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Emission Trading for agricultural methane.
Drawing insights from EU ETS.

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Abstract

This thesis discusses the economic viability of incorporating agricultural methane emissions in the European Emission Trading System (EU ETS). European lawmakers so far have placed significant focus on industry carbon emissions in their efforts to meet the goal of 55% reduction in greenhouse gas (GHG) emissions by 2030. Carbon emissions from heavy industry, oil, gas and chemicals were regulated by EU ETS initially, with later additions of commercial aviation, heating and electricity. Methane remains largely unregulated and is not part of the current EU ETS. Agriculture, responsible for the largest share of EU methane emissions, is almost free of efficient GHG regulation. Incentives through subsidies to encourage emission reduction through the Common Agricultural Policy (CAP) have been found unimpactful.

As groundwork for discussing agricultural ETS, the study begins by outlining the critical role of methane in global warming. It then continues with a summary of cap-and-trade theory and the history of EU ETS, followed by a detailed analysis of successes and shortcomings of the policy. Agriculture was chosen for evaluation because waste management and energy supply, which are the second and third largest emitters of methane in the EU, are planned to be included or are already covered by EU ETS. The potential extension into agriculture is assessed by drawing conclusions from EU ETS evaluation literature, pilot ETS policies in agriculture and literature on greenhouse gas pricing in agriculture. Lessons learned will be outlined and important criteria for a successful EU ETS in agriculture will be presented.

Key findings are that an agricultural ETS needs to avoid the fundamental mistakes made during early EU ETS. Overallocation, grandfathering and offset substitution must be avoided, as they pose risk to efficient cap-and-trade. In addition, robust monitoring infrastructure is needed to avoid friction cost in methane trading. Insights from pilot systems in Australia, Canada and California have shown frictions in farm level measuring and monitoring. Finally, the EC should include the sector in CBAM, should it intend an agricultural EU ETS for CH4. The thesis advises the implication of an agricultural EU ETS for methane and emphasizes the large potential environmental benefits.

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1. Introduction

The European Union currently targets a 55% reduction in greenhouse gas emissions by 2030. The Green New Deal, brought by president von der Leyen, promised grand changes on all fronts of European environmental pollution. Coined as Europe's "man on the moon moment" (Simon, 2019) it promised significant environmental effects. This paper will address the lack in regulation for methane, the second most important greenhouse gas. Following this, it will discuss a possible regulation by including the main methane emitting sector, agriculture, into the existing policy against greenhouse gas emissions, EU ETS.

Generally, European environmental effort in agriculture through the Common Agricultural Policy (CAP) has been inefficient (European Court of Auditors, 2021). EUR 100 billion have been spent in six years (2014 - 2020) through the CAP, with little impact on European greenhouse gas (GHG) emission in agriculture (European Court of Auditors, 2021). Though policies have been inefficient, agricultural methane emissions have decreased relative to 2019. This decrease is significantly smaller than those achieved in other methane emitting sectors. The EC considers the EU to have a leadership role in advanced agricultural practices (COM/2020/663) but has failed to make significant environmental impact in the sector (European Court of Auditors, 2021). Critically, methane, which makes up half of agriculture's greenhouse gas emissions (European Environment Agency, 2023), is not yet covered in EU ETS for industrial emissions.

EU lawmakers have increased their attention for CH4. In 2027, for example, the maritime transport industry will be obliged to offset their CH4 emissions with allowances as part of the EU ETS trading scheme. The European Emission Trading System (EU ETS) has been in operation for almost 15 years and achieved significant carbon emission reductions in the 11.000 firms covered by it. The policy has not been free of controversy, with quasi subsidies from overallocation and grandfathering (Venmans, 2012). Nevertheless, the policy caused significant abatement in the industries it applied to (Dechezleprêtre et. Al, 2023; Bayer and Aklin, 2020). Additionally, researchers found significant impact on emission innovation (Calel and Dechezleprêtre, 2016; Calel, 2020). These successes make the current EU ETS, in its strongly revised form, interesting for extension into unregulated sectors. To assess the possibility of extending EU ETS into agriculture, specifically for methane emissions, shortcomings and lessons learned in the existing carbon trading system will be discussed in this paper.

Agricultural GHG pricing has previously been researched by Bognar et al. (2023) on behalf of the EC. The environmental significance of this research is beyond deniability, given the little efforts currently being made in the EU to regulate methane (COM/2020/663). Legal aspects behind agricultural ETS have been researched by Verschuuren et al. (2024) and Leach (2022). The economic research on EU ETS for agriculture is largely focussed on all six major GHGs. Bognar et al. (2023) studied the viability of ETS in agriculture. The study was done for all atmospheric emissions from the sector. This paper will extend Bognar et al. (2023) with a detailed analysis of the current EU ETS, applying lessons learned from European carbon pricing successes and mistakes.

The paper will start by outlining the graveness of CH4 emissions for global warming, further explaining the economic theory behind cap-and-trade systems such as the EU ETS and summarize the history of the policy. The following section contains a detailed analysis of EU ETS with findings from highly cited and acknowledged research in environmental economics. Finally, a possible extension of EU ETS into agricultural CH4 will be discussed by combining lessons from current EU ETS with predictions on possible weaknesses of the policy extension. Research was done by combing most up-to-date and highly cited papers from economics and law for emission pricing in agriculture, as well as the most extensive policy reviews of EU ETS. This paper aims to answer the research question: What are the most important learnings from carbon EU ETS for a successful EU ETS extension into methane from agriculture.

2. Theoretical background

2.1 Methane

Methane is a gas, colourless and odourless, made up of one carbon atom bonded to four hydrogen atoms, its chemical formula being CH4. Although its entire volume constitutes to only roughly 0.00018% of earth's atmosphere, it plays a major role in disrupting climate balance (Britannica, 2024). Over the duration it spends in earth's atmosphere, CH4 has a significantly larger contribution to the greenhouse effect relative to CO2. This is reflected in the high Global Warming Potential (GWP) of CH4 (IPCC, 2022). Methane has a GWP of 84-87 for 20 years after emissions, meaning it contributes more than 80 times more to the greenhouse effect compared to CO2 (IPCC, 2022). Both the greenhouse effect and the GWP will be discussed briefly, highlighting the urgency of methane reduction action being taken. Notably, methane emissions stay in earth's atmosphere for significantly shorter durations compared to CO2. This implies that atmospheric CH4 levels can be significantly decreased in the relatively near future if emissions are stopped now.

Lead only by water vapor and carbon dioxide (CO2), methane is the third most abundant greenhouse gas (GHG) in the troposphere. The troposphere, making up the 8-15 kilometres of earth's atmosphere closest to earth's surface, is immensely important for the regulation of earth surface temperatures. The process underlying this is widely known as the greenhouse effect.

Our earth's surface is warmed by incoming solar radiation. The heating surface of planet earth emits infrared radiation (heat) towards space. Some of this infrared radiation is held up on its way into the atmosphere. A reflective layer of greenhouse gases is responsible for controlling the amount of outgoing radiation, namely water vapor, carbon dioxide (CO2) and methane (CH4). This cycle is partly responsible for ensuring liveable conditions on earth. A balance of radiation reflection and absorption enabled the life on earth and ultimately enabled the development of the homo sapiens towards the Anthropocene roughly 300.000 years ago.

Throughout history, this balance has been disrupted due to natural factors numerous times. Results of out-of-balance GHG levels in the troposphere are disrupted weather patterns, altered precipitation, and increases in the frequency as well as intensity of extreme weather events, the most extreme cases allowing for little to no organic life on earth's surface altogether (IPCC, 2022)

Methane has a relatively high variety of emission sources which can be split into biogenic and non-biogenic. Biogenic processes which often take place in agriculture, account for over 70% of CH4 emissions (IPCC, 2007). Bacterial decomposition of organic matter that takes place in flooded soils, landfills, waste disposals and digestive tracts of ruminants, produces methane as its primary by-product. The major non-biogenic source of CH4 emission is the processing, transmission, and distribution of natural gas. Being 90% methane, any leakage of natural gas contributes to increasing methane levels in the troposphere.

Methane concentration in our atmosphere has steadily been increasing since the industrial revolution. More recently, CH4 emissions due to anthropogenic activities in 2019 were roughly 30% higher than in 1990 (IPCC, 2022). Figure 1 shows atmospheric CH4 concentration almost constantly increasing over the past 40 years. The environmental implication of this trend is uncovered by the high global warming potential of methane.

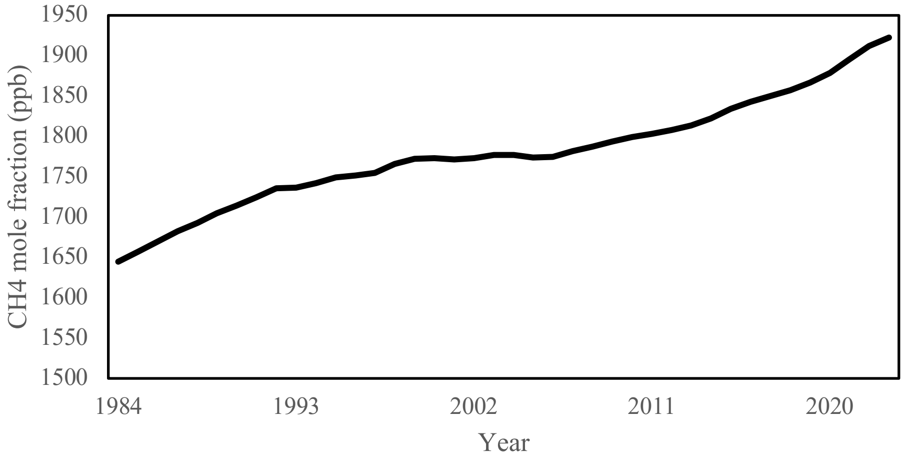

Figure 1. ***Atmospheric CH4 levels, global average in ppb between 1984 - 2023***

Adapted Source: U.S. Department of Commerce (2023)

Global warming potential (GWP) measures how effectively a GHG retains infrared radiation in the troposphere (IPCC, 2022). CO2, with a GWP of one, is the benchmark GHG. Being estimated for different timeframes, it allows for comparison of GHGs with different atmospheric lifespans. The most recent estimates provided by the IPCC show a kilogram of methane to reflect 84-87 times more infrared radiation back to earth's surface in 20 years (IPCC, 2022).

The high GWP value of 84-87 for the first 20 years methane spends in the atmosphere leaves no doubt that an effective emission mitigation strategy can yield great benefits to earth and climate. The United Nations environmental panel estimated that a maximum reduction of anthropogenic CH4 emissions would prevent 0.3 degrees Celsius of global average temperature warming until 2045 (UN environmental programme, 2021).

Currently, most of the ECs methane strategy is focused on monitoring and reporting of emissions (COM/2020/663). The GHG is not included in the EU ETS meaning firms are not yet obliged to offset their CH4 emissions. Although agriculture is the primary emitting sector of methane in Europe, it is entirely excluded of the vast EU ETS framework.

2.2 Cap-and-trade

The EU ETS is the EUs primary carbon abatement effort, initially aimed at abatement of all six major industrial greenhouse gases. For discussion of an agricultural methane ETS, it is crucial to understand the economic theory behind the system.

Cap-and-trade is an economic policy instrument developed to solve externalities, a major market failure in free-market operations. Methane emissions from livestock are one example for externalities in agriculture. Marshall (2009) first mentioned negative externalities in his 1890 "Principles of Economics", identifying them as economic effects not considered by the parties involved in a transaction, but harming outside entities.

In "The Economics of Welfare" of 1920, Arthur Pigou (2017) proposed taxes as a solution for externalities. Pigou distinguished between private, external and social cost. Pigou argued taxes can internalize external cost, given a government accurately estimates the damages of pollution. A tax set accurately to equal the external cost of a transaction efficiently internalizes the externality. In theory the optimal Pigouvian tax achieves a social optimum with consumption and production at the level most beneficial to all stakeholders.

The theory of Pigouvian taxes is often challenged by a key practical complexity: setting the tax. Verbruggen (2021), in his analysis of carbon pricing, points out the complexity of estimating the external cost of carbon pollution. The paper highlights the uncertainty involved in the estimation of the social cost of carbon (SCC) due to "far-stretching timespans, high degrees of doubt and looming irreversibility" (Verbruggen, 2021, p. 13). An emitted tonne of carbon can stay in the atmospheres for centuries. Finding the socially optimal amount for a Pigouvian tax is thus practically challenging, as damages over centuries must be discounted to a monetary value. For emission reduction in the European Union the EC opted for cap-and-trade, which avoids complexities from SCC estimation.

In 1960, Coase (2013) laid the groundwork for emission trading theory by introducing an alternative to Pigouvian taxes. Coase's Theorem argues that externalities can be solved with well-defined property rights, low transaction cost and negotiation. A farm, for example, might pay local residents for the right to emit greenhouse gases, in case the residents own the property rights over the local air. In contrast to Pigou, Coase's theorem argues that efficiency can be achieved through decentralized bargaining, given transaction costs are low. Regulation of pollution with policies based on bargaining, as proposed by Coase, was later extended with cap-and-trade.

Cap-and-trade was first implemented in 1990 through the Clean Air Act in the USA (Verbruggen, 2012), the theory builds on Coase's argument for bargaining and the market-based approach to environmental policy. In cap-and-trade theory, the government sets a cap on total emission by issuing a limited number of permits, each permit allowing for one unit of emission (Stavins, 2019). This creates a market for emission permits, where all firms under the policy can buy or sell. Reducing emissions enables firms to sell excess permits. If costs for abatement are lower than permit prices, a firm reduces emission and sells permit. The buying firms are those who have higher cost of abatement. The policy incentivizes emission reduction through decreased output but also low-emission innovation in production. Firms with cheap and efficient abatement strategies are most favoured under the policy, as low-cost emission reduction results in larger profits from selling permits at unchanged output levels (Stavins, 2019). In equilibrium, the price of permits will equal the marginal cost of abatement of selling firms and the marginal cost of emission of buying firms (Stavins, 2019). If permits are allocated to firms via auction, governments can raise revenue for public spending (Stavins, 2019). With an accurate cap and under assumptions (perfect competition, zero transaction costs, perfect information, no market failures) the permit price in cap-and-trade equals the external cost of one unit of pollution. The equilibrium permit price would be equal to a Pigouvian tax that achieves the same level of abatement.

In practice, the assumptions in cap-and-trade theory are unlikely to hold uniformly. Practical concerns are most importantly market failures such as friction costs, permit allocation mistakes and an inefficient cap-level. These practical shortcomings will be discussed in detail in chapters 3 and 5.

The first policy application was the Clean Air Act Amendments (CAAA) of 1990. For decades, American power companies emitted sulphur dioxide (SO2) without regulation (Verbruggen, 2012). High SO2 levels caused acid rains destroying flora and fauna. With support by then President George H. W. Bush, a sulphur dioxide emissions trading program was included in the CAAA in 1990 (Verbruggen, 2021). Academic research showed the policy to have been effective in reducing SO2 emissions (Burtraw (1999), Driscoll et al. (2001)) while also highlighting the cost-effectiveness of the policy (Chan et al., 2012).

The European Union implemented a carbon emission trading system in 2005. The EU ETS, covering all member states, has undergone several stages and variations. This paper will discuss the effectiveness and shortcomings of EU ETS. The evaluation will focus exclusively on the EU ETS to ensure comparative consistency as the goal of this thesis is a discussion of agricultural methane EU ETS, insights from the existing cap-and-trade in the EU are most important.

2.3 EU ETS

Launched 2005, EU ETS is one of the largest emission trading systems globally to this day. The first 20 years of operations included many missteps and adjustments (Venmans, 2012). The following section briefly covers the four phases of EU ETS since inception. Studying the lawmaking process behind the current ETS will contribute to understanding opportunities and challenges of a CH4 equivalent in agriculture.

The acid rain policy in CAAA of 1990 played an important role leading to the inception of EU ETS. During the COP3 of 1997 meetings, the EC was initially outspoken against cap-and-trade as emission reduction policy (Verbruggen, 2021). A year later, a change of stance occurred with the EC advocating for an ETS covering all six GHGs. Verbruggen (2021) attributes this change of direction to two factors. Firstly, some European member states were vehemently opposing a Pigouvian carbon tax. Additionally, the Clinton administration is said to have pushed for global applications of ETS during COP3.

In 2000, the EC released a green paper (COM/2000/0087) outlining a cap-and-trade scheme for GHGs. The EC explicitly states that a trading scheme for all six greenhouses gases, for all emission sources would result in greatest cost reduction for emission abatement (COM/2000/0087). The EC argued for auctioning of permits, meaning polluting firms would have to pay an initial price to the EU to obtain their permits. Emphasis was put on the significance of strictness in enforcing the policy.

The EU ETS finally started operation in 2005, only covering carbon and the 11.500 firms responsible for a significant share of emissions. Table 1 contains a list of all industries included in EU ETS, all being power generation and energy-intensive industries. Opposed to the stated benefit of excluding the widest possible range of GHGs and emissions sources, the EC opted to confine the policy to the largest sources of carbon dioxide, where monitoring and supervision is most accessible (COM/2000/0087). The focus on CO2 emissions was due to already existent regulation in member states, which provided an infrastructure for monitoring and supervision (COM/2000/0087). Over the past 20 years, the policy went through three phases, currently undergoing Phase 4.

Table 1 – Allowance Allocations, verified allowances, 19 countries, 2008-2019, in million tons of CO2 and profits from overallocation in EUR million using Data provided by CE Delft (2021)

Sector	Allocated	Verified	Difference	Profits
Extraction of crude oil and gas	194	224	-30	-285
Manufacture of coke oven products	65	76	-11	-124
Refineries	1.333	1.504	-171	-1.801
Industrial gases	70	71	-1	-24
Inorganic chemicals	122	109	12	156
Petrochemicals	684	645	39	601
Fertilisers	217	245	-28	-272
Manufacture of plastics in primary form	40	40	0	15
Flat glass	70	66	4	63
Hollow glass	116	122	-6	-45
Other glass	15	14	1	17
Manufacturing of bricks	122	88	34	478
Cement	1.561	1.310	251	3.057
Lime	340	309	30	477
Iron and steel*	1.678	1.766	-88	-707
Total (15 sectors)**	6.627	6.590	37	1.604

Notes: Excluding 608 mio t CO2, allowances allocated for waste gas transfers total can differ slightly due to rounding
Adapted Source: CE Delft (2021)

Phase 1 (2005-2008) started EU ETS with significant mistakes (Venmans, 2012). Permits were oversupplied, allowing emissions to exceed pre-ETS levels for many firms. Figure 2 shows permit prices to increase slightly up until April 2006, then followed by a crash close to zero. This price crash was due to the EC publishing verified emissions for the first year of trading. This disclosure, according to Alberola et al. (2009) first informed participating companies of permit oversupply, which led firms to sell their excess permits in bulk. The EC did not auction permits, as initially intended. Instead, permits were provided to polluters free of charge based on individual historic emissions (grandfathering). Allocation free of charge enables polluters to offset their emissions without paying, initially. This was done in attempt to prevent carbon leakages in form of relocation or import of goods without carbon regulation (Venmans, 2012).

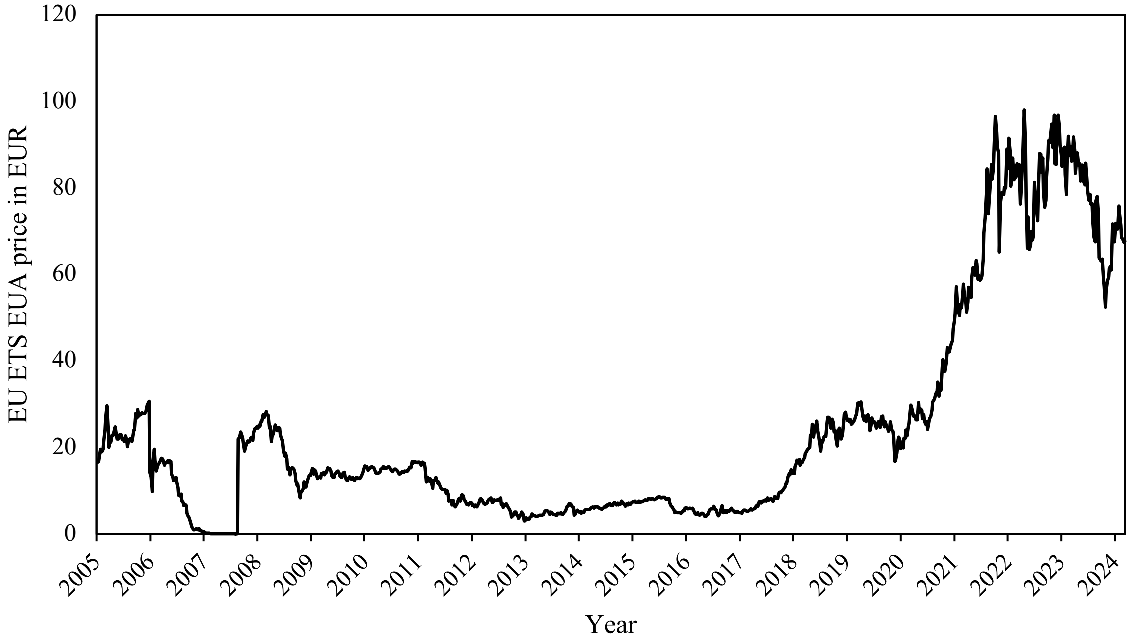

Figure 2. ***EU ETS permit prices in EUR, 2005-2024 in EUR***
Adapted Source: Investing.com

Phase 2 (2008-2012) started two years earlier than planned and fixed little in EU ETS. The early start of phase 2 was due to the need for immediate response to problems caused by overallocation (Venmans, 2012). Merely 3.5% of new permits were auctioned during this phase, with the other 96.5% allocated free of charge. The EC intervened by lowering the cap through a reduction of new allowances brought into circulation. (Venmans, 2012). The 2008 economic crisis brought sharp decreases in output, which subsequently caused lower emissions. Consequently, permit supply still exceeded limits by 2 billion permits according to Verbruggen (2021).

Phase 3 (2013-2020) encompasses important changes. Auctioning became the default mechanism for permit allocation (EC, 2021). Industries facing international competition were excluded from auction to prevent cross-border leakage of emissions. The EC focussed strongly on limiting permit supply to address initial overallocation. The price increased sharply during this phase from “€5/permit to around €25/permit at the beginning of 2020” (Verbruggen, 2021).

Phase 4 is focussed on adjusting permit supply to abatement goals. The phase has plans for inclusion of maritime transport and waste management into the policy. The EC succeeded in balancing permit supply and demand, reflected in higher prices (figure 2). For periods, the permit price was approaching $185, the estimated SCC by IPCC (2022). This was achieved by the addition of the Market Stability reserve which will be further explained in chapter 3.7. Extending the system to generally cover other GHGs besides carbon is not currently planned.

3. Lessons from EU ETS

EU ETS covers 11.500 plants in 27 member states that are responsible for 40% of carbon emissions (Venmans, 2012). To evaluate an extension of the System into agricultural methane, lessons from the past 18 years of EU ETS will be reviewed. Most gravely, the EC failed to set an accurate cap in its first phases. The consequences of said overallocation are discussed in this section. Additionally, there is concern regarding of windfall profits, leakages and monitoring and reporting robustness. The policy showed to be successful in abatement and incentivizing innovation. This chapter gathers insights from econometric, qualitative literature and ex-ante studies for EU ETS, gathering mistakes and successes of the policy.

3.1 Windfall Profits

In theory, cap-and-trade incentivizes abatement and innovation through cost increases to producing firms (Stavins, 2019). In practice, many firms saw profits rise after the EU ETS began operation. Sales of unused permits, substitution of cheaper offset schemes and cost-pass-through resulted in windfall profits for emitting industries. Independent research organization CE Delft (2021) found these three factors to cause beyond EUR 30 billion in industry profits during 2008 – 2019. A sizeable portion of allowances were allocated free of charge to participating companies. This was done to prevent some industries from being replaced by international competition. A breakdown of sources for industry profits after EU ETS implementation is offered below.

3.1.1 Overallocation

An accurate cap is a crucial element of cap-and-trade (Stavins, 2019). Unfortunately, policymakers failed in this regard, particularly during the initial stages of EU ETS. The high cap minimized abatement incentives due to low permit prices for the early phases of EU ETS (Venmans, 2012).

The early years of EU ETS were evaluated by Venmans (2012). The study presents a strong consensus among researchers that the number of permits allocated during phase 1 (2005 - 2008) exceeded optimal levels. Permit were allocated based on historic carbon emissions. This resulted in an incentive for industries to inflate their carbon emissions before the allocation deadline. This caused less abatement pressure on firms (Venmans, 2012).

There are three definitions of overallocation, all suggesting policymakers vastly exceeded the optimal level of permits. Firstly, Anderson and Di Maria (2011) define overallocation simply as allocated permits exceeding business-as-usual (BAU) levels. This was the case for 6% of all grandfathered permits (Anderson and Di Maria, 2011). Secondly, Ellerman and Buchner (2008) identify overallocation by taking per country ratios of companies long or short on permits. The paper identifies overallocation in 11 countries, which allocated 28% of permits (Ellerman and Buchner 2008) at a ratio threshold of 0.6. A ratio is taken of total excess allowances in a country and the aggregate excess allowances of all firms with more allowances than emissions. A ratio close to +1 confirms that almost all firms have overallocation, as the net overallocation is similar in size to aggregate overallocation from firms in excess. Finally, Clo (2009) considers overallocation proven if permit amounts for industries exceed those agreed upon in the Kyoto agreements. This as well was found to be the case during Phase 1 (Clo, 2009).

Overallocation caused price crashes for carbon permits. After oversupply was reported by the EC the prices of permits crashed from 29.20 €/t to 13.35 €/t in April 2006 and finally bottomed at 0.08 €/t a year later (Alberola et al., 2009). Firms faced 8 cents as offset cost for emitting a ton of CO2 in 2007. Phase 2 (2008-2012) shows no signs of ex-ante overallocation according to Venmans (2012) but suffered from the effects of economic downturn. This resulted in actual oversupply due to demand decreasing more than expected.

Table 1 contains data on allowance allocations compared to actual verified emissions between 2008-2019. The profit column in Table 1 sums all profits from selling off excess permits. Table 1 shows significant losses to most industries, which corresponds with priced in carbon emissions. For some firms, profits were positive, showing EU ETS overallocation to result in subsidies for emitting industries such as petrochemicals, cement and lime.

In response to excess supply due to overallocation and unexpected demand decreases, the European Union added the Market Stability Reserve (MRS) to EU ETS (PE/9/2023/REV/1). The instrument was implemented to control allowance quantities and prices. The EC took drastic measures to correct allowance overallocation. As a short-term response, 900 million allowances were removed from the market in 2014 – 2016 (PE/9/2023/REV/1). For more sustained stability on the EU ETS market, the MSR will control the supply side of the market. In accordance with a set of rules the MSR either absorbs or releases allowances.

3.1.2 Offset Substitution

Another source of company profit from EU ETS was substitution with equivalent offset allowances. In Phase 2 the EC allowed firms to offset some of their emissions with alternative allowances (CE Delft, 2021). Global trading systems were agreed upon during the Kyoto protocols. The resulting schemes (Certified Emission Reductions and Emission Reduction Units) were conditionally eligible to be used in EU ETS (CE Delft, 2021). As these were cheaper than market prices of EU-ETS Allowances (EUAs) companies used alternatives and sold off the more valuable EUAs. Until usage of external allowances was restricted, profits amounted to around EUR 3 billion between 2008 – 2019 (CE Delft, 2021). Cap-and-trade assumes bargaining on permit prices depending on supply and demand (Stavins, 2019). Allowing firms to bargain in other offset markets with different demand and supply on permits hinders an efficient convergence of abatement cost across the European market. This is not intended in cap-and-trade theory.

3.1.3 Cost-pass-through

The largest industry profits from EU ETS were caused by cost-pass-through. CE Delft (2021) shows significant proof that firms increased prices beyond the direct costs from EU ETS. One driver for such price increases was the anticipation of future cost increases from higher anticipated permit prices. Additionally, the paper found firms increasing prices due to the opportunity cost of using a permit for production. As grandfathered allowances can be sold off, each allowance used for production is foregone revenue (CE Delft, 2021). EUR 26 – 46 billion in cost-pass-through-profits were generated between 2008 - 2019 (CE Delft, 2021).

3.1.4 Auctioning

One major adjustment in EU ETS was the shift towards allowance auctioning. Initially almost all allowances were grandfathered, allowing for offset substitution profits and cost-pass-through. Auctioning of allowances was far outnumbered in phase 1 and 2 with less than 1% of all allowances (Venmans, 2012). As of phase 3, auctioning became the main method of allocation with an estimated 57% of new allowances. The EC expects auctioning of new permits to continuously make up 57% of new allowance allocation in future years (European Commission, 2021). Auctioning revenues generated between 2012 and 2020 exceeded EUR 57 billion, 78% of which being used for climate and clean energy purposes (European Commission, 2021). As discussed in chapters 3.1.2 and 3.1.3, grandfathering resulted in quasi subsidies to some firms. Pricing carbon at allocation would prevent emitting firms from benefitting monetarily from the factors presented earlier. Removing the possibility to avoid EU ETS permit cost for some firms would contribute to equalisation of marginal abatement cost across industries, as cap-and-trade theory intends (Stavins, 2019).

3.2 Leakages

Pricing in the damages of carbon emission often causes concerns for leakages. Leakages occur when emissions are shifted to unregulated countries. Theoretically, EU ETS could price in the SCC which is estimated to be $185 per ton of CO2 (IPCC, 2022). Consequently, producers under foreign jurisdictions without carbon pricing have a cost advantage. Leakages negatively affect domestic producers while simultaneously hindering aggregate global abatement. Ex-post research carried out by Naegele and Zaklan (2019) shows little leakage of EU emissions during the first ten years of EU ETS.

Leakages in the context of carbon EU ETS would primarily be caused by two sources: competition from unregulated companies and the relocation of EU companies abroad. Before the implementation of EU ETS stakeholders were concerned about the strong economic implications of such shifts (Naegele and Zaklan,2019). Naegele and Zaklan (2019), using a trade flow analysis, found no evidence for carbon leakages in the industries covered by EU ETS. The study explains the lack thereof with negligible changes in production costs, high relocation cost, subsidy effects and the innovation potential in the EU.

Naegele and Zaklan (2019) find the cost of priced in carbon to be below 0.65% of total material cost for the average affected firm. This marginal change is likely not large enough to give a cost advantage to foreign producers (Naegele and Zaklan, 2019). Overallocation played a crucial role in keeping cost increases marginal with permit prices crashing close to zero during early stages (Naegele and Zaklan, 2019). Accordingly, foreign producers were unable to gain a competitive advantage over the regulated EU entities.

Additionally, Naegele and Zaklan (2019) found European firms to avoid relocating outside the EU due to high fixed costs and opportunity costs. EU ETS covers heavy industry with highly complex production plants. Construction of plants, transportation infrastructure and the necessity for highly specific human capital all played a role in preventing industrial plants to be moved outside of the EU (Naegele and Zaklan, 2019). Benefits of remaining in the EU are economic and political stability, research and development (R&D) capabilities and advantages in global trade (Naegele and Zaklan, 2019). The paper put special emphasis of the R&D advantage of being part of EU ETS. Firms are said to expect a competitive advantage from being early adaptors of low carbon innovation.

In anticipation of leakages, the European Union extended their import tariff regulation by the Carbon Border Adjustment Mechanism (CBAM) since October 2023 (PE/7/2023/REV/1). CBAM is a mechanism of leakage protetction, it prices in carbon emissions for imported goods (PE/7/2023/REV/1). As permit prices have increased sharply (figure 2) the chance of leakages has risen. CBAM was implemented to counetract such effects. Importers of goods with siginficant carbon leakage risk (cement, iron and steel, aluminium, fertilisers, electricity and hydrogen) have to surrender CBAM certificates for CO2 emissions caused in production. Starting 2026, the CBAM permit price will match the weekly average of EU ETS permit prices. Producers whose carbon emissions are priced in by respective domestic mechanisms must pay the difference between CBAM price and their domestic price. (PE/7/2023/REV/1).

3.3 Monitoring

Cap-and-trade requires monitoring and reporting of emission as well as purchase and sale of permits. These firm level frictions were a concern before EU ETS, as these processes were entirely new to some companies under regulation (Schleich and Betz, 2004). Sandoff and Schaad (2009) interviewed 114 Swedish company's months after the implementation of EU ETS. The paper studied time investment for policy compliance by firms under EU ETS. No significant transaction cost to firms was identified by Sandoff and Schaad (2009).

Schleich and Betz (2004) outlined key concerns for EU ETS before the policy went into action. The paper argues that monitoring, reporting and verification of abatement could be a large transaction cost especially for smaller companies. This is due to the assumption that some monitoring, reporting and validation (MRV) cost is fixed and does not depend on company size (Schleich and Betz, 2004). This effect was later studied by Sandoff and Schaad (2009). The research found a mean time investment of 27 man-hours per months for EU ETS compliance (Sandoff and Schaad, 2009). Small firms of revenues below 100 million SEK in 2008 (EUR 15 million adjusted to inflation in 2024) used an average 17 man-hours a month. This shows that the assumption by Schleich and Betz (2004) did not hold entirely, as smaller firms did incur less cost for MRV. The qualitative research found most firms to be unconcerned with transaction cost of EU ETS compliance (Sandoff and Schaad, 2009). Over time, Schleich and Betz (2004) argue, the policy will find standardisation of measuring, reporting and verification mechanisms to result in a decrease in MRV cost.

3.4 Successful abatement

Dechezleprêtre et. al (2023) used the threshold set up of EU ETS for a difference in difference (DiD) analysis. DiD is a tool used in econometric impact evaluation. It offers accurate estimation of policy impacts by comparing treated and untreated firms that do not differ in most other characteristics. Companies marginally below the revenue and emission thresholds for EU ETS are assumed to be very similar to those marginally above (Dechezleprêtre et. al, 2023). Dechezleprêtre et al. (2023) finds carbon emission reductions from EU ETS to be 10% on average between 2005 – 2012. It can be concluded that abatement efforts were successful even though the policy set up was not an optimal implementation of cap-and-trade as discussed earlier. According to Dechezleprêtre et al. (2023) a large share of abatement was achieved through low carbon innovation. The research shows not only the success of EU ETS but puts emphasis on the fact that carbon emissions were reduced without necessarily limiting outputs.

In another estimation, Bayer and Aklin (2020) researched emission reduction effects of EU ETS during 2008 – 2016. The study finds EU ETS to cause 3.8% carbon emission reduction compared to a non-EU ETS setting. Though smaller than the estimates found by Dechezleprêtre et. al (2023), the estimate of 3.8% is roughly half the emission reduction the European Union set out to achieve (Bayer and Aklin, 2020). These sizeable estimates were found in periods where prices were significantly lower than from 2020 onwards. It should be noted that emission reduction effects could be significantly larger during later periods due to high permit prices incentivizing more costly innovation (Stavins, 2019). To meet their emission reduction goals, the EC would need to lower the cap significantly faster than intended (Zaklan et al. 2021). Notably, Teixidó et al. (2019) highlights the lack of econometric estimates using emission data post 2012, where prices were singificantly higher than during phase 1 and 2.

3.5 Low emission innovation

Innovation for cheap low emission production enables firms to raise revenue from excess permits under cap-and-trade (Stavins, 2019). Achieving outputs with lower emissions per-unit theoretically results in additional revenue from permit sales, depending on the cost of innovation.

Calel & Dechezleprêtre (2016) found firms under EU ETS to be more innovative in carbon reduction technologies. The study compares patent filings for carbon efficient production technologies. According to Calel & Dechezleprêtre (2016) initial emission reduction in industries was achieved by switching to renewable fuels or adapting technologies that existed but were not economically viable before EU ETS. Additionally, the research found EU ETS firms to have 10% more patent filings than those outside EU ETS. Importantly, Calel & Dechezleprêtre (2016) also conclude that this did not crowd out patenting for other technologies in firms. Calel & Dechezleprêtre (2016) researched companies between 2005 – 2009. It is important to note that permit prices were significantly lower in these periods than nowadays.

More recently, Calel (2020) researched the impact of EU ETS on R&D and patenting for low carbon technologies. The research was done using data from 400 firms in the UK, estimates were made by using a matching approach. EU ETS is found to cause a 25% increase in low carbon patenting on average. Additionally, EU ETS increases low carbon R&D by 32% on average. Though research was done for the UK exclusively, the estimation is the only highly cited research to include data beyond 2009. It can thus be concluded that EU ETS successfully incentivized low carbon innovation. Even during periods that saw permit prices below EUR 1, significant patent filing increases were found.

4. Methane regulation

4.1 Emission Sources

Methane is widely acknowledged as the second most important greenhouse gas. According to the EC methane strategy report a global reduction of emissions by 50% by 2050 could prevent 0.18 degrees Celsius in warming (COM/2020/663). European methane emission sources are presented in this section, highlighting the significance of agricultural emissions.

Data by the European Environment Agency (EEA) used in the EC's methane strategy (COM/2020/663), indicates that the largest source of EU anthropogenic methane is agriculture. The three major CH4 sources in Europe are: agriculture (53%), waste management (26%) and energy (19%). Figure 3 shows emission reduction in all three sectors since 1990. Waste management and energy supply achieved reduction in yearly emissions by 44% and 63% respectively (ECA, 2022). Agriculture is significantly lacking behind the other sectors, only emitting 24% less than in 1990. Notably, figure 3 shows no sizeable reduction in agricultural methane emissions over the past ten years.

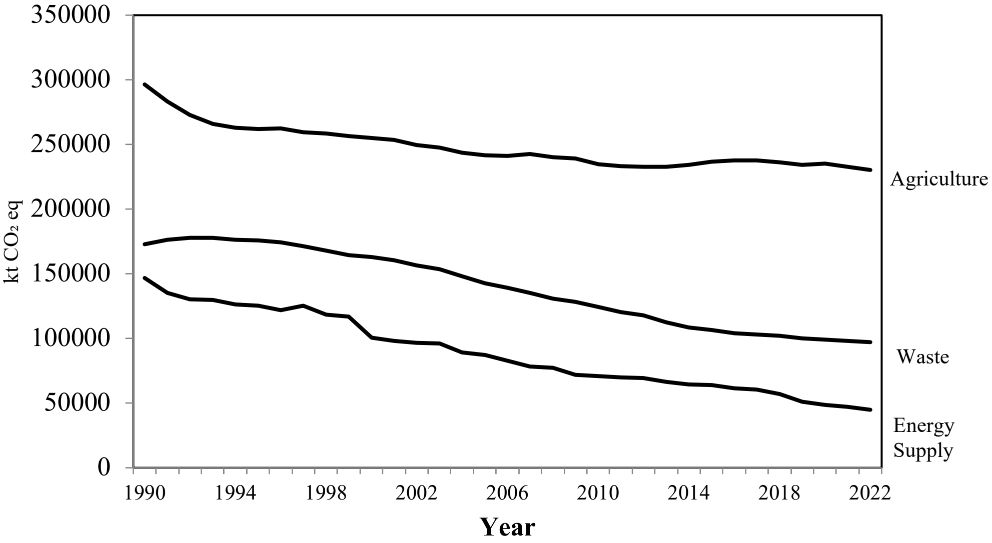

Figure 3. ***CH4 emission trends by sector in EU27, 1990-2022. Measured in kt CO_2 eq***
Adapted Source: ECA (2021)

Energy supply has been part of EU ETS starting in 2005. The sector follows strict regulation for its CO2 emissions. An infrastructure for monitoring, reporting and verification of emissions has been established in the industry. From 2026, waste management will be assessed for EU ETS inclusion (Kunst, 2023). Agriculture is not yet included in EU ETS regulation. This paper will focus specifically on EU ETS inclusion for methane for agriculture because the other major emitters of methane are already or will be included in GHG regulation in the near future. The following section outlines current policy in agriculture which targets CH4 emissions.

4.2 CH4 policy in agriculture

The EC admits to having insufficient CH4 regulation in their strategy report (COM/2020/663). Greenhouse gas emissions from agriculture are addressed by the CAP and the Farm to Fork strategy (COM/2020/381). Both are general policy frameworks for agriculture, not solely aimed at greenhouse gas emission reduction. The CAP encourages uptake of technologies and practices for emission reduction. It pays rewards to farmers for participating in voluntary greenhouse gas emission reduction and requires farms to employ certain technologies for emission reduction (ECA, 2021). As discussed, the policy was unsuccessful in causing reduction of agricultural emission overall (ECA, 2021). The 24% reduction shown in figure 3 can thus not be attributed to the CAP.

The *Farm to Fork* strategy (COM/2020/381), as part of the ECs Green New Deal, sets for a *"fair, healthy and environmentally-friendly food system"* (COM/2020/381). Farm to Fork is not an enforceable piece of legislature, but a communication by the EC. The legislature focusses on manure management technologies for CH4 reduction. No limits of emission are suggested and no tax on farm emissions proposed.

It can be concluded that agriculture lags other methane emitting sectors in emission reduction. The other main emitters of CH4 are already in, or considered for, EU ETS for carbon. Waste management and energy supply are deemed fit to operate under a carbon ETS. Thus, there is no need to assess a possible ETS extension into these sectors, discussions for methane extension of existing ETS is beyond this paper. Agriculture causes the largest share of methane emissions in Europe. EU ETS for methane in agriculture will be assessed and discussed in the following chapters.

5. Challenges and chances of an agriculture EU ETS

Carbon EU ETS has been a successful policy, causing abatement and emission innovation. The following chapter will consider lessons learned from carbon ETS and evaluate which aspects are crucial for a successful ETS on agricultural CH4. Some jurisdictions have considered an inclusion of agriculture in their ETS policies. Insights of these pilot projects will be included in the following section. The most prominent cases for such legislature have been made in Canada, Australia and California. Combining insights from these pilot schemes with lessons from the existent EU ETS and literature on GHG pricing in agriculture, a possible extension of EU ETS towards agriculture will be discussed.

The most important weaknesses identified in chapter 3 were overallocation and windfall profits. It has also been shown that researchers were concerned with leakages and monitoring complexities but did not find negative effects in ex-post analysis. The following chapter will outline essential criteria for an agricultural CH4 ETS based on carbon EU ETS findings.

5.1 Windfall Profits

As discussed in chapter 3.1, carbon EU ETS caused profits in emitting industries. Three factors contributed to subsidising industries that were intended to be regulated through carbon pricing. The major contributors to windfall profits through EU ETS were overallocation, offset substitution and grandfathering resulting in cost-pass-through profits. Cap-and-trade theory intends to benefit only those firms that reduce emissions at lowest cost (Stavins, 2019).

Firstly, an accurate cap is crucial for successful ETS. Research presented in chapter 3.1.1 shows a strong consensus among researcher that carbon EU ETS had overallocated allowances during the beginning phases of the policy. Overallocation minimizes abatement pressure for firms which decreases the chance that aggregate emission targets are met. In addition, firms sold off excess permits from overallocation to achieve profits (table 1). As firms became aware of overallocation in 2006 permit prices crashed due to bulk selling (Alberola et al., 2009). Such low permit prices cannot achieve efficient cap-and-trade, as abatement would not be incentivized (Stavins, 2019). An accurate cap on methane emissions in agriculture is crucial to achieve the policy's goal of abatement. To prevent low prices from unexpected demand decrease, the EU should include agricultural methane permits in the MSR. The reserve can help prevent low prices from demand crashed such as 2008.

In addition, lawmakers must prevent the possibility to offset emissions with permits other than EU ETS. CE Delft (2021) showed sizeable profits to carbon EU ETS firms from using cheap offset permits from Kyoto Protocol systems to substitute EU ETS permits. This led to profits, because grandfathered permits were sold for revenue (CE Delft, 2021). A successful extension of EU ETS into methane must prevent unintentional subsidies to emitting farms through offset substitution. Usage of cheaper external permits by some farms would counteract efficient equalisation of marginal abatement cost across EU farms, as is intended in cap-and-trade theory (Stavins, 2019).

5.2 Auctioning

Chapters 3.1.2 and 3.1.3 showed the negative implications of allowance grandfathering. Instead of internalizing carbon prices, firms were able to generate profits from free allowances. Research has shown that grandfathered profits hindered efficient cap-and-trade in the beginning stages of EU ETS. The EC has steadily increased the share of auctioned allowances from new allocation (European Commission, 2021). For a new ETS for methane agriculture auctioning should be adapted as the default method of allocation, as is intended for carbon EU ETS (European Commission, 2021).

5.3 Monitoring

Ex ante discussions of EU ETS were concerned with the disproportional cost of compliance for smaller companies (Schleich and Betz, 2004). The lower bound of firm sizes in Sandoff and Schaad (2009) was set at EUR 15 million (adjusted to inflation). In contrast, Thünen Institute (2024) reports dairy farms to have generated EUR 420.157 in revenue on average in 2020 – 2023. Farms differ from firms under carbon EU ETS not only in size but also in number, as the estimated count of farms on EU soil is 6.2 million (Verschuuren, 2024). Though Sandoff and Schaad (2009) have not found compliance cost to be a major complexity of EU ETS during adaption stages, there could be difficulties for agriculture with more and smaller firms to be covered. The concerns brought by Schleich and Betz (2004) will be assessed by using insights from three voluntary agricultural ETS.

Australia, California and the Canadian province of Alberta all have voluntary carbon allowance schemes for agriculture (Verschuuren, 2024). Farmers can obtain allowances from reducing emissions and reduction and sell them either in permit markets or to governments. Verschuuren (2024) finds robustness of abatement estimation for these voluntary permits to be their primary weakness. Measurement and verification are challenging to both farmers and governments due to the wide range of GHG sources in agriculture (Verschuuren, 2024).

The wide range of sources for CH4 in agriculture are reported to be a challenge for abatement robustness because of measurement complexities (Verschuuren, 2024). An extension of EU ETS for CH4 from agriculture should ensure robust solutions for measurement and monitoring of farm level emissions.

The voluntary schemes in Australia, Alberta and California include a specific set of emissions reduction practices to fulfilled by farms. Governments aim to reduce the complexity of emission estimation by focussing on exact measures to be undertaken for abatement. Stakeholder interviewed by Verschuuren (2024) showed discontent with the lack of free choice for abatement. In addition, a mandatory set of abatement techniques in cap and trade would hinder the goal of lowest marginal cost for abatement (Stavins, 2019). Such policy would come closer to the current CAP policy framework, where specific abatement efforts are rewarded monetarily (ECA, 2021).

In another attempt at simplifying on farm measurement complexities, Verschuuren et al. (2024) suggests pricing emissions from farm outputs at wholesale level. Wholesalers would have to offset emissions from agricultural products by buying EU ETS permits. The number of firms would be decreased significantly, as wholesalers combine outputs from multiple farms. Emissions would be estimated by standard values for individual product categories such as milk, beef or pork. Removing farm level estimation for an agricultural Methane EU ETS would not be advisable, as the policy intends to incentivize firm level emission reduction (Stavins, 2019).

Research for farm level CH4 emission estimation has been done by Van der Zee et al. (2021). The paper offers a model to be applied for cattle farming CH4 emissions. The model includes factors of emissions for different livestock categories, where energy intake from feed and the composition of feed are main emission drivers. Additionally, Verschuuren et al. (2024) mentions herd activity and pasture rotation as drivers for enteric fermentation emissions. An estimation model which encompasses a wide range of emission sources, such as Van der Zee et al. (2021) can be combined with digital measuring capabilities for farmers. Development for such technology has been innitiated by the European Commission in its methane strategy report (COM/2020/663). A digital tool for measurement and data collection of agricultural methane emissions was intended to be available by 2022. A combination of a digital navigator and a model such as Van der Zee et al. (2021) would offer a digital solution to measurement frictions on farm level. Recent developments in artificial intelligence can further contribute to simplifying the emission measurement process. The Thünen Institute (2023) is currently developing AI backed GHG detection systems for open ventilation pig and cattle stalls.

5.4 Leakages

Naegele and Zaklan (2019) found little leakage effect of carbon EU ETS over the first ten years of the policy. Though not a concern in carbon EU ETS, leakages are an important consideration for a CH4 ETS in agriculture. Isermeyer et al. (2019) argues that leakages in agriculture would have to be prevented by high tariffs on agriculural outputs. Accurate tariffs cause imported goods to have equally high prices as domestic goods under methane pricing.

Isermeyer et al. (2019) contains a theoretical prediction of leakage effects under methane emission pricing for meat and dairy production. The paper argues that, in an open economy, the EU would turn into a net importer of meat and dairy. As production costs for meat and dairy farms would increase significantly, cheaper imports from unpriced region would supply the European market. This would make methane pricing in agriculture ineffective in terms of environmental goals (Isermeyer et al., 2019). High tariffs can prevent leakages, by increasing prices for foreign producers equivalently. Isermeyer et al. (2019) shows that tariff protection on meat and dairy is currently high in the EU. Maintaining or increasing current tariffs on meat and dairy can result in an effective climate policy, Isermeyer et al. (2019) shows. Though the status quo of tariffs could be sufficient to prevent methane leakage (Isermeyer et al., 2019) lawmakers should pay close attention on tariff levels to ensure a leakage free policy. The EU is currently employing the CBAM mechanism against carbon leakages, an extension of this would be a possible tariff scheme for agricultural ETS.

5.5 Innovation potential

Low emission innovation is incentivized by cap-and-trade, as revenues from excess permits incentivize abatement (Stavins, 2019). As discussed in chapter 3.5 carbon EU ETS has successfully caused patenting and R&D for low emission innovation. AI innovation for measuring such as Thünen Institute (2023) is for cost-efficient compliance. An important measurement for ETS success is abatement innovation. Possible sources of low methane emission innovation in agriculture will be presented in the following chapter to assess the potential of such ETS. Emission reduction through changes in cattle feed type were found by Hatew (2015). In an earlier study, Knapp et al. (2011) identified herd structure, management practices, genetic selection and rumen function as additional abatement innovation sources in dairy farming. Savian et al. (2018) found a herd rotation strategy called Rotatinuous Stocking to reduce methane emissions per output product by 170% in sheep farming. The research shows a broad field of innovation sources. An agricultural ETS, if implemented according to cap-and-trade theory (Stavins, 2019) can cause for the most cost-efficient abatement sources in these categories to be widely implemented.

6. Discussion

Carbon EU ETS has been found successful in incentivizing abatement and innovation in this thesis. The importance of regulating methane from agriculture has been stated and possible environmental effects of methane abatement have been shown. An ETS for methane in agriculture could prove successful, like carbon EU ETS has been, if key checkpoints are met and resolved.

EU ETS has proven successful over the past 18 years. Overallocation and the resulting industry profits were grave mistakes made during early stages of the policy. The EC is still dealing with these mistakes to date. Introduction of the MSR and cancelling millions of allowances is one such response to those missteps in 2008 – 2012. Nevertheless, research has shown that the policy caused significant carbon emissions reductions.

Another argument in favour of EU ETS for CH4 from agriculture is innovation potential. Technological innovation was strongly incentivized by EU ETS in carbon industries. Such technological advances could be achieved as AI technology in indoor farming or adjustments in other operational processes as presented in chapter 5.5. Hatew (2015) showed the possibility of significantly reducing emissions from enteric fermentation. Using cap-and-trade to incentivize further innovation in livestock farming can cause cost-efficient abatement innovation (Stavins, 2019). The potential for such has been shown in the wide range of abatement possibilities in chapter 5.7.

An essential checkpoint for methane EU ETS in agriculture would be a robust policy framework. The major mistakes from early EU ETS stages, namely excessive grandfathering and overallocation must be avoided. These faults have shown to significantly benefit emitting industries. Such quasi subsidies are not intended by cap-and-trade theory (Stavins, 2019) and should be avoided.

In addition, concerns for monitoring must be resolved. There is an incentive for misreporting emissions of farmers. Both misreporting and friction cost from measuring and monitoring emissions could be avoided by a robust monitoring infrastructure. Early EU ETS literature has presented concerns for high friction cost to smaller companies. As agricultural companies are significantly smaller than carbon EU ETS participants, findings by Sandoff and Schaad (2009) could differentiate from reality in agriculture. This thesis proposes a combination of a digital carbon navigator as planned by the EC in combination with estimation models such as Van der Zee et al. (2021) and AI innovations such as Thünen Institute (2023). Such solutions would need to be implemented to achieve trading with little friction as cap-and-trade intends (Stavins, 2019).

Finally, the EC needs to ensure a robust methane EU ETS for agriculture by anticipating leakages and including the sector in CBAM. Leakage protection for agricultural products is crucial. This has been shown in a case for methane pricing in agriculture by Isermeyer et al. (2019). CBAM will be in full operation in roughly two years. The EC can apply the same regulation to a methane ETS in agriculture to prevent leakages of emissions

7. Conclusion

The aim of this thesis was answering the research question: What are the most important learnings from carbon EU ETS for a successful EU ETS extension into methane from agriculture. In conclusion, the key lessons learned from carbon EU ETS is that abatement and innovation were successfully incentivized, as shown in the literature. Learning from mistakes during early stages of EU ETS was found essential for a successful CH4 ETS in agriculture. Namely, overallocation and grandfathering. Additionally, topics of concern before carbon EU ETS should be reconsidered, though not affecting the EU ETS so far. Important checkpoints in this case are leakage and monitoring. From an environmental standpoint, this thesis finds an increase in regulation for methane emissions necessary, as current laws were found to be too loose, especially in agriculture.

Lawmakers must learn from carbon EU ETS and avoid overallocation. Allocation should be done primarily through auctioning, as the EC intends for carbon EU ETS. The policy should only be implemented once monitoring technology is available and applicable in agriculture. Leakages should be addressed in agriculture ETS as they in carbon ETS: price imported goods by including them in CBAM. Meeting these crucial checkpoints can enable a successful ETS for methane in agriculture, yielding large environmental.

More generally, this thesis advises the inclusion of CH4 in EU ETS for energy supply and waste management. Large methane emitters are already covered by carbon ETS. Including the second most important GHG for the same sectors can contribute to European climate objectives. Further investigation into the environmental benefits of regulating said sectors is advised. The thesis found a lack in estimations of EU ETS impact after 2012. Further research should be carried out on the abatement achievements under higher prices, after 2016. Furthermore, a detailed analysis of abatement achievements in the pilot schemes of Australia, Canada and California are needed to assess possible successes of agricultural EU ETS. Finally, a study on digital GHG navigators for agricultural emissions would benefit plans for EU ETS extension.

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