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Anatomy of Emissions Trading Systems: What is the EU ETS?

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ABSTRACT

An anatomy identifies four main components of actual or proposed Emissions Trading Systems (ETS): (1) Pursued policy goals with the ETS instrument; (2) Public authority allocations of permits to the regulated participants; (3) Carbon emissions price levels; and (4) Participants' abatement expenses dependent on the ready availability of affordable abatement techniques or of low-carbon innovation opportunities. These components cover a range of options. A different assemblage of options delivers different ETS exemplars. Two main exemplars are identified. The actual EU ETS is highly successful in meeting the goal of low financial burdens on EU industry, thereby precluding carbon leakage. The other exemplar opts for high carbon emissions prices in the EU to induce industrial innovations towards a low-carbon economy. Incumbent industrial interests oppose this exemplar. Contrary to current policy discourse and to wishful proposals, both ETS exemplars cannot co-exist. ETS anatomy offers insight and structure for thorough analysis and evaluation of existing ETS, resulting in context–specific and appropriate designs of the carbon trading systems.

1. Introduction

The world has seen a substantial increase in the use of carbon emissions trading schemes to mitigate greenhouse gases (Rabe, 2018; Wettestad and Gulbrandsen, 2018). One example is EU's Emissions Trading System (ETS), launched as a cap-and-trade system in its first phase [2005–2007]. Significant adaptations preceded every following phase. The evaluation of what the EU ETS has become and effectuates is contentious (Schmalensee and Stavins, 2017; Rabe, 2018). Opinions about the desirability and functioning of ETS differ among climate policy-makers, stakeholders and scholars (Cramton et al., 2015). For example, Gollier and Tirole (2015) are strong proponents; Schmalensee and Stavins (2017); Woerdman and Nentjes (2019) are conditionally in favor of ETS; Pearse and Böhm (2014) reject ETS as a preferred climate policy choice. Striking a common understanding is difficult for some reasons. Unclear and divergent meanings are assigned to essential concepts, such as 'carbon price', 'emissions cap' and 'efficient emission reductions'. Institutional, political, social, economic, and technical realities may conflict with economics textbook's assumptions. Interests and agendas vary for participants in the debate, including politicians, officials, company directors, consultants, and NGOs (Meckling, 2011). This all causes confusion and misunderstanding about the role of ETS in the climate policy debate. This paper aims to elucidate the ETS debate by offering an analytical framework with clear definitions of key concepts and referring to empirical findings. This framework is an anatomy of ETS, based on the economics ideas and propositions commonly used by ETS proponents. Anatomy is "the art of separating the parts of an organism in order to ascertain their position, relations, structure and function" (Merriam-Webster's Collegiate Dictionary). For keeping the analysis as transparent and tractable as possible, the leanest version of the ETS anatomy is pursued. The anatomy of ETS is complementary to recent studies and reports, analyzing and evaluating ETS (e.g. Marcu et al., 2017; Schmalensee and Stavins, 2017; Narassiham et al., 2018; Wettestad and Gulbrandsen, 2018). The anatomy represents the essential parts and projected functioning of the market-based environmental policy instrument "emissions trading". This explains the central position in the anatomy assigned to pricing, and the by economists announced results of pricing policies, in particular price-induced technological innovation for attaining lower abatement expenses. As a consequence, this paper belongs to the domain of neoclassical economics and microeconomics as part of the environmental economics literature. By focusing on just the anatomy and on the underlying economic theory and assumptions, we deliberately skip an actual evaluation of particular ETS systems (which will be the subject of further study and analysis, where also a more distant position from neoclassical economics will be taken). The value tree methodology (Cummings,

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2006) is used in the anatomy, which involves a philosophically informed analysis to identify and clarify conceptual and technical issues raised by neoclassical economics conceptions of ETS. The conceptual part of the value tree methodology clarifies the fundamental moral values at stake in the design and implementation of ETS. These fundamental values count as the evaluative yardstick for the functioning of an ETS 'organism' as a whole. The technical analysis reveals whether (and to what extent) moral values are likely to be met, given a certain internal composition of an ETS 'organism'.

Interrelated figures support the description of the anatomy's four constituent components: [i] Policy goals pursued by the responsible public authority (the European Union, with the European Commission (EC) as acting administration), [ii] Costs of abatement to realize intended goals, [iii] Pricing of carbon emissions, [iv] Allocations of tradable emissions permits. In the leanest version of the ETS anatomy, the four constituent components are necessary and sufficient to explain the essence of this 'market-based' instrument. However, more aspects are usually considered, e.g. ETS '*design*' studies generally consider a list of *characteristics* (attributes, properties). The U.S. Environmental Protection Agency (EPA, 2001; Smith, 2002) lists eight of characteristics: scope, cap, commodity being traded, allocation of permits, trading ratio, banking, monitoring, and environmental benefit. Wettestad and Gulbrandsen (2018) also adopt eight – albeit different – design *characteristics* for ordering the descriptions of various carbon markets by various authors. Several characteristics (including coverage, emissions cap) need specification when an ETS is practically implemented (Narassimhan et al., 2018).

Compared to the taxonomic studies, the anatomy helps to describe different ETS design varieties, called 'exemplars'. Drawing upon the value tree methodology, it also gives systematic insights in the different values (reflecting ethical theories or stakeholder concerns) related to the four constituent components of ETS. A value tree is a hierarchy of high-level (but general, unspecified) *moral values* at the top, branching into *norms*, more context-specific prescriptions for or restrictions on particular actions or policy designs, further branching in *design requirements* embodying the norms in specific designs. The value tree methodology is applicable when designing products, services or policy strategies ((van de Poel, 2013)). This allows observation of possible value conflicts or 'mismatches', e.g., between what ethical reasoning based on moral values dictates and the interests of stakeholders.

When the ETS anatomy is placed in the context of values and norms, potentially promising results may emerge, for example:

- Facilitating a structured dialogue among actors involved in ETS, resulting in better understanding of each other's arguments. By clarifying the different expectations and involved moral values, contentions become visible.
- Generating new perspectives, opening future deliberations and increasing the solution space beyond prevalent political compromises (Oosterlaken, 2015).
- Improving ETS design processes by identifying influential values and value conflicts a priori, before their incorporation in future ETS designs.

For didactic reasons, the aforementioned components (policy goals, abatement costs, pricing, and allowance assignments) are discussed in the seemingly 'odd' sequence [i], [iv], [iii], [ii] over the Sections 2–5. A comprehensive figure subsequently links the components in 'normal' order for revealing different ETS exemplars in Section 6. Section 7 concludes.

2. Goals of EU policy (component [i])

Standard normal distributed opinions about the EU ETS range from 'complete failure' to 'big success', around a critical but complacent, silent majority. The spread is caused by differences in worldviews, interests fostered, and goals pursued. Performance is ultimately gauged by the degree the instrument is meeting clearly specified goals. Often not a single goal, but several goals are pursued. When the several goals are hierarchical, aligned and matching, the ultimate goal is advanced by realizing sub-goals. Different from being aligned, goals may be far apart or even conflicting. Tinbergen's rule (1952) states that one cannot realize far apart or conflicting targets with a single instrument, neither with some kind of 'balanced' application. Many assume the EU ETS is exceptional, being able to realize the conflicting goals of climate protection and incumbent industrial activity protection[1]. This line of thinking emerges from the hybrid nature of the ETS instrument (component [iv]), and is covered by the dominant discourse on the superiority of amalgamated emissions trading (Aldy et al., 2010; Gollier and Tirole, 2015; Schmalensee and Stavins, 2017).

The EU ETS strives to reconcile two different policy goals, which are labeled as:

- **A**-goal for Atmospheric stability and cleanness, and
- π-goal for Profit-Protection of incumbent companies emitting voluminous amounts of carbon.

The value tree methodology relates policy goals to moral values, norms and design requirements, which will be elaborated below in the context of ETS.

The **A**-goal can be formulated as follows: '*In all industrial activities, carbon emissions should be brought down to a (almost) zero level by the nearest date (at least 80–95% emissions reduction by 2050)*' for contributing to the global mission of reducing carbon emissions to non-dangerous levels (UN, 1992; IPCC, 2014; EU, 2003). Such an **A**-goal may be seen as the non-negotiable baseline of climate policy (Brown, 2010). It is based on the moral value that we should act on climate change now, not because the future costs of inaction exceed those of mitigation, but because the failure to mitigate harms others. This overarching moral value translates into the norm (or sub-goal) for climate policy designs: '*Induce thorough and disruptive innovations to make European industrial activities (almost) carbon-free'* (component [ii]). The ETS community (including economists) generally considers innovation as mainly price induced with the subsequent design requirement for ETS: '*Increase carbon emission permit prices to sufficiently high levels for permanently inducing decarbonizing innovations at a speed and depth as required by the **A**-goal'* (component [iii]).

The EU's and Member States' responsibility for the economic welfare of the region's citizens is expressed in the π-goal as: '*Maintain (preferably expand) EU's industrial activities, business and employment*', with as a subsequent ETS design requirement: '*Protect energy-intensive industries and avoid carbon leakage caused by high permit prices (or tax rates) on voluminous carbon emissions*'. In other words: the ETS should not occasion significant financial burdens (compared to other world regions) on Emissions Intensive, Trade Exposed (EITE) activities. The π-goal differs from pursuing 'reductions of greenhouse gas (GHG) emissions in a cost-effective and economically efficient manner' (EU, 2003). 'Carbon leakage', mainly seen as an economic-financial question and less as an environmental issue (Marcu et al., 2017, p. 18), is of high concern in EU climate policy (Heilmayr and Bradbury, 2011; Böhringer et al., 2012; Juergens et al., 2013; Zeng et al., 2018). The absence of carbon leakage in EU's industrial activities (Dechezleprêtre et al., 2014; Marcu et al., 2017; Joltreau and Sommerfeld, 2018), witnesses the priority of the wider π-goal in EU's climate policy making.

Nevertheless, some industrial activities are moved from the EU to overseas (mainly Asia) due to price differentials in production factors other than fossil fuels and their related emissions. Assessing the extent of this type of displacements is important to identify the actual meaning and proper size of the emissions *cap* on industrial stationary sources in the EU ETS (which is a design requirement), and to evaluate the environmental effectiveness (or: efficacy) of the instrument (Narassimhan et al., 2018). Emission caps can (and should) be lowered when carbon-

Fig. 1. Component [iv] Allocation of tradable emissions permits.

intensive material, half-finished, and finished products are imported from outside the EU (Mehling et al., 2018).

3. Allocation of tradable emissions permits (component [iv])

Starting an artificial market for trading atmospheric pollution space faces creational problems both at the market's demand and supply side. One issue is how participants obtain the permits, as they are mandated to yearly deliver an amount equal to the tons of carbon they emitted in the previous year, and to pay a penalty for the amount of emissions not covered by permits (Ellerman et al., 2000; Hepburn et al., 2006; Heilmayr and Bradbury, 2011).

Fig. 1 shows the range of available allocation options, some of which have been applied. The green-to-brown box, listing the allocation possibilities of permits, reflects the hybrid character of the various allocations as ETS design options, with each option differing also in financial impact on the participants.

A first possibility is a public authority auctioning the yearly total quota of emissions in a competitive bidding among all participants, excluding the opportunity of banking. When the cap is meaningfully lower than the sum of historical non-regulated emissions, the auction would settle at a positive price. Repeating auctions year after year, while reducing the cap according to stepping up climate change mitigation exigencies, would create an increasingly stronger carbon price signal. The financial burden on emitters would increase when they cannot command the means to reduce their emissions keeping pace with increasing permit prices (component [ii]). This version of carbon emissions trading is awfully akin to levies (carbon taxes) set by a public authority. This first possibility of starting the EU ETS was unacceptable for the ETS supporting carbon coalition as an anti-taxation alliance of big emitters (Ellerman and Buchner, 2007; Meckling, 2011).

Descending from top green to bottom brown in Fig. 1 means passing consecutive '*levies-permits*' cocktails. At the bottom the allocation resembles familiar emissions permit assignment regulation. Public authorities assign free emission permits to the various sources according to their demands, tempered by the standards of '*Best Available Technologies'* (BAT). A performing permits assignment system requests reliable knowledge about emission sources, about actually applied and best available technologies, and about expenses of abatement measures, among other things (Ellerman et al., 2000; Aldy et al., 2010; Juergens et al., 2013). When this information is lacking, 'grandfathering' (free allocation based on historical emissions) is a crude approximation of diligent permit assignment.

With standard permit allocations, companies cannot transfer surplus permits. In an ETS, surplus permits are transferable and generally bankable. At the beginning of the EU ETS, the intention was to cap-and-trade emissions within sequential phases of a number of years, without banking across the phases. Permit trade may reduce the total sum of abatement costs, which is the major selling point of ETS (Stavins, 1995; EC, 2000). More exchange is triggered the more the initial permit distribution over the participants was economically inefficient, i.e., when the numbers of permits received by the various participants are not based on the equalization of their marginal abatement costs (Stavins, 1995). For an administrative allocation of permits to installations equalizing their marginal abatement costs, the necessary information and know-how are lacking (Ellerman and Buchner, 2007; Juergens et al., 2013). The implementation of the ideal economic permit allocation principle becomes more illusionary the more diverse the emission sources are. When an ETS is limited to one sector or sub-sector of economic activity with rather homogeneous production and abatement technology (such as electric power generation), a workable proxy of the ideal marginal abatement cost based economic allocation could be attempted.

Another trigger to an exchange of permits is the growth or decline of company activities causing carbon emissions. 'Grandfathering' in permit assignment increases the likelihood of rewarding incumbent laggards at the expense of dynamic business activities. Hence, volumes of trade in an ETS may correspond to the degree of distorted allocations. In case of free permit assignment, assessed benefits of trade in the ETS are actually a measure of the extent of economic bias in the initial assignments. Notwithstanding the economic biases caused by free allocation of permits, free permits were the main driver of the carbon trade coalition to advocate emissions trading (Stavins, 1995; Markussen and Svendsen, 2005; Meckling, 2011; Pearse and Böhm, 2014).

In the 3rd phase [2013–2020] of the EU ETS, almost half of the permits are auctioned: at the middle of the stack in Fig. 1, a hybrid ETS was created (Woerdman and Nentjes, 2019). EITE industrial activities get free permits to preclude carbon leakage. Non-exposed activities, mainly electric power generation, must obtain their shortfall in permits via allocation auctions or purchase transactions (for instance from excess stocks obtained by EITE industrial companies). The bills of purchased permits for emissions of electric power plants largely end up on the invoices paid by electricity customers (Gullì, 2008). Depending on the market structure and regulatory conditions, power companies may charge significantly higher amounts than their actual bills for obtaining the permits. The differences are generally named 'windfall' profits. However, other name labels, such as 'excess' or 'monopoly' profits, better clarify the deliberate construction of the money skimming from electricity customers that are mainly non-ETS electricity users (Point Carbon, 2008; CAN, 2018)

Member States may reimburse EITE companies 75%–85% of the permit-price driven charges on their electricity bills (COM, 2012; EU, 2018). This money comes from permit auction revenues distributed by the EC. The customers outside the ETS receive no rebates, which ultimately means that they pay the ETS to function. This unveils the standard mantra of 'ETS puts a price on industrial carbon emissions'.

Permit allocations relate to the moral value of distributive justice. At the most general level, distributive justice implies that "*people should be treated equally unless there are morally relevant reasons for treating people differently*" (Brown, 2010). In practice, two considerations determine whether an ETS exacerbates or reduces inequality (Caney and Hepburn, 2011): the impact of higher emissions costs on different industrial sectors, and the wealth transfers by billing free allocated emissions allowances. When significant windfall profits are observed, ETS designs conflict with baseline expectations on distributive justice.

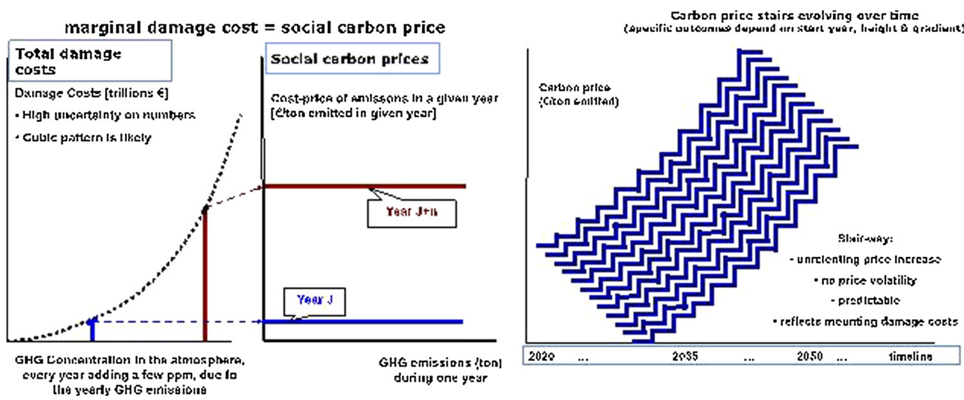

Fig. 2. Component [iii] Carbon emissions pricing.

4. Carbon emissions prices (component [iii])

In the climate policy debate, setting ‘the carbon price’ is the holy grail of economists (Aldy et al., 2010; Cramton et al., 2015; Wagner et al., 2015; Stiglitz and Stern, 2017). In climate policy circles, however, the carbon price is linked to various moral or empirical foundations, origins and meanings, including:

a) Welfare-maximizing emissions prices
b) Incentivizing prices for emitters to reduce their GHG emissions[2]
c) Permit prices observed in emissions trading systems (in case the EU ETS)

The kind and amount of information necessary to assess the proper level of actual prices as a design requirement for ETS is unduly complicated and enormous in case (a), still very intricate and extended in case (b), and rather trivial in case (c) because spot and several future prices (derivatives) are daily posted in carbon markets. The significance of the three kinds of carbon prices is different.

Ad (a) Welfare-maximizing emissions prices

Environmental economics propositions about optimal emissions quantities and corresponding emissions prices are based on minimization of the sum of two groups of costs. One group consists of damage costs, rising with higher levels of pollution (for climate change, pollution is measured by the GHG concentration in the atmosphere). Damage is a public bad, or less damage is a public benefit. The other costs are abatement[3] or mitigation expenses incurred for reducing emissions. Abatement is a polluter’s duty according the polluter pays principle (OECD, 1972). Minimizing the sum of damage costs and abatement expenses indicates the economic optimum level of pollution and of emissions. At these pollution and emissions levels the marginal damage cost equals the marginal abatement cost, which is labeled the ‘social optimum price’ or the ‘social cost of carbon (SCC)’.

The elegance of this logic is of dazzling simplicity, but practically applying the logic is an arduous mess. Implementation starts with the challenge of properly relating the optimal pollution level (in the public sphere of nature and environmental common goods) with the optimal emissions level (in the private sphere of emitters causing the emissions). Abatement expenses are amenable to identify and gauge, because they are mostly immediate, while uncertainties are manageable, and investments are revocable. Scholars (Kolstad, 1996; Pindyck, 2000) confused irrevocability of investments with intractable irreversibility of losses in unique commons like atmosphere and climate stability (Verbruggen, 2013). Incentivizing prices (case (b)) are (or should be) based on evaluations of abatement (mitigation) expenses.

Assessing public damage costs is tricky and its results are highly unreliable when the costs are spread over long periods (sometimes up to millennia or even eternity), with cost drivers that are highly uncertain and moreover poorly or not reversible (for example, the concentration of GHGs in the atmosphere and its direct effects such as temperature and sea-level rising). Reliable estimates of the global and long-term damage costs of climate change are beyond human capability.

However, some scholars and institutes have dared to derive numbers. For example: In 2002, the UK Government Economic Service recommended an illustrative estimate of SCC of £70/ton[4] carbon, within a range of £35 to £140/ton, for use in policy appraisal across government (Watkiss, 2005). The author emphasizes the difficulties to obtain reliable numerical outcomes. Aldy et al. (2010, p.911) note: ‘Especially striking is the difference between Stern at $85 and Nordhaus at $8 per ton of CO_2 – a difference largely dependent on discount rate assumptions’. Also Weitzman (2013) problematizes the impact of risk-modified discount rates on assessments of the SCC. Pindyck (2017) observes SCC marginal price ranges in the literature from around $10 to well over $200 per ton CO_2-eq emitted. Notwithstanding huge uncertainties over very long horizons of climate damage, Pindyck estimates an average SCC at around $100/ton.

Avoiding the pitfall of spurious quantitative accuracy, only the shape of a ‘carbon emissions price stair’ is logically deducible from qualitative information about climate change damage costs (Fig. 2). The left panel of Fig. 2 holds a graph with as driving variable (on the horizontal axis) the atmospheric GHG concentration. Due to yearly emissions of ca. 50 billion tons of CO_2-eq the GHG concentration goes up with a few ppm year after year (IPCC, 2014). The vertical axis is a measure of the damage costs in trillions of euros (€). The dashed curve expresses a likely exponential pattern with high uncertainty about actual cost numbers. Two vertical bars placed at a time interval represent two net ppm additions during an earlier and a later year. The consecutive yearly net GHG additions accumulate to the total GHG concentration, a summary indicator of all human-induced drivers causing climate change.

The middle panel of Fig. 2 shows the flat carbon price in €/ton-emitted for all emissions during a given year. This social cost price is derived from the first panel of Fig. 2 via the slope of the total damage cost curve at the top of the bar in a given year, equaling the marginal damage cost. When total GHG concentration increases, the curvature of the total damage cost function becomes steeper and the derived flat carbon prices during a year are positioned higher and higher (Richardson and Fraas, 2013).

The third panel of Fig. 2 represents the information of the middle panel, assembled for a sequence of tens of years (the timeline on the horizontal axis). With time passing the SCC goes up. When connected year after year they deliver a stair of carbon prices, which would drive the carbon emissions in the right direction and would charge the occasioned climate change damage costs on the emitters. Notwithstanding the huge uncertainty about the real numbers of damage costs, as a corollary about the proper height of the risers and treads of the carbon price stair, the stair shape supports a *pattern of unrelenting price increase over time without rebound and without volatility*. The multifold of parallel stairs in the third panel of Fig. 2 reflects the huge uncertainty about the numbers (Watkiss, 2005; Aldy et al., 2010; Weitzman, 2013; Pindyck, 2017).

If year-by-year emissions were charged by levies of the appropriate level, public authorities would collect financial means to compensate experienced damages, or to finance adaptation measures. To practically implement such levies, policy faces impediments, such as: (1) assigning numerical values to the levies; (2) resistance of most constituencies against levies, alias against paying for the public good; (3) allocation of the damage compensations or adaptation budgets.

Ad (b) Incentivizing prices for reducing GHG emissions

Here the focus is only on the abatement (mitigation) expenses. The purpose is to minimize the sum total of expenses polluters incur when meeting set emission reduction targets over a given period. This type of pricing is discussed in Section 5 about abatement costs.

Ad (c) Observed permit prices in ETS

In theory, the permit price in a cap-and-trade system results from an equilibrium between the supply of permits and the demand for permits. In the artificial ETS market, administrative rules create supply and demand. The EU planned to establish the artificial markets in consecutive, independent phases, uniformly covering all major emission sources facing the inelastic supply of a single cap. This approach was most congruent with the theoretical model announcing high performance on criteria such as environmental effectiveness, cost-effectiveness and dynamic efficiency through innovation induced by the permit prices.

However, thirteen years of experimenting showcased considerable deviations from the theoretical concept. The EU ETS exhibited volatile prices in its first and second phase, and administrative interventions manufactured acceptable permit prices for the participating companies, the MS and the EC. Reforms agreed in November 2017 for phase 4 [2020–2030] institutionalize a variant of price controls via a quantity-based correction mechanism, called the Market Stability Reserve starting in 2019 (EC, 2015; Brink et al., 2016; Hepburn et al., 2016; Perino and Willner, 2017; EU, 2018; Wettestad and Gulbrandsen, 2018).

An anatomy study cannot address whether the resulting ETS prices are in conformity with welfare-maximizing prices or whether those prices are sufficient to incentivize least-cost emissions reduction pathways. However, concerns expressed about the low ETS prices by many scholars (e.g. Edenhofer et al., 2017), policy-makers and NGOs (Carbon Market Watch, Sandbag) seem to suggest a significant shortfall of the permit prices posted on the trade boards. Since the end of 2017, quoted prices follow a growing trend within a volatile band (https://markets.businessinsider.com/commodities/co2-emissionsrechte).

5. Costs of abatement (component [ii])

As textbook economics prescribes, carbon emission permit prices should be set at sufficiently high levels for permanently inducing decarbonizing innovations at a speed and depth as required by the **A**-goal. In this section, we focus on the cost of abatement (mitigation), i.e., on the perspective and interests of private actors causing the GHG emissions. When stricter standards or higher prices on emissions are imposed, extra emission reductions by regulated activities are due for compliance with either legal mandates or economic rationality. Putting a price on emissions creates economic incentives for the emission sources to reduce the emitted quantities as long as the marginal cost of abating is lower than the permit price or levy rate. Extra reduction means extra abatement spending. Generally, short-term marginal abatement costs (MAC) are running up, from shallow to steep, the higher the reduction percentage of emissions by particular activities becomes (Fig. 3). The description in this paper is based on aggregate MAC (the horizontal addition of the MAC curves of all regulated emission sources, i.e. their demand curves for emission permits). The aggregate curve encompasses very different activities under very different conditions.

The top graph in Fig. 3 shows three 'static' benefit-cost equilibriums in three consecutive [1,2,3] periods (e.g., decades). The marginal abatement cost (MAC) curves start at a point on the horizontal axis (for example q° for the period 1 curve); this point corresponds to the amount of emissions without extra abatement effort, avoiding extra abatement spending. The minimum of the sum of damage costs and abatement costs is obtained where marginal damage cost (which is the social carbon price line; Fig. 2) cross the marginal abatement cost curve at point S^1, indicating the economic social optimum level of emissions q^1.

By accumulating and integrating innovation, technical progress and learning, the marginal abatement cost curve is expected to shift to the left, showing lower abatement costs. In period 2 a new equilibrium is established: the higher carbon price line at P^2 and the shifted MAC curve deliver equilibrium S^2, at emissions level q^2. Similar logic applies when shifting to period 3.

The dynamic efficiency transition from q^1 over q^2 to q^3 (and so on) complements static efficiency in one period, and is key in making low and zero-carbon emission industrial activities feasible and economically affordable.

Realizing dynamic efficiency shifts connects to policies and instruments for promoting inventions and innovations (Jaffe and Stavins, 1995; Grübler, 1998; Fischer and Newell, 2008; Calel and Dechezleprêtre, 2016). Within the scope of financial incentivizing, different visions on economic mechanisms suggest other approaches. For example, German renewable energy policy was effective in market creation for renewable wind and solar technologies by direct project subsidies (Agora Energiewende, 2013). The program was also efficient without excessive rents by careful technology-specific regulations (Verbruggen and Lauber, 2009). Despite the incredibly fast and thorough technological success of photovoltaic and wind electricity development and deployment realized in Germany, largely financed by non-ETS electricity consumers, economists complain that it was not market based and thus too costly (Frondel et al., 2009).

In climate policy economists prefer and advertise price-induced innovation (Fischer and Newell, 2008; Aldy et al., 2010; Cramton et al., 2015). This is also inherent in ETS advocacy, expecting innovation success as a result of increasing and high prices on carbon emissions. The foreshadowed effect of price-induced innovation is graphically illustrated in the bottom-left graph of Fig. 3. When carbon prices increase, the financial rationale for polluters is to decrease emissions. At starting (low) carbon prices, the readily available abatement options are the only way to reduce emissions. When prices increase by multiples and remain at robust heights (Fig. 2), moving along static short-term MAC curves will result in skyrocketing abatement costs, possibly even leading to bankruptcy or to significant leakages as drastic remedies to reduce emissions. Hence, polluters will search for inventions and innovations to shift abatement cost curves downwards (e.g. Woerdman, 2019), allowing bigger steps in emissions reduction (from I^1 over I^2 to I^3 in the bottom-left graph, resulting from economic cost minimizations at the crossings S^1, S^2 and S^3). When no innovations are feasible, high permit prices would crush the output levels of carbon-intensive products and services supplied by the regulated companies.

When innovation works and the (short-run) MACs are shifting leftward, the dashed curve through the points S^1, S^2 and S^3 is the long-term marginal abatement cost curve. In this curve, accumulated learning, innovations and inventions over the foregone years have been incorporated.

By accelerated technological development of mainly wind and solar power (though realized by renewable energy policies outside the ETS), electricity generation is exemplary for a path to full de-carbonization of a crucial industrial, economic and societal activity at affordable and lowering expenses[5]. Other industrial activities may use carbon-intensive technologies that are difficult and expensive to replace by low-carbon technologies (Hepburn et al., 2006; Juergens et al., 2013). Then, high carbon prices would merely extract high financial transfers from

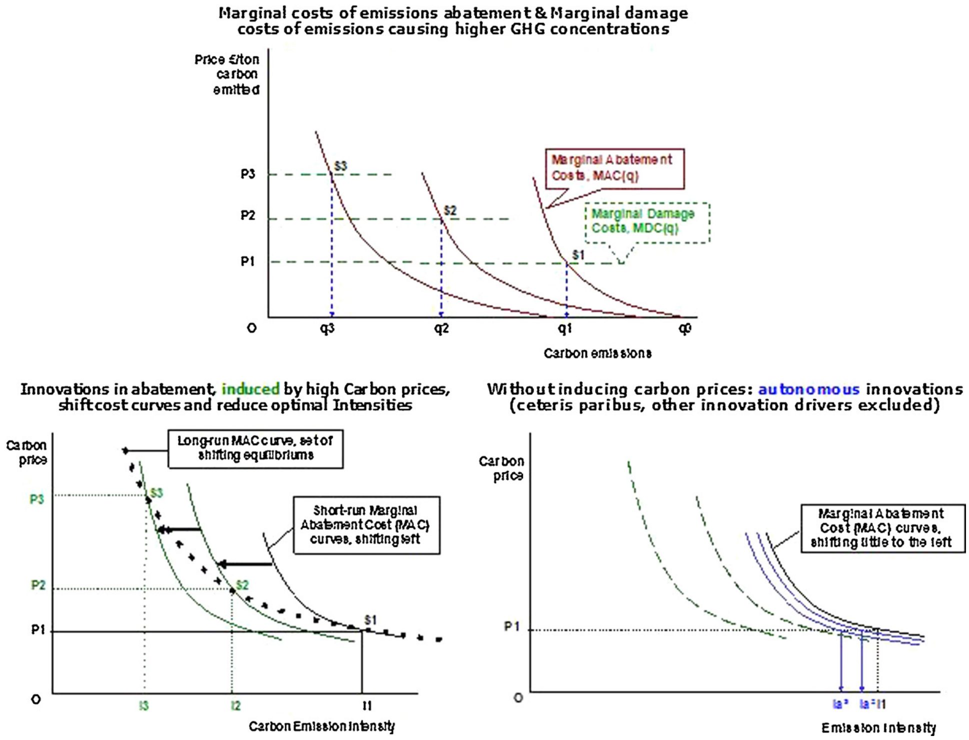

Fig. 3. Component [ii] Marginal abatement costs and price-induced innovation.

emitting activities without effective inducement of innovations.

This helps to explain why several industrial sectors initially manifested reluctance towards the adoption and implementation of the EU ETS. The reluctance faded when the financial department of the major companies took over from the engineering departments, which were responsible for environmental issues and aware of technological feasibilities. Company reluctance turned into support by experiencing that the EU ETS offered free permits and that posted carbon prices were low. Moreover, positive prices offered revenue opportunities when the company was over-allocated in permits, and in the rare cases of under-allocation the prices were only applied on the fringe emissions of these companies. Their carbon emissions bills were low and hardly sufficient as financial inducement to vigorous low-carbon innovation, apart from some minor innovations (Calel and Dechezleprêtre, 2016).

By lack of the pressure from high and rising carbon prices and related bills, only 'autonomous' innovations in reducing carbon emissions emerge. This arguably limited progress is then based on spontaneous improvements in techniques, processes and industrial practices, developed anyhow in modern industrial economies, for instance to reduce fossil fuel bills. The bottom-right graph in Fig. 3 illustrates the small shifts of the MAC curves and the little reductions in emissions intensity; the two dashed curves nearer to the ordinate axis are included in the graph as representation of non-realized technological emissions reduction opportunities.

6. Linking the four components of ETS

The four ETS components are juxtaposed as sewn stacks in Fig. 4. Different combinations of the various options in the stacks generate different carbon ETS exemplars. However, combinations cannot be assembled arbitrarily. Realistic combinations belong to horizontal bands cutting through the four stacks. Differing GHG abatement costs (stack [ii]) explain the wide span of companies' willingness to reduce their emissions. The aggregated MAC curves cover a range from shallow to sticky-steep curves. Neoclassical economics accepts the aggregate as representative because ETS trade equalizes marginal abatement costs of all companies. Trade also installs maximum cost-effectiveness. Reducing abatement costs over time by innovation is the result of the uniform price on emitted tons of GHG. Here the link with stack [iii] is important: the higher the price the more inducement of innovation (= shifting MAC to the left). In the artificial market of emissions permits, the tightness of the policies determines the height of the price (levy on the emitted ton GHG). Stack [iv] shows a range of options an ETS exemplar can adopt for setting the prices (stack [iii]), with decisive impact on innovation and emissions reductions (stack [ii]), which correspond with the attainment of particular de-carbonization policy goals.

Two combinations, linked to the two major goals described in Section 2, are highlighted.

The EU's dominant combination runs over the bottom of Fig. 4, because the π-goal has largely overwhelmed the **A**-goal. Abatement spending for EITE activities is low to zero to preclude carbon leakage. The permit price is only applied on the fringe – if any – of ETS companies' emissions in periods [2005–2007] and [2008–2012], and on a subset of the emissions in period [2013–2020], mainly the carbon emissions of fossil-fired electric power generation plants. The permits were predominantly grandfathered, and since phase 3 attributed as free emission permits based on product benchmarks for sanctioning growth of the EU based activities of the corporate industry. This exemplar of carbon ETS is welcomed and supported by the major corporates (Markussen and Svendsen, 2005; Meckling, 2011; Verbruggen et al., 2015).

The alternative for the dominant EU exemplar, and favored by green NGOs (such as CarbonWatch, Sandbag), is a combination flying at the ceiling of Fig. 4, with the **A**-goal prevailing. Then, industrial activities must fully de-carbonize without delay, requesting a thorough innovation of products, services and technologies. As economists generally prescribe, carbon pricing should induce the necessary innovations. For activities with 'sticky' technologies the carbon price should stay at the highest treads of the carbon emissions price stair, before significant change starts. The allowances quota would be capped severely, with auctions in order to maintain stringent regulation. This alternative ETS exemplar may be the hope of green NGOs, but unlikely to come to life. Basically, the EU ETS is not up to this challenge, because of the following factors.

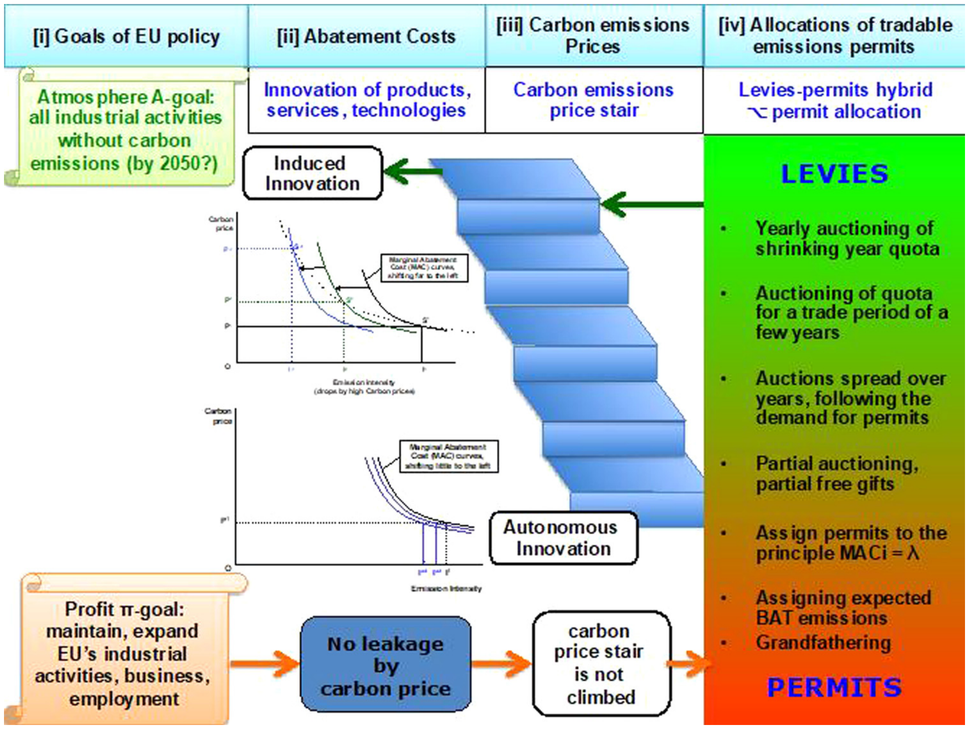

Fig. 4. ETS anatomy consisting of four components and their relations.

First, EU ETS advocates adopt the mathematical Lagrange principle for ubiquitous coverage to obtain equal marginal abatement costs overall. This supports their claim on superior efficiency for ETS. However, the EU officials are confronted daily with the broad and intense diversity of activities, technologies, and contexts, which determine essential characteristics of the emission sources, in particular their marginal abatement cost curves. Rather than addressing the diversity, all sources are amalgamated under a single umbrella. However, the equal-marginal cost rule is broken by free assignments of permits to additional emissions from EITE activities, now depending on specific benchmarks (Woerdman and Nentjes, 2019; Heilmayr and Bradbury, 2011).

Second, by amalgamating all sources, attention for their differences is narrowed down to focusing on trading opportunities, overlooking the discrepancies in real technologies and their capabilities in reducing the carbon intensity of industrial activities. Considering actual technologies is necessary, to measure how sticky they are regarding price-induced innovation, and to find ways for significant reduction or elimination of GHG emissions. 'The EU ETS on its own may not provide sufficient incentives for fundamental changes in corporate innovation activities' (Rogge et al., 2011).

Third, applying the uniform carbon price EU-wide or worldwide is a dysfunctional myth (Bataille et al., 2018). The social carbon price is unknown and largely unknowable, but certainly it is several times higher than the past range of €5-€25 per ton CO_2 in the EU ETS. The higher price may not be volatile and should be applied on all emitted volumes, not only on the fringes. A significant increase of the price of carbon emissions permits and of the related bills would create a high financial burden on industrial activities, especially the ones with sticky abatement cost curves due to lacking de-carbonization technologies. Leakage due to carbon pricing would then become a more likely reality. A price shock might even lead to devastating economic impacts on the EU industry. The coalition keeping the present EU ETS alive on intensive care would probably walk away from the high permit price ETS exemplar and let it die.

7. Conclusions

The anatomy study is analytical and descriptive of mainstream ETS thinking, hence not a comprehensive evaluation of any ETS. Sections 2–5 describe and comment upon the main components of a carbon ETS. Section 6 documents the relations between the components and two carbon ETS exemplars: the π-goal (profit-protection) pursuing exemplar, which is a clone of the EU ETS; and the **A**-goal (atmosphere) pursuing exemplar, which, according mainstream ETS thinking, requires high permit prices to induce innovation and is unlikely to be implemented with the present power distribution over the engaged stakeholders. This inconvenient truth tends to be obfuscated by 'pragmatic' ETS experts and academics working within the confines of the 'politically feasible'.

The EU ETS, successful in meeting the π-goal, is likely to continue because it metamorphosed over time from the initially advertised 'cap-and-trade' quantity-control instrument to a hybrid price-control instrument. The regulated industries are influential via the Brussels negotiation cenacles and also via hoarded permit stocks. The official EU plans for the future EU ETS (EU, 2018) confirm the implied price control strategy via the Market Stability Reserve (from 2019 onwards). Many academic ETS proponents have accepted the metamorphosis and contribute to the discussion about price floors, ceilings, and collars (Wood and Jotzo, 2011; Edenhofer et al., 2017). It is unlikely that this will advance the **A**-goal, because the financial pressure of price-induced innovation remains faint.

The ETS exemplar unequivocally pursuing the **A**-goal is conceptual, and not evident to be brought to life. Reaching the **A**-goal requires policies and instruments forcing technological breakthroughs. Proposals and endeavors to boost the emissions permit prices in the EU ETS are little helpful. For example, the idea of a 'carbon floor price that starts at a significant level and rises over time would trigger cost-efficient de-carbonization of the economy' (Edenhofer et al., 2017) confirms the belief in price-induced innovation. However, these authors provide no convincing roadmap for realizing their ideas and seem unaware of the real financial-industrial interests influencing the policy arena.

Some propositions may be based on the anatomy study. First, the EU ETS exemplar is a hybrid of free permit allocations moderated via specific benchmarks for EITE activities on the one hand, and increasing auctioning of permits for the electric power generation sector on the other hand. Renewable power innovations (realized outside, on loggerhead with, the EU ETS) offer now affordable and decreasing-cost decarbonization options for the electricity sector (IRENA, 2018). The power sector can pass on the bills of the acquired permits to non-ETS customers. A fuller description and analysis can reveal the interactions between both approaches under a single cover, and compare it with the touted merits of cap-and-trade. Second, the two conflicting policy goals pursued by the EU cannot likely be met with a single ETS exemplar. Third, a high-cost ETS exemplar is unlikely to substitute for the presently prevailing, industry interests serving exemplar.

The anatomy framework is helpful in situating further research. This research develops in two directions: 'inward' and 'outward' the mainstream neoclassical and business economics paradigms. Inward, reality checks on the actual functioning of price-induced innovation, on the differences between marginal cost pricing and fringe pricing, and on the validity of the "independence property" (Hahn and Stavins, 2011) have been performed, with results summarized in a submitted paper. Outward, the value tree methodology may identify and compare fundamental ETS design choices in the available anatomy framework, as a prerequisite for turning the focus on policies and instruments that design and incentivize low-carbon technologies. Finding bridges between inward-outward approaches, which could imply re-thinking the economy-environment relationship, is part of the research challenge.

8. Notes

1 For example, the compromise on ETS reform of November 9, 2017, was commented upon as 'striking a delicate balance, seeking to be ambitious on climate while still offering protection for energy-intensive industries that might otherwise relocate abroad to avoid climate legislation.' (EURACTIV 20171109)

2 Those are not necessarily the welfare-optimizing emission quantities, but quantities acceptable for emitters and regulators as an obligation, e.g., to maintain temperature rise below 1.5/2 °C.

3 Often, compliance is synonym for abatement/mitigation. For Narassimhan et al. (2018), compliance costs are only the expenses made for MRV (Monitoring, Reporting, Verification) of emissions. The cost terminology in the ETS literature is ambiguous.

4 In a 2018-publication, prices should be inflated over the period 2002 – 2018. Because a ton of carbon now mostly refers to a ton of $CO_{2\text{-eq}}$ emissions, prices need division by 3.67. Including more impact categories of climate change and the possibility of negative surprises to be more likely than positive ones (Watkiss, 2005), better known in 2018, would increase the assessed SCC.

5 The technological transition has not been driven by the EU ETS, but by dedicated renewable energy targets and technology support. Moreover, in 2015/2016 European power companies (ENGIE, RWE, EON) commissioned large new coal-fired power plants (sited in the Netherlands and Germany), revealing the neglectful impact of (actual and expected) EU ETS prices on their investment decisions.

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