6) The EU-ETS at almost 20 years old

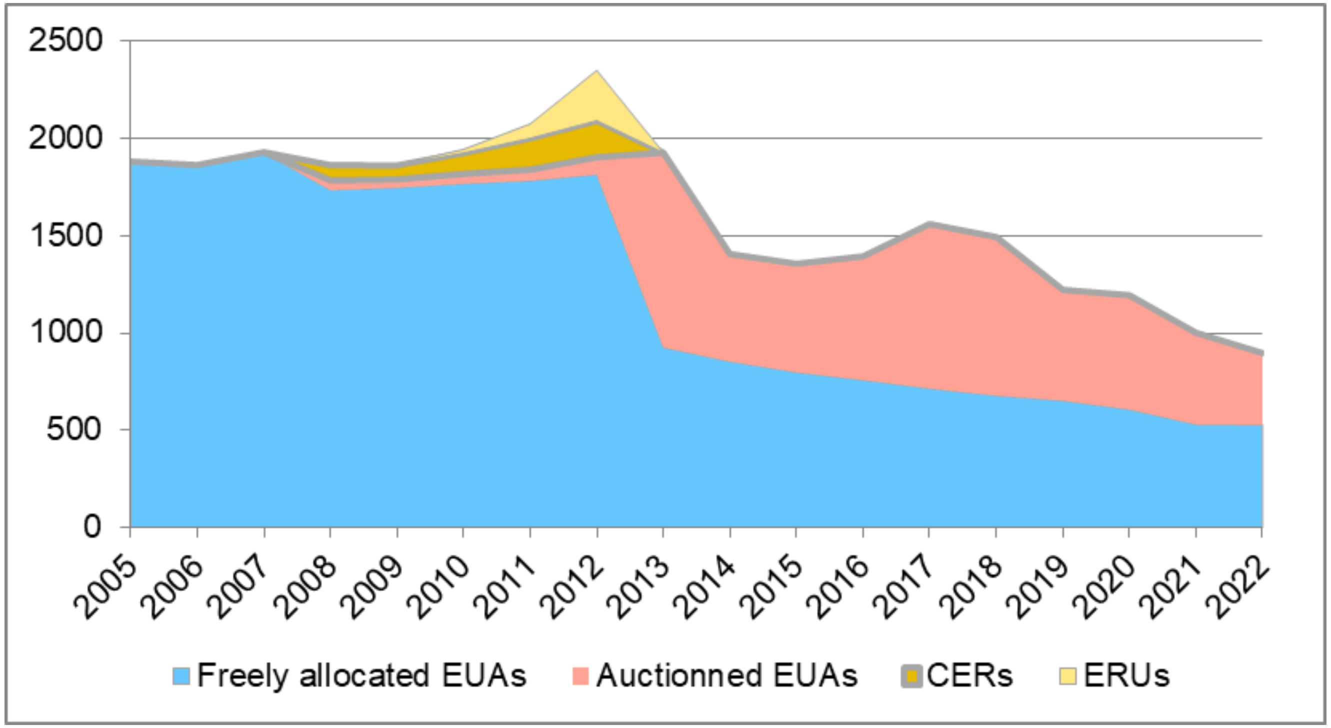
- Changes introduced in Phase 3 are drastic



Source: European Environmental Agency
https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

6) The EU-ETS at almost 20 years old

- Changes introduced in Phase 3 are drastic



Source: European Environmental Agency
https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

6) The EU-ETS at almost 20 years old

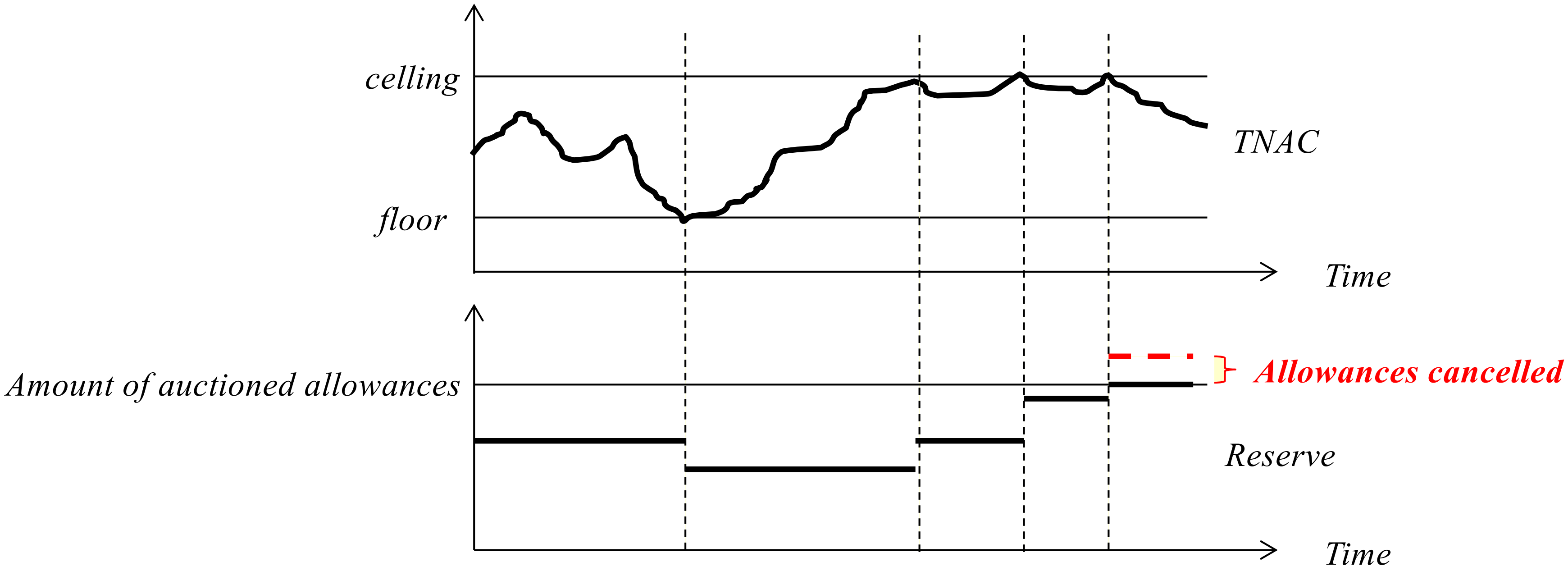
- Due to the large surplus of allowances and credits cumulated all along Phase 2, the spot price remained quite low during several years
- … this effect was reinforced by **poor coordination with other public policies**, in particular direct support for renewable energies through a Feed-in Tariff mechanism that diminished the demand of allowances by the power sector
  - From the very first years of Phase 3, there was a need for further reform

6) The EU-ETS at almost 20 years old

- Reforms introduced during phase 3
  - A first reform has been introduced in 2014 is **back-loading**
    - The EU Commission postponed auctioning of 900 million allowances until 2019-2020
    - This 'back-loading' of auction volumes did not reduce the overall number of allowances to be auctioned during phase 3, only the distribution of auctions over the period changed.
    - As a result, the auction volume was reduced by 400 million allowances in 2014, 300 million in 2015, 200 million in 2016.
  - As only the final cap matters (see slide 13), no significant increase in the price of allowances resulted from back-loading
  - A more long term reform has been introduced in 2019, the **Market Stability Reserve (MSR)**
    - The 900 million allowances that were back-loaded in 2014-2016 have been transferred to the reserve rather than auctioned in 2019-2020.
    - The reserve operates entirely according to **pre-defined rules** that leaves no discretion to the Commission or Member States in its implementation.
    - If the total number of allowances in circulation reaches a predefined celling (floor) a percentage of allowances should be placed in (sold from) the reserve
      - It was initially cap-neutral in the long term and some argued that it would thus have had no effect => it has been reformed before its inception in 2019

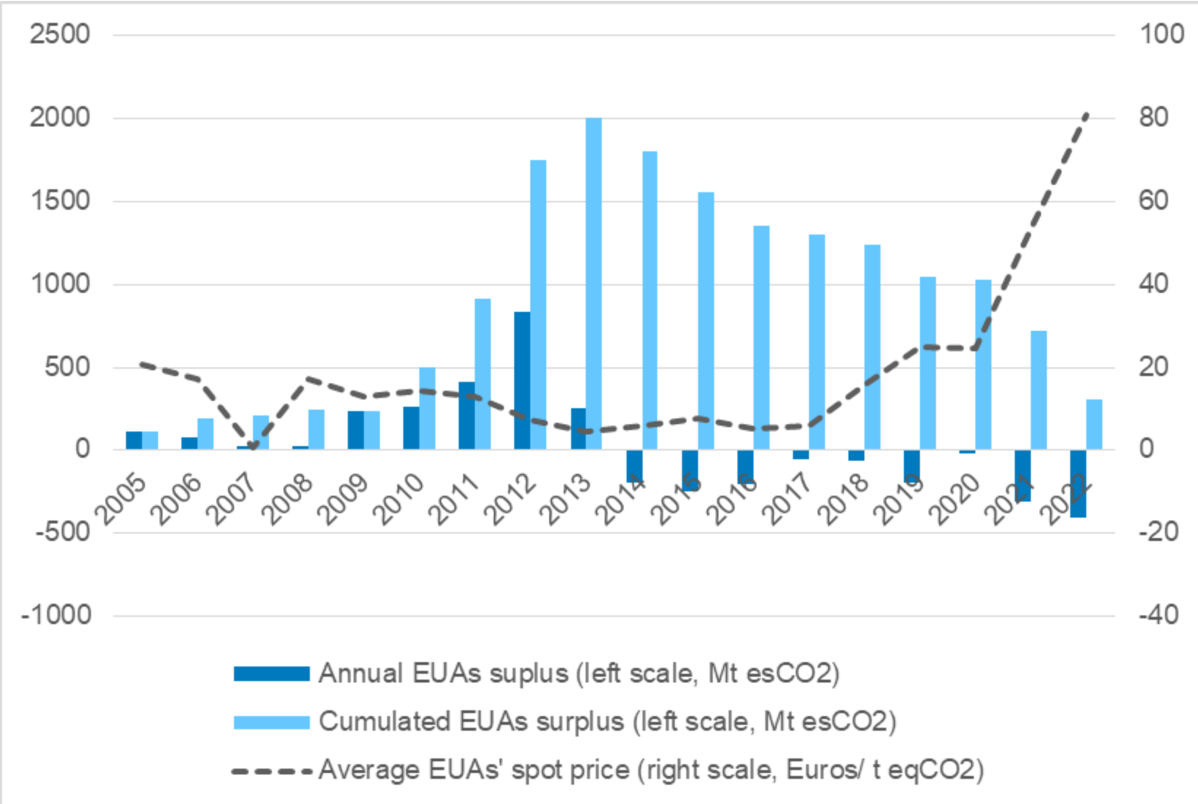
6) The EU-ETS at almost 20 years old

- The key idea of the MSR is to adjust the amount of allowances auctioned to the Total Number of Allowances in Circulation (TNAC)
  - Neutral impact on the price if EUAs are "just" displaced from one year to another one (see section on intertemporal trading)
  - The MSR reduces the supply of allowances if the TNAC reaches a certain celling
    - **+** if the amount of allowances in the MSR exceeds the amount of auctioned allowances, allowances are permanently cancelled from 2023 onwards => increases the price!
  - The MSR increases the supply of allowances if the TNAC reaches a certain floor



6) The EU-ETS at almost 20 years old

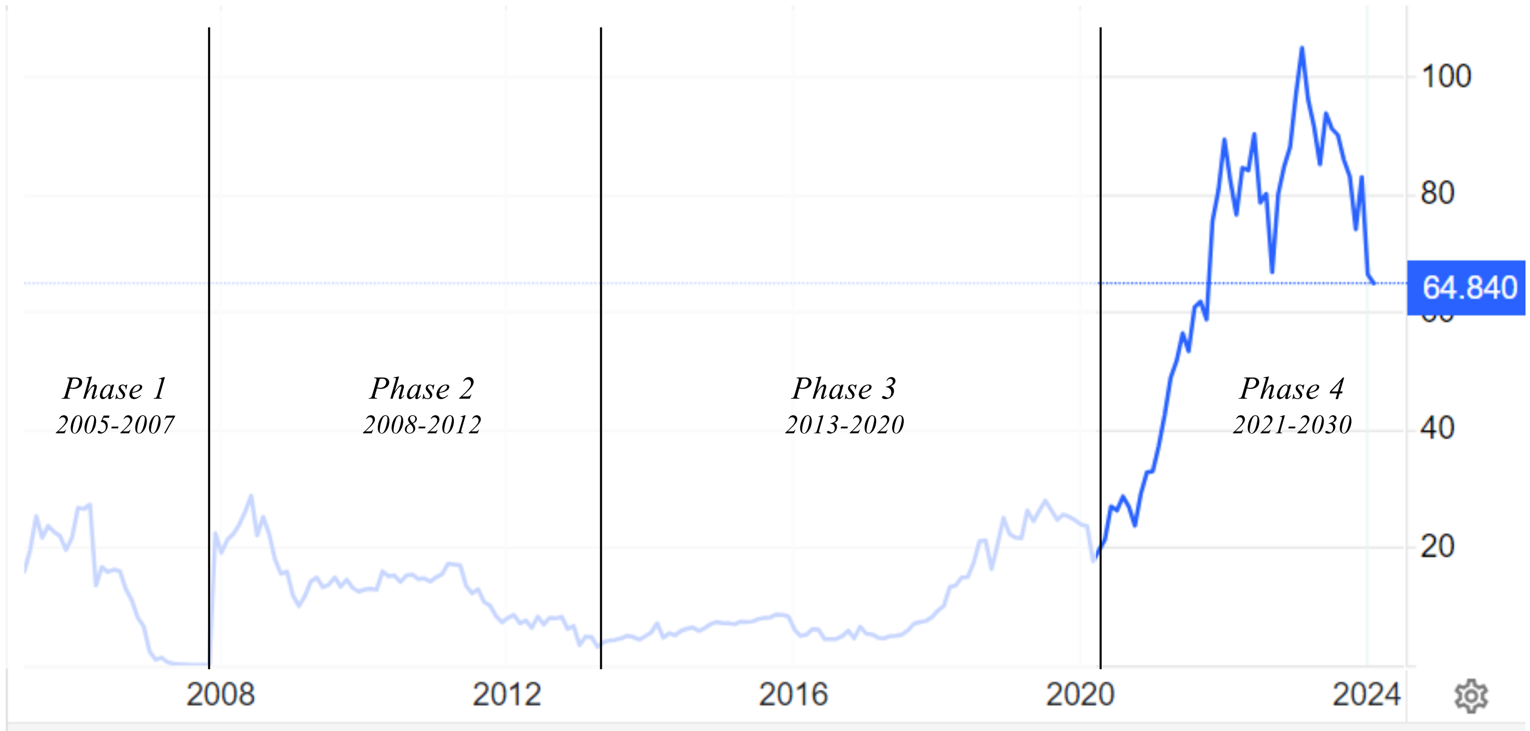
- These reforms and the long lasting efforts to address the excess of supply have been successful in solving the problem (for at least some times…)



Source: European Environmental Agency
https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

6) The EU-ETS at almost 20 years old

- Phase 4 (2021-2030)
  - The EU Commission proposed in its "Fit for 55" package to increase the EU ETS reduction target for 2030 to -61% compared to 2005
  - In conjunction with the MSR (from 2019 onwards), it seems to have resulted in a sharp increase in the spot price



6) The EU-ETS at almost 20 years old

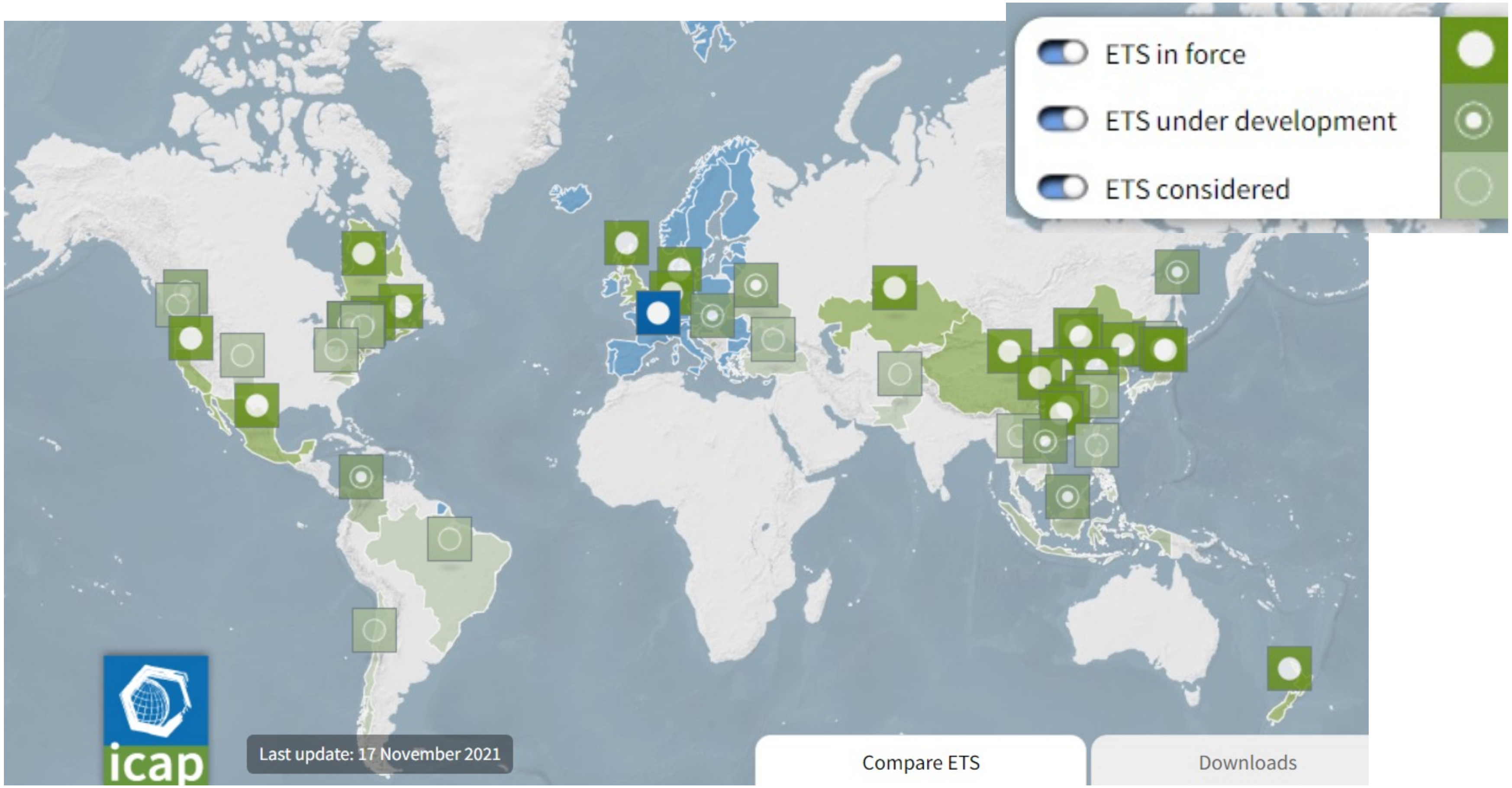
- Key changes have also been introduced in 2023 and 2024
  - The Carbon Border Adjustment Mechanism has entered in force the 1st of October 2023
    - See Chapter 5 for a discussion of the CBAM
  - Rules have changed for the aviation sector on the 1st of January 2024
    - Most of allowances for aviation are now auctioned
    - A compulsory uptake of Sustainable Aviation Fuels (SAF) is put in place in EU airports, with a minimum of 2% in 2025, 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045 and 70% in 2050 (**ReFuelEU aviation regulation**).
    - The price gap between SAF and conventional fuels is compensated by allocating allowances that have not been auctioned to SAF users
      - Aims at boosting the demand for SAF
  - In parallel for the first time companies from countries which voluntary joined the CORSIA will have to offset their additional emissions compared to 2019
    - The **C**arbon **O**ffsetting and **R**eduction **S**cheme for **I**nternational **A**viation has been put in place by the **I**nternational **C**ivil **A**viation **O**rganization
    - Every 3 years emissions have to be offset by financing project of carbon sink (e.g. forestry) that would not be realized in the absence of this extra financial support (additivity criteria)
    - In addition to the EU, US and China have join CORSIA
    - For EU companies, CORSIA covers extra European flights (=> do not substitute to EAUs)

6) The EU-ETS at almost 20 years old

- The **maritime sector is covered** by the EU-ETS since the 1st of January 2024
  - For ships above 5000 gross tonnage
  - 100% of emissions for intra EU routes **AND** 50% of emissions for routes to or from extra EU ports
  - CO_2 emissions in 2024, plus methane and nitrous oxide in 2026
  - Progressive inclusion: compliance on 40% of emissions in 2024, 70% in 2025, 100% in 2026.
- Will be reinforced by the **FuelEU maritime regulation** in 2025
  - aims to support the decarbonization of the shipping industry
  - it will increase the share of renewable and low-carbon fuels (synthetic fuels produced with "green" electricity in the fuel mix of the maritime sector
  - Also sets a well-to-wake greenhouse gas (GHG) emission intensity requirements on energy used on board
- Will be revised in 2027 depending on the final market-based instrument decided by the International Maritime Organization to regulate GHG emissions by the maritime sector at the international level
  - 90% of international trade involves shipping
  - Ongoing discussions to decide which type of market-based instrument will be implemented (carbon levy, ETS, feebate…)

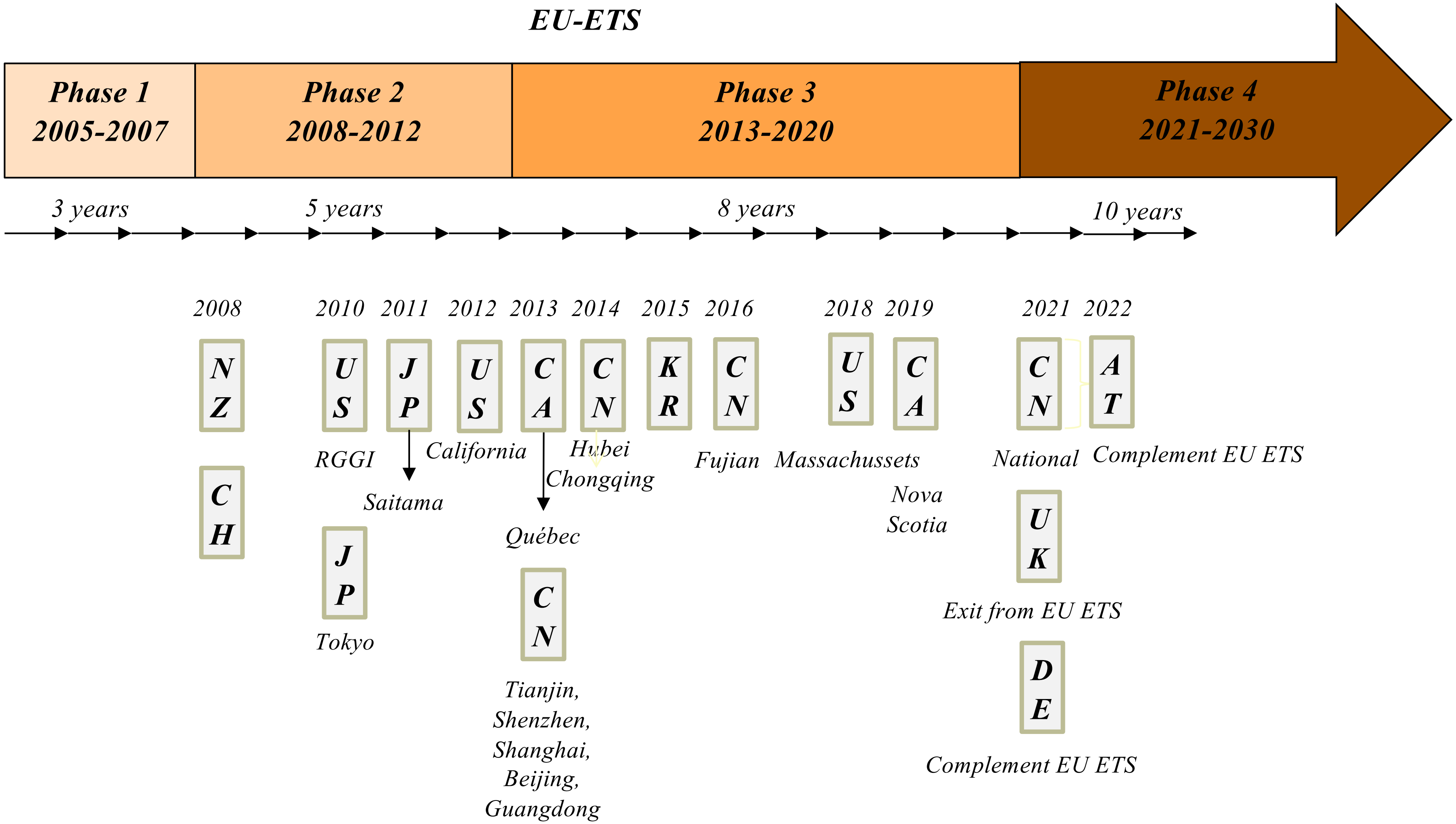
7) Beyond the EU-ETS

Since 2005, other ETS have been put in place all around the world



Source: International Carbon Action Partnership (ICAP) - ETS Map (icapcarbonaction.com)

7) Beyond the EU-ETS



Source: nInternational Carbon Action Partnership