Carl von Ossietzky Universität Oldenburg

Master Program Sustainability Economics and Management (M. A.)

MASTER THESIS

Long-Term Effects of Climate Campaigns on Total Greenhouse Gas Emissions under Cap-and-Trade Schemes – The Example of the EU Emissions Trading System and the Market Stability Reserve

vorgelegt von

Laura Schürer

laura.schuerer@posteo.de

Gutachter:

Prof. Dr. Carsten Helm

Prof. Dr. Christoph Böhringer

Oldenburg, 30.12.2020

Abstract

Facing the immense societal challenge to limit global warming, measures to mitigate climate change are becoming increasingly important. These include efforts to reduce individual carbon footprints as well as key policies like cap-and-trade schemes that set a cap on greenhouse gas emissions and allow for trade of emission permits to achieve cost-effective emission reduction. However, Perino (2015) derived that climate campaigns that aim at individual carbon footprint reductions by decreasing the demand of specific goods tend to even increase overall greenhouse gas emissions if these goods are produced by sectors regulated by a partial cap-and-trade scheme like the EU Emissions Trading System (EU ETS), the world's biggest carbon market. Due to the new rules that the EU adopted in 2018 and that include a market stability reserve (MSR) and a cancelation mechanism for the EU ETS, these findings are partially invalidated. The present thesis updates Perino's (2015) results by extending his analytical model and pursues the question, what the effects of temporary, sector-specific climate campaigns on long-term total emissions under a partial cap-and-trade scheme with a market stability mechanism are, particularly investigating the example of the EU ETS and the MSR. The results indicate the importance of being aware of the regulatory environment and possible interaction effects with climate campaigns. Considering the current rules of the EU ETS, under specific conditions, climate campaigns can have a total emissions reducing effect due to the MSR and the cancelation mechanism. However, the size of the effect is smaller than probably expected by consumers. Additionally, a framework for the differentiation of six cases based on the functioning of the MSR is provided and the increased complexity of the EU ETS due to the reform is critically discussed.

Table of contents

1 Introduction

With its special report issued in 2018, the Intergovernmental Panel on Climate Change (IPCC) emphasized once again the urgent need to reduce greenhouse gas emissions in all sectors to limit global warming to 1.5°C above pre-industrial levels and avoid further risks (IPCC, 2018). Facing this huge challenge for societal transformation, one key policy to mitigate climate change are cap-and-trade schemes that set a cap on greenhouse gas (GHG) emissions and allow for trade of emission permits to achieve cost-effective emission reduction. As the International Carbon Action Partnership (2020a) notes, these emissions trading systems (ETS) are used worldwide, "with 21 systems now operating across four continents and 24 further systems under development or under consideration" (p. 7). While the global average carbon footprint amounted to 6.7 t CO2eq per capita in 2015 (Crippa et al., 2019), emissions are "highly unequally distributed across income groups and countries" (Ivanova et al., 2020, p. 2), as the average carbon footprints per capita of North America (13.4 t CO2eq/cap) and Europe (7.5 t CO2eq/cap) in contrast to that of Africa and the Middle East (1.7 t CO2eq/cap) show (ibid.). To be able to achieve the goal of limiting global warming to 1.5°C, an emission reduction to an average of around 2.8 t CO2eq per capita by 2030 is required, assuming a world population of 8.5 billion in 2030 (ibid.). Although these are only estimates, this shows the magnitude and relevance of individual life-style and consumption choices as well as their potential for emission reduction, especially in the global north.

However, in his paper on "Climate Campaigns, Cap and Trade, and Carbon Leakage: Why Trying to Reduce Your Carbon Footprint Can Harm the Climate", Perino (2015) derived that climate campaigns[1] aiming at "voluntary behavioral change" (p. 470) of individuals to mitigate climate change by reducing demand for certain goods and services, e. g. electricity or flights, tend to even increase overall greenhouse gas emissions if these goods are produced by sectors regulated by a cap-and-trade scheme like the EU Emissions Trading System (EU ETS). One reason for this is that campaigns usually do not take the regulatory environment into account (ibid.). However, this is problematic since emission reductions in the household area are indispensable for achieving the 1.5 °C target and

[1] In the following, "climate campaign" or "campaign" refers to a campaign which successfully aims to encourage voluntary changes in consumer behavior, i. e. individual carbon footprint reductions through demand changes, in order to contribute to greenhouse gas emissions reduction and climate change mitigation.

hence, it is crucial that people setting up campaigns are informed about the potential effects and interactions of the campaign with the existing regulations and know how to inform citizens so that they are able to effectively contribute to climate change mitigation. Further, if campaigns do not take the regulatory environment into account, they support the misconception of consumers about the impact of their behavior on total emissions (ibid.). Nevertheless, existing regulations and their interactions with effects of campaigns might be complex and difficult to evaluate. Therefore, the aim of the present thesis is to update Perino's findings with regard to the case of the current EU ETS rules including the market stability reserve (MSR) and the cancelation mechanism. Thereby the focus is on the effects of temporary, sector-specific climate campaigns that lead to a temporary decrease in demand for a specific product or products of specific sectors that are regulated by a cap-and-trade scheme and not on general climate campaigns that try to convince consumers to reduce their carbon footprint in general or that aim at permanent behavior changes. However, possible effects of the latter will be discussed later on.

Because of the "trend to extend the use of both cap-and-trade schemes and campaigns stimulating voluntary behavioral change" (Perino, 2015, p. 470) it is highly relevant to study the interaction effects of both. Perino (2015) focuses on the question whether "they [are] complements, as Ostrom (2012) and Dietz et al. (2009) suggest, or […] rather substitutes, as is implied by the literature on interventions overlapping a cap-and-trade scheme (Fischer and Preonas 2010; Goulder 2013; Böhringer 2014)?" (ibid.). The focus is on Perino's (2015) work since, to the best knowledge, it is the only paper that analyzes climate campaigns in the context of a partial cap-and-trade scheme, although this topic is closely related to the literature dealing with policies overlapping cap-and-trade systems.

Perino (2015) stated that climate campaigns can only help in reducing overall emissions if they change consumers preferences in the right direction which depends on the regulatory background. He further indicated that if a sector-specific campaign reduces the demand in sectors regulated by a cap-and-trade scheme, then aggregate emissions tend to increase. This is also the case if the campaign aims at reducing carbon footprints in general if the capped sectors, i. e. the sectors subject to a cap-and-trade scheme, are more emission-intensive than the other sectors in the economy (ibid.). In both cases, the intuition behind Perino's (2015) insight is that since emissions in the capped sector are fixed due to the binding cap of the cap-and-trade scheme, they cannot decrease due to the waterbed effect, while emissions in the uncapped sector increase as a consequence of the demand shift, leading to an overall increase in aggregate emissions. The waterbed effect is a well-established term in the literature dealing with cap-and-trade schemes and refers to the scenario that under a cap-and-trade scheme with a fixed cap, an additional abatement, like e. g. a climate campaign, will not reduce emissions due to the fixed cap and instead reduces the demand for emission permits and hence also the price for emissions, so that emission-intensive industries benefit and their activities become profitable again, letting emissions elsewhere rise accordingly (e. g. Böhringer & Rosendahl, 2010; Rosendahl, 2019a). Hence, due to the waterbed effect, an additional abatement is "affecting who emits but not how much is emitted in total" (Perino, 2018, p. 262). Nevertheless, Perino (2015) indicated that campaigns can help to reduce overall emissions if they successfully reduce the demand of sectors not subject to cap-and-trade schemes or, if these uncapped sectors are the more emission intensive ones, if the campaigns successfully encourage consumers to reduce their carbon footprints in general.

Importantly, Perino (2015) assumed that emissions in the capped sector do not change, since it is regulated by a binding and exogenous cap on emissions and hence, whenever there is an additional abatement, the waterbed effect occurs. However, when considering the EU ETS, this assumption is no longer feasible today due to the new rules that the EU adopted in 2018 for phase 4 of the EU ETS (European Commission, 2020a). These include the MSR with the cancelation mechanism which mitigates the waterbed effect (Perino, 2018). As a consequence, the cap of the EU ETS is no longer fixed but a result of the market outcome and hence, "much of the critique on climate policies overlapping the EU ETS" (ibid., p. 264), including Perino's (2015) analysis of the effects of climate campaigns, "while correct given the rules at the time, has been partially invalidated by the recent adjustments" (Perino, 2018, p. 264). Due to the facts that the cap is now endogenous, that it is possible that the abatement in one year affects the MSR functioning of the following time period until the MSR intake stops and that allowances will be permanently canceled by the cancelation mechanism, the focus of the present thesis is on long-term effects in contrast to Perino's (2015) focus on the medium-term where he assumed that the cap is fixed until the end of the current trading period. Since the EU ETS is the world's biggest carbon market, accounting for about 40 % of EU emissions (European Commission, 2020a) and since other ETSs are using market stability mechanisms as well and they will probably be considered and implemented more often in the future (International Carbon Action Partnership, 2020b), updating and extending Perino's results with focus on the new rules of the EU ETS including the MSR is of high relevance.

Therefore, the present thesis will pursue the following research question: What are the effects of temporary, sector-specific climate campaigns and intended individual carbon footprint reductions by consumers on long-term total emissions under a partial cap-and-trade scheme with a market stability mechanism, taking into account the example of the EU ETS including the MSR? Additionally, it is investigated how climate campaigns and consumers can contribute to climate change mitigation with regard to the current EU ETS. In order to evolve an answer, first important terms are defined and fundamental facts concerning climate campaigns and carbon footprint reduction, cap-and-trade schemes in general and the EU ETS specifically are laid out. Secondly, Perino's (2015) general equilibrium model is summarized before the following section introduces the model of Rosendahl (2019a) which comprises the mechanisms of the MSR. Afterwards, these two models are combined to analytically derive the effects of a climate campaign on emissions in both sectors under the conditions of the current EU ETS with the MSR and the cancelation mechanism. Following this, the magnitude of the results are illustrated numerically before the results are discussed and the last section concludes. A nomenclature as an overview of the variables and parameters used as well as the proofs, derivations and calculations not included in the text can be found in the appendix.

2 Fundamentals

To be able to answer the research question, in the following, relevant terms are defined, different types of climate campaigns are discussed, the functioning of cap-and-trade systems is explained and some real world examples are mentioned before the EU ETS is addressed in detail, including its basic functioning and historical development, the waterbed effect as well as the latest reform and its implications.

2.1 Climate Campaigns and Carbon Footprint Reductions

Due to a broad variety of types and designs of climate campaigns or footprint reduction approaches, in the following, some definitions as well as different types of campaigns and factors influencing them are briefly discussed.

Moser (2010) states that "Campaigns try to motivate individuals to act on the problem, and empower and enable them to translate their values and motivations into real action" (p. 38) while noting that "they typically portray such actions as relatively easy, generating personal and social benefits (such as cost savings, a better lifestyle, greater social acceptance, peace of mind, etc.)" (ibid.). Besides, Detenber et al. (2016) indicate that

“Governments and environmental organizations typically use public engagement campaigns to provide information to citizens to educate them about the impact and risks of climate change, and encourage behavior change that will benefit the environment“ (p. 4737). Alongside, Kotchen (2013) uses the broader term of “voluntary- and information-based approaches (VIBAs)” (p. 276) which “include more decentralized policies, programs, and market trends, such as programs that disclose information about potential environmental liabilities, markets for “green” goods and services, third-party eco-labeling” (ibid.). The fact that Moser's (2010) definition places a greater focus on the empowerment function of campaigns, while Kotchen (2013) emphasizes the voluntariness and Detenber et al. (2016) focuses more on the educational function, makes it apparent that that there is a huge array of different campaigns possible as well as varying definition approaches. However, they have in common that they explicitly target individuals, citizens or households.

Although Perino (2015) did not explicitly define the term climate campaign, he specifies measures, initiatives or projects where “[r]esearchers […], governments […], and environmental NGOs […] advise households on how to reduce their carbon footprint by providing specific lists of actions or carbon footprint calculators” (Perino, 2015, p. 470). Or put differently, “campaigns stimulating voluntary behavioral change” (ibid.) try to make use of the “potential of contributions made by individuals and households as part of their consumption and life-style choices” (Perino, 2015, p. 469), whereby contributions to emission reductions as part of climate change mitigation is meant.

In the present thesis, analogous to Perino (2015), “climate campaign” or “campaign” refers to a campaign which successfully encourages voluntary changes in individual consumer behavior, i. e. individual carbon footprint reductions through demand changes, in order to contribute to greenhouse gas emission reduction and climate change mitigation. It is important to note that for the present thesis, the change in demand towards less emission-intensive products is crucial, as this is the starting point of the analysis. However, the intention or focus of the campaign does not play a major role. Therefore, campaigns which e. g. aim at promoting awareness or spreading knowledge about climate change that do not primarily target and explicitly recommend individual behavioral changes, can still encourage voluntary changes in individual consumer behavior and cause a group of people to aim at personal carbon footprint reduction. Hence, these are also included in the term as used here. Additionally, the term refers analogously also to individual behavior changes of a group of people aiming at contributing to climate change mitigation via personal carbon footprint reduction without the influence of a campaign, since the effect of demand change analyzed is the same and hence, “climate campaign” or “campaign” is used in the following as an abbreviating, simplifying generic term.

Wiedmann and Minx (2007) define the term “carbon footprint” generally as “a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product” (p. 5) while “all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, downstream) need to be taken into account” (ibid.). Hence, the term refers to emissions “technically associated with specific choices or products” (Perino, 2015, p. 486) but not to emission effects after consideration of the regulatory regime. For the present analysis, due to the limited scope and the focus on a temporary change, the demand change of consumers within the time period of a year is relevant. Further, as the effects under the EU ETS are analyzed and the EU ETS covers not only emissions of carbon dioxide but since 2013 also of nitrous oxide and perfluorocarbons (Directive 2009/29/EC, 2009), when the term “carbon footprint” is used in the following, all three gases are considered.

The potential of behavior change for climate change mitigation in the EU was investigated i. a. by van de Ven et al. (2018) who found that “modest to rigorous behavioral change could reduce per capita footprint emissions by 6 to 16%, out of which one fourth will take place outside the EU” (p. 853). Next to the benefits of climate change mitigation, this would help to “reduce the costs of achieving the internationally agreed climate goal of the EU by 13.5 to 30%” (ibid.) and at the same time to enable co-benefits for consumers since they might save money or contribute to protecting their health or animal wellbeing (ibid.). However, there is a broad variety of climate campaigns or comparable calls, recommendations or challenges with very different narratives and storytelling techniques from governments, federation of states like the EU, NGOs, to a limited extent also from businesses or even from individuals like politicians or celebrities (Anderson, 2011). In case of climate campaigns from governments, one reason for their increased use is that “information disclosure or voluntary programs” (Kotchen, 2013, p. 278) are “likely to face less political opposition than attempts to impose new taxes or regulatory standards” (ibid.). Furthermore, campaigns can take many different designs, forms and measures with which they can be associated with, e. g. lists of actions or products and services as alternatives to more emission-intensive ones, carbon footprint calculators or labels

(Perino, 2015). Apart from that, another option for carbon footprint reduction is to buy carbon offsets (Bruns & Perino, 2019; Gerlagh & Heijmans, 2019).

Further, Perino (2015) differentiates between sector-specific and general climate campaigns. The former are “campaigns directly targeting specific products discouraging their consumption” (p. 473), so “the purpose of such campaigns is to reduce emissions in the targeted sectors, that is, those that experience a reduction in demand” (p. 476). Therefore, sector-specific campaigns aim at encouraging individuals to reduce their demand for products and services that are either emission-intensive in production or provision or during or after the use phase, e. g. electricity, meat, petrol or flights. Instead of aiming at reducing demand of emission-intensive products, it is also possible that campaigns are designed to promote alternatives to these and hence rather aim at increasing the demand for less emission-intensive products, e. g. “green” electricity tariffs, plant-based food, bicycles or train journeys. However, since both options aim at changing demand in the same direction and might induce similar results, both are referred to as “demand reducing” in the following. Next to these, general climate campaigns “aim at increasing the intrinsic motivation of consumers to reduce their carbon footprint generally and leave it to consumers how they want to achieve this” (p. 473). In this case, consumers have to rely on information about the carbon footprint of products and services which is often calculated via an environmental impact assessment or a life-cycle analysis using standards like ISO 14040, ISO 14044 or ISO 14067 (International Organization for Standardization, 2018, 2020a, 2020b). However, both types of campaign recommendations are given and carbon footprint specifications are calculated without taking environmental policy instruments or regulations like cap-and-trade schemes or carbon taxes into account (Perino, 2015). Above, Rosendahl (2019a) differentiates between a temporary and a permanent abatement or demand reduction, whereas temporary means the demand change is only in one year and permanent stands for a demand change that lasts from the year when the first demand change is made onwards. According to this two differentiations, the focus in the following will be on sector-specific climate campaigns with a temporary effect, since Perino (2015) focused on them as well and the goal is to update his findings. However, possible effects of general campaigns and of campaigns that lead to permanent behavior changes will be discussed later on.

Notably, it has to be assumed that it is even possible for individuals to switch to less emission-intensive products and services. Hence, complementary to climate campaigns, barriers to realize the recommended behavior changes have to be reduced as well, e. g. through infrastructure changes (Moser & Dilling, 2012). Therefore, the impact of a climate campaign on total net emissions depends on many factors like the messengers, the audience, the goal, message, the media channels used (Moser, 2010), the perception of the campaign by the target group (Bruns & Perino, 2019), or the economic and political (Moser & Dilling, 2012) as well as the regulatory environment (Perino, 2015). Hence, there are many factors that influence and determine the effectiveness of a campaign and its impact on overall emissions, and this thesis analyzes only a small fraction of them.

2.2 Cap-and-Trade Schemes

In view of climate change mitigation goals on several levels, greenhouse gas emissions as externality of global significance can neither be countered appropriately with voluntary approaches like the above discussed campaigns alone nor with private bargaining according to the Coase Theorem, since transaction costs are too high (Phaneuf & Requate, 2016). Therefore, there is a need for government intervention and environmental regulation. This is often associated with the "'polluter pays' principle, whereby the entity producing emissions is responsible for bearing the cost of pollution prevention *and* compensating victims for their damages" (ibid., p. 41). One possible option for an environmental policy aiming at emission reduction are cap-and-trade schemes or transferable emission permit systems whose general functioning is explained in the following before the historical development and some real world examples are briefly outlined.

In contrast to institutional approaches and command and control instruments, marketable or transferable permits or rights to pollute are a pollution control instrument of the group of economic incentive or market-based instruments (Perman et al., 2003) which "can be applied at many points in the production-to-pollution process" (ibid., p. 219). Accordingly, there are transferable permit systems for the extraction of natural resources, e. g. water like in the Australian system, or concerning the harvesting, e. g. fishing quotas, or permits for construction in land management issues like in the USA or France (ibid.). However, although the results might be transferable in some cases, in the following the focus will be on permits on greenhouse gas emissions and hence on uniformly mixing pollutants, meaning "the location of the emission source […] is irrelevant as far as the spatial distribution of pollutant concentrations is concerned" (ibid., p. 178) and hence "pollution levels will depend only on total emissions levels" (ibid., p. 209). Contrasting, pollution levels of pollutants that are non-uniformly mixing also depend on the locations of the sources (ibid.). Cap-and-trade schemes focusing on GHG emissions are called emissions trading systems (ETSs).

These transferable emissions permit schemes are characterized by a limited total number of emissions allowed whereas how that quantity is distributed is not regulated which is why "any increase in emissions must be offset by an equivalent decrease elsewhere" (Perman et al., 2003, p. 219). They can be further differentiated into two systems, cap-and-trade schemes or emissions trading systems and emission reduction credit systems. In the case of the latter, a baseline emission quantity for each individual source is set. Those sources emitting more face a penalty while others that make successful abatement efforts and emit less than their baseline volume receive emission reduction credits which they can sell to those that might emit more than their baseline level (ibid.). Hence, in an emission reduction credit system, the number of credits is not known ex ante.

On the contrary, in a cap-and-trade scheme, the total number of emission permits allowed, the so called "cap", is set beforehand by the government and "should be equal to that target level of emissions" (Perman et al., 2003, p. 223). Further, no entity or firm is allowed to emit more than the number of permits it owns, otherwise it might have to face penalties as well. Initially, permits can be issued via auction or free distribution whereby they are called "grandfathered" if they are freely distributed and "if this is done proportionally to previous unregulated emission levels" (ibid., p. 232). The regulator guarantees that free trade of permits is possible and hence a market for emission permits is created where entities holding more permits than their emission level sell and entities with less permits might buy or abate (Perman et al., 2003; Phaneuf & Requate, 2016). Hence, the abatement costs of sellers are comparatively small whereas buyers face abatement costs that are relatively high (ibid.). On this market, an equilibrium price is formed which is "determined by the value of the aggregate marginal abatement cost at the level of abatement implied by the total number of issued permits" (Perman et al., 2003, p. 225), assuming that there is one price at which all permits are sold (ibid.). Hence if the number of permits decreases or equivalently the stipulated abatement level rises, the price will increase as well (Perman et al., 2003). Notably, the total number of issued permits is the only factor on which the magnitude of abatement and hence emission reduction depends (ibid.). Which method is chosen for initial allocation, i. e. auctioning or free distribution, does not influence emissions but it affects how income and wealth are distributed between firms (ibid.). Due to the fact that in equilibrium, all firms will have equal marginal abatement costs, a cap-and-trade system can “achieve any given target at least cost” (ibid., p. 224). Regarding this cost-effectiveness and its effects on emissions and output, a cap-and-trade scheme can be equivalent to an optimal tax or subsidy scheme if “the total quantity of permits issued […] is identical to the level of emissions which would emerge from an emissions tax (or an abatement subsidy)” (ibid.).

While Calel (2013) gives an historical overview of carbon market experiences starting with early theory development in the 1960s and the Clean Air Act in the 1970s, Michaelowa et al. (2019) provide an overview of the evolution by describing four phases from 1997 to 2018. During the first phase from 1997 to 2004, mechanisms of the Kyoto Protocol, the Clean Development Mechanism and Joint Implementation, pilot projects and different methodologies, e. g. for monitoring, were tested and established, before in the second, “‘gold rush’ period” (ibid., p. 1) phase from 2005 to 2011, the EU ETS started and was connected with the Kyoto mechanism (ibid.). There was a great expansion of carbon markets but criticism was expressed as well, e. g. concerning problems of environmental integrity (ibid.). During the third period from 2012 to 2014, carbon prices decreased rapidly “following the economic recession, emissions reductions due to other policies (e.g., renewable energy), as well as the inflow of international offsets” (ibid., p. 10). After the Paris Agreement was resolved in 2015, there was a stabilization and although prices remained relatively low and “the international carbon market remains uncertain, an increasing number of domestic carbon pricing initiatives have been launched around the world in the past several years” (ibid., p. 17). Therefore, today carbon markets can be called an “integral part of international climate change policy” (Calel, 2013, p. 107).

As “international government forum that brings together policymakers from all levels of government that have or are interested in introducing an ETS” (International Carbon Action Partnership, 2020a, p. 149), the International Carbon Action Partnership annually publishes a report that provides an overview of current ETS systems, trends and developments. According to this report, ETSs cover nine percent of global GHG emissions and are operating at different governmental levels, i. e. from one supranational system, namely the EU ETS, over five countries to 16 provinces and states and seven cities. Besides these, there are “24 further systems under development or under consideration” (ibid., p. 7). The largest emissions trading systems in force by capped GHG emissions are the ETSs of the EU (1.816 MtCO2e (2017)), the Republic of Korea (548 MtCO2e (2017)), Guangdong in China (465 MtCO2e (2018)), California in the USA (334 MtCO2e (2017)) and Mexico (271 $MtCO_2e$ (2017)) (ibid.). Further, the latest ICAP report (2020) indicates that next to an ETS, complementary policies like innovation funds and standards are needed and that "most of the 78 billion USD collected in auction revenues to date has been invested into innovation and further emission reductions" (p. 7). The report states that "[w]hen carefully crafted, policy packages that combine carbon pricing with other types of regulation can provide the most certain and cost-effective path to carbon neutrality" (ibid.).

The literature on cap-and-trade schemes and ETSs has focused on topics like waterbed effects in relation with overlapping instruments and leakage (e. g. Böhringer et al., 2016; Eichner & Pethig, 2019; Jarke & Perino, 2017; Perino et al., 2019), economic performance assessment (e. g. Baylis et al., 2013; Fuss et al., 2018), sector coupling (e. g. Jarke-Neuert & Perino, 2019) or distributional effects (e. g. Fullerton, 2011).

2.3 EU Emissions Trading System

The EU ETS started in 2005 on the basis of the 2003 EU ETS Directive as a policy instrument to meet the emission reduction targets prescribed by the 1997 Kyoto Protocol (Directive 2003/87/EC, 2003; European Commission, n. d.–c). It was launched as the world's first carbon market and is still the biggest emissions trading system around the world, accounting for about 40 % of EU emissions (European Commission, 2020a). All EU countries and additionally Iceland, Liechtenstein and Norway are involved in the system (ibid.) which covers emissions of carbon dioxide and since 2013 also of nitrous oxide and perfluorocarbons (Directive 2009/29/EC, 2009). The sectors covered include the generation of electricity and heat (European Commission, 2020a), commercial aviation since 2012 (European Commission, 2020b) as well as energy-intensive industries like e. g. oil refineries or the industries producing metals, chemicals, paper products, cement, glass, lime or ceramics (European Commission, 2020a). This means that companies in these sectors have to participate in the EU ETS but in some sectors only if they have a specific size and other small installations do not have to participate if there are other governmental policies in place ensuring that they reduce their emissions by an equal amount (ibid.). Further, until the end of 2023, only flights within Europe are covered (ibid.).

By the end of 2020, the EU ETS had gone through three trading periods or phases and will enter its fourth phase in 2021 (European Commission, 2020a). After the start in 2005 there was a first pilot phase until 2007, in which there was mostly free distribution (European Commission, n. d.–c). Due to the facts that there were national caps on the EU

ETS allowances (EUAs), that these were results of estimates and that keeping allowances to use them in the next period was not possible, there were more allowances supplied than demanded which was why in 2007, the price was equal to zero (ibid.). Böhringer (2014) noted that this overallocation was mainly due to the fact that the member states applied different allowance allocation rules, "providing opportunities for strategic industrial policies as well as lobby activities by industries" (p. 9). During the second phase from 2008 to 2012, the caps were set lower, 90 % of allowances were distributed freely and Iceland, Liechtenstein and Norway joined (European Commission, n. d.–c). Nevertheless, according to the European Commission (n. d.–c), due to the economic crisis in 2008, emissions decreased more than expected, leading to a surplus of allowances and a low price. However, Koch et al. (2014) found "that only variations in economic activity and the growth of wind and solar electricity production are robustly explaining EUA price dynamics" (p. 676) and their "findings do not support the widely-held view that negative demand shocks are the main cause of the weak carbon price signal" (ibid.). Further, Böhringer (2014) indicated that "the three stated objectives of the European Emissions Trading Directive—that is, cost effectiveness, harmonization of allocation rules, and free allocation of allowances – turn out to be incompatible" (p. 9) since "achieving efficiency when there is free allowance allocation implies that similar firms operating in different countries will generally receive different emission assignments, which contradicts the harmonization objective" (ibid.).

Therefore, there were significant rule changes for the third trading period from 2013 to 2020, during which auctioning was used as the default allocation method while the residual free distribution followed harmonized rules (European Commission, 2020a). Further, only one cap applied for the whole EU ETS instead of the national caps of phases 1 and 2 and, like mentioned above, more gases and sectors were covered (ibid.). Since the surplus of allowances increased until 2013, the EU started a short-term measure called backloading where the auctioning of 900 million allowances should be postponed by reducing the auction volumes from 2014 to 2016 (European Commission, n. d.–b). However, in 2015, Decision 2015/1814 was adopted which included the establishment of a Market Stability Reserve (MSR) as a long-term solution as well as the regulation that the backloaded allowances should be moved to the MSR instead of being auctioned (Decision (EU) 2015/1814, 2015; European Commission, n. d.–b).

Before the rules for the fourth trading period were adopted, any additional emission abatement measures like complementary climate policies had no effect on aggregate emissions due to the waterbed effect (Perino, 2018). Perino et al. (2020) differentiated the waterbed effect and internal carbon leakage and argued that both have to be considered to analyze the climate benefit of overlapping policies within carbon-pricing systems like the EU ETS. The waterbed effect refers to "the system-wide impacts arising from any induced changes to the equilibrium path of the system-wide carbon price" (ibid., p. 6) which means that "if an overlapping policy reduces EU-wide emissions demand (say, from power generation) by 1 ton of CO2, this will be precisely offset by increased demand of 1 tCO2 elsewhere in the system—the 'waterbed effect' is 100%" (ibid., p. 2). The name of the effect is "alluding to sitting on a waterbed changing the distribution of water in the bed, but not how much the bed actually holds" (Perino, 2018, p. 262). Note that this is not an error of cap-and-trade schemes which "act as an environmental 'safety net', helping ensure a specific environmental outcome regardless of the performance of other policies" (International Carbon Action Partnership, 2020a, p. 7). In contrast, internal leakage is defined referring to an "emissions displacement within the system […] for a given systemwide carbon price" (Perino et al., 2020, p. 5). An example is a unilateral carbon price for a certain sector that decreases domestic demand and emissions by 1 tCO_2e within this country's sector but increases imports and with that emissions elsewhere by 1 tCO_2e so that the leakage rate is 100 % and the effect on total emissions is zero (ibid.). Note that in this case, the internal leakage effect "applies irrespective of the extent of the waterbed effect" (ibid., p. 3) since the impacts do not arise from the carbon price of the whole carbon-pricing system (ibid.). According to Baylis et al. (2014), the leakage rate is defined as "the change in emissions elsewhere as a percentage of abatement in the regulated sector" (p. 55). Concerning the research question of the present thesis, the regulated sector corresponds to the targeted sector by a climate campaign, which has a leakage effect if consumers increase their demand in another sector instead. Above, it is possible that a waterbed effect occurs, which amounts to 100 % in Perino's (2015) analysis.

For the fourth trading period from 2021 to 2030, there was a major revision of the EU ETS Directive in 2018 in order to comply with the 2030 emission reduction target of the EU as well as the Paris Agreement (Directive (EU) 2018/410, 2018; European Commission, 2020a). This new rules for phase 4 of the EU ETS "fundamentally change its character" (Perino, 2018, p. 262) especially through a new mechanism for the MSR which started operating in 2019. An important indicator is the "total number of allowances in circulation” (Decision (EU) 2015/1814, 2015, L 264/2), which is also called “bank” in the literature as it refers to the allowances that are currently unused and “banked for future use” (Perino, 2018, p. 263). Specifically, when there are more than the upper threshold of 833,33 million[2] allowances in circulation on the 31st December of a particular year, then in the following year, the number of allowances which are auctioned is reduced by 24 % of the number of allowances banked and these allowances are placed in the MSR (Decision (EU) 2015/1814, 2015; Directive (EU) 2018/410, 2018). After 2023, a rate of 12 % instead of 24 % applies (ibid.). To be more precise, “[i]f the bank, […], exceeds 833 million at the end of a given year (in 2017 or later), then the number of allowances auctioned in the 12 months following October of the following year (but not before January 2019) is reduced by a certain percentage of the size of the bank” (Perino et al., 2020, p. 27). However, although this is more precise and should be kept in mind, for the sake of simplicity, in the following the formulation is used that the intake of allowances into the MSR depends on the bank of the previous year, since this version is also predominantly used in the literature (e. g. Bocklet et al., 2019; Gerlagh et al., 2019; Perino, 2018; Rosendahl, 2019a; Tietjen et al., 2019). This continues each year until the allowances in circulation are less than 833,33 million (Decision (EU) 2015/1814, 2015). If they fall even below the lower threshold of 400 million allowances, in each following year, 100 million allowances are released, i. e. they leave the MSR and are added to the auction volume (ibid.). This is done until the reserve is empty, i. e. if there are less than 100 million allowances in the MSR, all remaining allowances are released (ibid.). With this, the MSR would only delay the supply of allowances and the long run cap would be unaffected (Kollenberg & Taschini, 2019; Perino & Willner, 2015, 2016, 2017, 2019). But as an essential additional rule, the cancelation mechanism was adopted in 2018: From 2023 onwards, the MSR has an upper limit which corresponds to the total number of allowances auctioned in the previous year. This means that the number of allowances corresponding to the difference between the number of allowances in the MSR before and the number of allowances auctioned in the last year lose their validity, i. e. get canceled each year (Directive (EU) 2018/410, 2018). Therefore, the cap of the EU ETS is no longer fixed but endogenous and a result of the market outcome (Beck & Kruse-Andersen, 2020;

[2] This upper threshold can be calculated using the following indication in Decision (EU) 2015/1814: “Each year, a number of allowances equal to 12 % of the total number of allowances in circulation, […], shall be deducted from the volume of allowances to be auctioned […] and shall be placed in the reserve […], unless the number of allowances to be placed in the reserve would be less than 100 million” (p. L 264/4).

Perino, 2018). Additional, Directive (EU) 2018/410 states that „ Member States should have the possibility of cancelling allowances from their auction volume in the event of closures of electricity-generation capacity in their territory" (p. L 76/5). Further, the linear reduction factor or the annual reduction of the number of allowances increased to 2.2 % (European Commission, 2020a).

With this, additional emission abatements like national policies or climate campaigns can reduce long-term total GHG emissions, "which is not possible in a standard cap-and-trade system" (Beck & Kruse-Andersen, 2020, p. 781) and was also not possible before the reform. Likewise, according to Bruninx et al. (2020), the impact the MSR has on emissions significantly depends on other policies as well as on the development of e. g. investment costs. Further, as intended, the cancelation mechanism "increases the attractiveness of long-run low-carbon investments, relative to the case without cancellations" (Perino & Willner, 2019, p. 859). However, Perino (2018) indicates that this "puncture in the EU ETS waterbed" (p. 262) is only temporary, retroactive, and incomplete. It is temporary since when the number of allowances in circulation falls below the upper threshold of 833,33 million, the MSR stops taking in allowances and therefore additional abatements cannot have an effect on long-term emissions and the waterbed effect is operating again, given that the upper threshold is not exceeded again in the future (ibid.). Further, the puncture is retroactive because the MSR intake depends on the number of allowances in circulation at the end of 2017 and the years afterwards (ibid.). Since banking have been allowed since phase 2 and since then there was always a strictly positive number of banked allowances, past additional abatements in phases 2 and 3 can have an effect on the long-term cap (ibid.). Perino (2018) even showed that the emission reducing effect of abatement that occurred between the start of phase 2 in 2008 and 2017 is higher than the effect of abatement occurring afterwards since in the case of "abatement occurring in 2018 or later, the marginal impact on the long-term cap decreases year by year until it reaches zero, which is when the waterbed effect is fully re-established" (p. 264). Also, the puncture of the waterbed can be called incomplete in the sense that "abating one ton of CO2 emissions results in an emissions reduction of less than one ton" (ibid. p. 262). Hence, Perino (2018) concluded that "the rules for Phase 4 have implications far beyond the EU ETS as they substantially alter the optimal policy mix" (p. 262). However, the MSR mechanism will be regularly reviewed, starting in 2022, and a "further change of rules, […], is quite likely" (ibid., p. 264).

However, a number of scholars criticize the rules for the fourth trading period, especially because they increase the complexity of the EU ETS significantly (Beck & Kruse-Andersen, 2020; Bocklet et al., 2019; Osorio et al., 2020; Perino, 2018; Perino & Willner, 2019) which "may hinder the implementation of cost-efficient national policies" (Bocklet et al., 2019, p. 4). Bruninx et al. (2019) emphasized that the cancelation mechanism "results in significant uncertainty on the cumulative emissions" (p. 1) while "overlapping policies […] may trigger paradoxical cumulative emission reductions or increases" (ibid.). Connected to the aspect of uncertainty, Osorio et al. (2020) stated that "the (unpredictable) *expectations* of market actors about future CO_2 prices and costs will – via the MSR – influence the size of the cap" (p. 28). Also, Perino (2018) called the new rules "probably one of the least transparent ways for endogenizing total emissions in a cap-and-trade scheme" (p. 264). Furthermore, Edenhofer et al. (2017) mentioned that "no sound theoretical and empirical analysis establishing the relationship between the quantity of EUAs in circulation and the EUA price is publicly available – even though the MSR and the options adopted in the trialogue apparently rest on the assumption that such a relation exists" (p. 9). Additionally, a number of NGOs including the European Environmental Bureau and Carbon Market Watch criticize in a recent joint report that although the latest reform "helped to raise the price of carbon within the EU ETS, it is clear that a serious revision of the EU ETS legislation is urgently needed to stay within the Paris Agreement 1.5°C temperature rise limit" (Sabbadin et al., 2020, p. 11).

Hence, a number of improvement possibilities are suggested, for instance a carbon price floor for the EU ETS (Edenhofer et al., 2017; Flachsland et al., 2020; Newbery et al., 2018). Flachsland et al. (2020) argued in favor of an EU ETS price floor "as a complement or substitute to the current Market Stability Reserve" (p. 1) since this "would be an important institutional innovation enhancing political and economic stability, and predictability of the EUA price" (ibid.). The option of a price floor is not only considered at the EU but also at national level (Böhringer & Fischer, 2020; Newbery et al., 2018) and different design options can have different implications (Böhringer & Fischer, 2020; Hintermayer, 2020). Apart from this, Osorio et al. (2020) suggested a "Price Stability Reserve" (p. 29) that would "trigger in- and outtake from the MSR by prices rather than emissions" (ibid.), arguing that this "would consolidate expectations about future CO2 prices and thus increase planning security for development of and investments into decarbonization technologies" (ibid.).

Above criticism and improvement suggestions, there are also some attempts to identify trends and make projections about how the EU ETS will develop given the rules of the fourth trading period. Considering the number of allowances that will be canceled, Osorio et al. (2020) found “that there is a broad range of MSR cancellation estimates from the literature (from 1.7 Gt to 13 Gt, making up 4% to 32% of the total pre-MSR budget)” (pp. 3-4) while their own estimation based on the detailed electricity and industry model LIMES-EU amounts to 5,1 Gt allowances canceled overall under the current rules. They point out that the magnitude of cancelation “var[ies] considerably depending on key design parameters set by policy makers, but also on market actors’ time horizons and discount rates, as well as their expectations about the future costs of abatement” (p. 28). Regarding the time period of the puncture of the waterbed, i. e. for how many years the MSR takes in allowances, the estimates vary significantly as well. While Perino (2018) stated that “the horrors of the waterbed […] will be back to their full strength by the middle of Phase 4” (p. 264), in the base case scenario by Rosendahl (2019a), the bank falls below the upper threshold in 2035, and Quemin (2020) found that this happens between 2030 and 2035. The reference scenario by Osorio et al. (2020) indicates that “[t]here is ongoing intake to the MSR between 2019 and 2042 (except for 2023 and 2025)” (p. 12) and that “cancellation of certificates […] takes place from 2023 to 2043 (except for 2024 and 2026) and later between 2047 and 2055” (ibid.). Because the estimates by Osorio et al. (2020) can be called both more recent and more detailed since they are based on a detailed sectoral model, they will be used later on as a basis for the numerical illustration, although the uncertainty due to varying projections will be considered.

3 Perino’s General Equilibrium Model

Since the approach to answer the research question is to update Perino’s (2015) model and to extend and combine it with Rosendahl’s (2019) model, in the following, the basics of both and especially the essential parts for the present analysis are briefly explained.

Perino (2015) used a general equilibrium model similar to the model by Baylis et al. (2013, 2014) who studied leakage effects occurring with a carbon tax or a cap-and-trade scheme but not effects of climate campaigns specifically. They based their model on the work by Harberger (1962). The focus of Perino’s model is the interaction between the capped and uncapped sectors of the economy regarding emissions, i. e. emission leakage between them. Perino assumed “two perfectly competitive sectors, each using two inputs, the clean input L and dirty carbon emissions C, to produce consumption goods x

('driving') and y ('electricity'), respectively" (p. 472) whereas y is a good produced in a sector regulated by a cap-and-trade scheme with a binding cap where permits are traded at a price $t_y > 0$ and x is a good produced in an uncapped sector that is regulated by an exogenous carbon tax $t_x \geq 0$. Besides, the capital letters X and Y represent the respective aggregate output quantity. The clean input L is "a composite of labor and capital" (ibid.), fixed in supply and "perfectly mobile between sectors and hence traded at the uniform price w" (ibid.) while y is traded at price p_y and x is the numeraire traded at price $p_x=1$. Furthermore, there is a constant-returns-to-scale technology $f_j\ (L_j,\ C_j)$ in each sector j. Regarding consumption, "[t]here is a representative consumer maximizing the utility function $u(X, Y; m)$, where m is a parameter that shifts the marginal rate of substitution between y and x up or down" (p. 473). This shift represents the effect of a climate campaign either targeting specific products or sectors (called sector-specific climate campaign) or aiming at convincing consumers to reduce their carbon footprints in general (general climate campaigns). The focus in the following will be on sector-specific climate campaigns which are characterized by "an exogenous change in the utility parameter m which shifts demand from one sector to the other" (p. 475) where at constant prices, an increase in m leads to a decrease in demand for good y and an increase in demand for good x and a decrease in m leads to an increase in demand for good y. Thereby the focus is on the former option. It is assumed that "consumers have some form of intrinsic motivation to contribute to the public good of greenhouse gas mitigation" (p. 473). Regarding the utility of the consumer, Perino (2015) assumed non-satiation in both goods, decreasing marginal utility, strictly positive demand at finite prices and asymptotic satiation as well as a homothetic utility function. Above, consumers face a budget constraint $X + p_yY \leq wL + t_xC_x + t_yC_y$ which is "derived from their endowment of the clean input and lump-sum transfers from permit auctions and carbon tax revenues" (ibid.).

Further, Perino (2015) assumed that the economy is in equilibrium and focused "on the comparative statics induced by a climate campaign represented by a change in the utility parameter m and represent[ed] proportional changes in endogenous variables by using the 'hat' notation" (ibid.). Baylis et al. (2013) specified this further in stating that "e.g., $\hat{X} = dX / X$" (p. 333), which is why it holds that $\hat{p}_x = 0$ as good x is traded as the numeraire. Concerning this setting, the following system of equations is stated (Perino, 2015, pp. 474–475):

(1) $\alpha_x \hat{L}_x + \alpha_y \hat{L}_y = 0$	totally differentiated resource constraint on the clean input *L*, where $\alpha_i = L_i / L$ is the share of the clean input used in sector *i* and $\alpha_x + \alpha_y = 1$
(2) $\hat{X} = \theta_{XL} \hat{L}_x + \theta_{XC} \hat{C}_x$ (3) $\hat{Y} = \theta_{YL} \hat{L}_y + \theta_{YC} \hat{C}_y$	totally differentiated production functions, where θ_{ij} is the share of income used on input *j* in the production of good *i* and $\theta_{iL} + \theta_{iC} = 1$
(4) $\hat{X} = \theta_{XL} (\hat{L}_x + \hat{w}) + \theta_{XC} (\hat{C}_x + \hat{t}_x)$ (5) $\hat{p}_y + \hat{Y} = \theta_{YL} (\hat{L}_y + \hat{w}) + \theta_{YC} (\hat{C}_y + \hat{t}_y)$	totally differentiated zero-profit conditions
(6) $\hat{C}_x - \hat{L}_x = \sigma_x (\hat{w} - \hat{t}_x)$ (7) $\hat{C}_y - \hat{L}_y = \sigma_y (\hat{w} - \hat{t}_y)$	totally differentiated marginal rates of technical substitution (MRTS), where $\sigma_i > 0$ is the elasticity of substitution of the input factors in the production of good *i*
(8) $\hat{X} - \hat{Y} = \sigma_u (\hat{p}_y + \frac{1}{\sigma_m} \hat{m})$ (9) $\hat{X} - \hat{Y} = \sigma_u (\hat{p}_y + \hat{m})$	totally differentiated marginal rate of substitution (MRS), where $\sigma_u > 0$ is the elasticity of substitution in consumption between *x* and *y; m* is a utility parameter that represents the impact of the climate campaign through shifting the marginal rate of substitution between *x* and *y* up or down; σ_m is the elasticity of the MRS with respect to a change in *m;* for the case of the constant elasticity of substitution utility function, (8) simplifies to (9)

These conditions are very similar to the ones used in the model by Baylis et al. (2013, 2014) and show similarities to general equilibrium models established in the literature on tax incidence (e. g. Fullerton & Metcalf, 2002; Harberger, 1962). This system of eight equations with eight unknowns applies generally, meaning both for the case of a tax in both sectors or of a partial cap-and-trade scheme, with the former used later as a reference scenario for comparison. Concerning the policy regime of a partial cap-and-trade scheme, according to Perino (2015, p. 478), the following lemmas are valid:

> **Lemma 3:** Given conditions (1)–(7), and if sector *X* is regulated by a carbon tax and sector *Y* by a binding cap-and-trade scheme, then a shift in relative demand of *x* and *y* has no impact on the equilibrium price of the clean input, that is, $\hat{w} = 0$. In sector *Y*, output price and the sector-specific carbon price move in the same direction ($\hat{p}_y = \theta_{YC} \hat{t}_y$).
>
> **Lemma 4**: Given the conditions of lemma 3, inputs and outputs of sector *X* expand or contract proportionately ($\hat{X} = \hat{L}_x = \hat{C}_x$) in response to a shift in relative demand of *x* and *y*. In sector *Y*, output is determined by the change in the use of the clean input ($\hat{Y} = \theta_{YL} \hat{L}_y$), which also determines the change in output of sector *X*, that is, $\hat{X} = -\alpha_y / \alpha_x \hat{L}_y$.

Regarding the research question pursued, especially Proposition 2 is relevant, which derives the changes in emissions due to a specific climate campaign in the context of a partial cap-and-trade scheme from the above equations (Perino, 2015, p. 479):

> **Proposition 2:** If sector *X* is regulated by a carbon tax and sector *Y* by a binding cap-and-trade scheme, and given conditions (1)–(7) and (9), then a climate campaign represented by a change in the utility parameter *m* induces the following changes in emissions:
>
> - Sector *X*:
>
> $$\hat{C}_x = \frac{\sigma_u}{1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m},$$
>
> - Sector *Y*: $\hat{C}_y = 0$ (by assumption),
> - Total emissions:
>
> $$\hat{C} = \varepsilon_x \hat{C}_x = \frac{\varepsilon_x \sigma_u}{1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m},$$
>
> where $\varepsilon_x = C_x / C$.
>
> Hence, total emissions increase in response to an exogenous increase in *m*.

The proof for this can be found in Perino's (2015) appendix. The intuition behind this result is that since emissions in the capped sector are fixed and cannot decrease while emissions in the uncapped sector increase due to the leakage effect, there is an overall increase in total emissions. However, since $\hat{C}_y = 0$ is no longer feasible, this proposition will be updated later on considering the EU ETS and the MSR whereby the binding cap will be replaced by an endogenous cap which is a result of the market outcome.

4 Rosendahl's Model of the EU ETS

Concerning sector *Y*, the new rules for phase 4 of the EU ETS require an extension to the model used by Perino (2015). Analytical models that take into account the latest reform of the EU ETS, including the features of the MSR and its cancelation mechanism, have been developed i. a. by Bocklet et al. (2019), Gerlagh et al. (2019), Rosendahl (2019a) as well as Tietjen et al. (2019). The model by Rosendahl (2019a) was chosen since it was found to be intuitively most comprehensible and most compatible with Perino's (2015) model. Hence, in the following, the stylized model of the EU ETS by Rosendahl (2019a) is introduced shortly to be able to derive the change in emissions in sector *Y* afterwards.

Rosendahl (2019a)[3] uses a "stylized, dynamic model of an ETS incorporating the features of the MSR" (p. 2) to show that additional abatement efforts within the sectors subject to the EU ETS might increase cumulative emissions if they are permanent or occur at a later point in time. The focus of the model is the functioning of an ETS with MSR and its cancelation mechanism in *n* periods, where the supply and demand of allowances are called S_t and D_t, respectively. Whereas supply is initially fix, demand depends on the price of allowances t_{yt} and can be construed as emissions in period *t*. The number of allowances which are banked at the end of period *t* is denoted B_t. Regarding the reserve, the size of the MSR at the start of period *t* is denoted M_t . M_t^{IN} indicates how many allowances were withdrawn from supply and enter the MSR during period *t* (inflow or intake) and M_t^{OUT} states how many allowances leave the MSR and increase the supply in period *t* (outflow or outtake). K_t denotes the number of allowances in the MSR that get canceled. With this, the following system of equations is given (Rosendahl, 2019a, pp. 2–3):

(1) $M_t^{IN} = \mu_t B_{t-1}$	inflow into MSR if the number of banked allowances of the last period B_{t-1} is above a certain upper threshold λ , i. e. $B_{t-1} > \lambda$, where $\mu_t \in (0,1)$ is the withdrawal rate
(2) $M_t^{OUT} = Min\,(M_{t-1}; \gamma)$	outflow from MSR if B_{t-1} is below a certain lower threshold η , i. e. $B_{t-1} < \eta$, where $\eta < \lambda$; γ refers to the maximum number of allowances leaving the MSR and entering the market
(3) $K_t = M_t - \beta\, S_t$	number of excess allowances in the MSR canceled if $M_t > \beta\, S_t$, where β is a certain share of S_t (in the EU ETS, β is equivalent to the share of S_t which is auctioned) [4]
(4) $M_t = M_{t-1} + M_t^{IN} - M_t^{OUT} - K_{t-1}$	equation of motion for the number of allowances in the MSR M_t

[3] In order to avoid two-fold meanings or characters when looking at the models of Perino (2015) and Rosendahl (2019a), the *C* in Rosendahl's model is named *K*, α_t is named μ_t and P_t is named t_{yt}.

[4] The equation (3) $K_t = M_t - \beta S_t$ may seem as if it does not reflect the fact that the number of allowances auctioned *in the previous year* is decisive for the number of allowances canceled if $M_t > \beta S_t$, since one would intuitively expect $K_t = M_t - \beta S_{t-1}$ to hold. However, the model corresponds to this circumstance, which becomes evident when one inserts K_t in M_{t+1}, because rearranging $M_{t+1} = M_t + M_{t+1}^{IN} - M_{t+1}^{OUT} - (M_t - \beta S_t)$ yields $M_{t+1} = \beta S_t + M_{t+1}^{IN} - M_{t+1}^{OUT}$. With this it is apparent that the number of allowances auctioned *in the previous year* βS_t is decisive for the maximum number of allowances in the MSR M_{t+1} or the number of allowances canceled if $M_t > \beta S_t$.

(5) $S_t - M_t^{IN} + M_t^{OUT} = D_t(t_{yt}) + B_t - B_{t-1}$	market balance in the emission allowance market where S_t refers to the supply of allowances and D_t to the demand depending on the allowance price t_{yt}
(6) $t_{yt} = \delta\, t_{yt+1}$	assumption that banking happens until there are no further arbitrage possibilities, where $\delta = 1/(1+r)$ is the discount factor and r the market interest rate

Regarding equation (3), Rosendahl's (2019a) mathematical representation of the cancelation mechanism is not accurate since he just uses the initially fixed share of supply of allowances βS_t, which corresponds to the fix gross auctioned supply in the EU ETS, to determine the number of allowances which are canceled. However, according to the EU Decision 2015/1814 of the European Parliament and of the Council, "[e]ach year, a number of allowances equal to 12 % of the total number of allowances in circulation, […], *shall be deducted from the volume of allowances to be auctioned by the Member States* [emphasis of the author] […] and shall be placed in the reserve" (2015, L 264/4, art. 1, par. 5). Note that EU Directive 2018/410 requires the rate to increase to 24 % until 2023. Further it states that „from 2023 allowances held in the reserve *above the total number of allowances auctioned during the previous year* [emphasis of the author] should no longer be valid" (2018, L 76/8, par. 23). Therefore, "the total number of allowances auctioned during the previous year" (ibid.) refers to the auctioned net supply as the basis for the calculation of the allowances which are canceled. Since the net supply is depicted by the left side of the market balance equation (5), namely $S_t - M_t^{IN} + M_t^{OUT}$, and since in the EU ETS, β represents the share of supply auctioned and M^{IN} is directly withdrawn from and M^{OUT} directly added to the auction volume, in this thesis, the auctioned net supply is defined as $N_t = \beta S_t - M_t^{IN} + M_t^{OUT}$. Therefore, in the following, instead of equation (3), $K_t = M_t - N_t = M_t - \left(\beta S_t - M_t^{IN} + M_t^{OUT}\right) = M_t - \beta S_t + M_t^{IN} - M_t^{OUT}$ is used if $M_t > N_t$ [5].

[5] The existing analytical models of the EU ETS and the MSR and its cancelation mechanism differ significantly with regard to this decisive factor: Gerlagh et al. (2019) use a term to indicate cancelation which is content-equivalent to the work by Rosendahl (2019a) using only the initially fixed auctioned supply. In the model by Bocklet et al. (2019), cancelation depends on the auctioned net supply but, transferred to the notation used here, it is calculated using $K_t = M_t - \beta\left(S_t - M_t^{IN} + M_t^{OUT}\right)$ which does not reflect reality since according to the rules, M_t^{IN} and M_t^{OUT} are deducted directly from the auctioned supply and hence, the share of the supply which is auctioned β is not to be applied to these values. Tietjen et al. (2019) use a model were cancelation depends on the net auction volume which is content-equivalent to the equation applied here. These different implementations in models show that the interpretation of the law is not trivial, which is why I contacted the German Emissions Trading Authority, which confirmed that the interpretation used here is correct (personal communication, 20th of August 2020).

Nevertheless, Rosendahl's (2019) model still provides a concise and useful mathematical description of ETSs with a market stability mechanism.

5 Analytical Effects of a Climate Campaign under Partial Cap-and-Trade

To find an answer to the question, what effects a climate campaign can have on long-term total emissions within a cap-and-trade scheme with a MSR , in this section, the effects of a climate campaign on emissions under the conditions of the current EU ETS with the MSR are analytically derived, whereby first the effect in sector *Y*, second in sector *X* and finally the total effect is deduced. The focus in the following is on temporary, sector-specific climate campaigns where at constant prices, an increase in *m* leads to a temporary decrease in demand for good *y* and an increase in demand for good *x*. The effect of campaigns shifting demand in the opposite direction from *X* to *Y* will be discussed later. More precisely, the focus is on climate campaigns that are temporary in the sense that the demand shift only occurs in one year, not in every year following, and that there is no rebound effect, i. e. that the additional allowances in the bank will not be overcompensated by an even stronger decrease of the bank in one of the following years.

As explained above, Perino's (2015) assumption that emissions in sector *Y* do not change, i. e. that $\hat{C}_y = 0$ holds, is no longer feasible when considering the EU ETS with the MSR where the number of allowances overall and thereby also the change in emissions is depending on the market outcome. That is why Proposition 2 should be updated. Therefore, first the emission change in Sector *Y* will be derived for six different cases using mainly Rosendahl's (2019a) model and in a second step, the change in emissions in sector *X* will be calculated using Perino's model. To be able to determine these effects, in the following, analogous to Perino (2015) it is assumed that the economy is in equilibrium and the focus is "on the comparative statics induced by a climate campaign represented by a change in the utility parameter *m"* (p. 474). Further, the "hat" notation is used for the representation of "proportional changes in endogenous variables" (ibid.). Note that in lemma 4, $\hat{Y} = \theta_{YL}\hat{L}_y$ no longer holds since it was a result from condition (3) $\hat{Y} = \theta_{YL}\hat{L}_y + \theta_{YC}\hat{C}_y$ and $\hat{C}_y = 0$. Since $\hat{C}_y = 0$ is not assumed anymore, only condition (3) holds instead. Apart from this change, lemma 3 and 4 are still valid.

5.1 Emission Changes in Sector *Y*

Considering the EU ETS, the long-term change in emissions in sector Y is fully described by the number of allowances canceled due to the cancelation mechanism because apart from that the MSR only delays the supply of allowances and the waterbed effect is still operational as noted above. Therefore, the question has to be answered, if allowances would be canceled and if yes how many would be canceled due to a climate campaign, represented by an increase in the utility parameter m, i. e. $\hat{m} > 0$, leading to an increase in demand for good x, i. e. $\hat{X} > 0$, and a decrease in demand for good y, i. e. $\hat{Y} < 0$. Because the answer depends heavily on the number of banked allowances B_t and the number of allowances in the MSR in the following period M_{t+1}, one has to distinguish at least three different cases, as Figure 1 shows. Note that in the following, B_t and M_{t+1} should be understood with the change due to the campaign, unless it is mentioned otherwise.

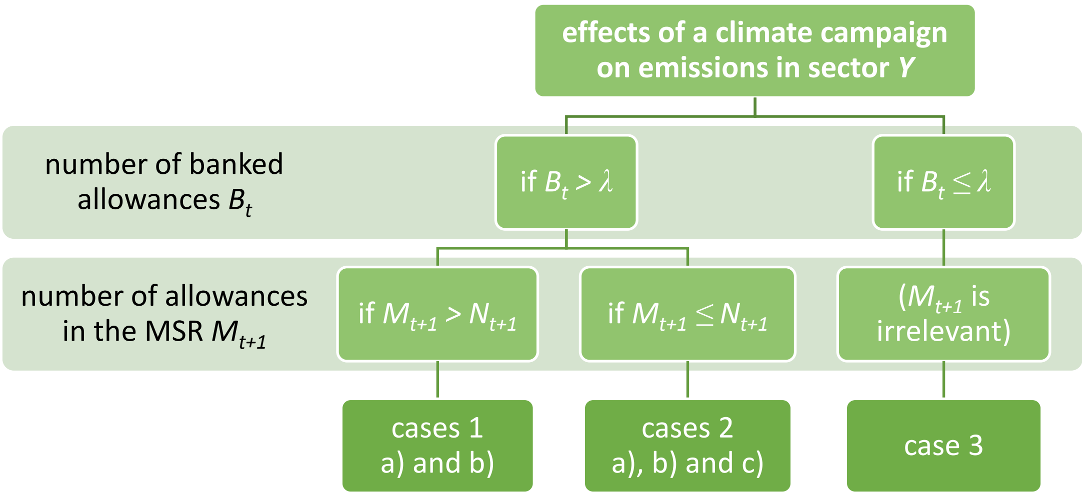

Figure 1: Visualization of the distinct cases

In the following, there will be a further differentiation of cases 1 and 2 and the theoretical effects of a climate campaign in all six cases will be explained.

First, in any of the six cases, the climate campaign induces a decrease in demand in the capped sector Y and production in this sector will decrease. Hence, there will also be less demand for emission allowances leading to a higher number of allowances banked or in circulation. Here the simplifying assumption is made that the number of allowances in circulation increases by the same amount that the demand for good y decreases, namely $\hat{B} = -\hat{Y}$. Depending on the total number of allowances in the bank afterwards (B_t), one has to distinguish different cases since this number is decisive for whether there is an intake of allowances into the MSR or not.

5.1.1 Cases 1 a) and b)

In case 1, B_t is assumed to be greater than a certain upper threshold λ, i. e. $B_t > \lambda$ holds. In this case, each following year the number of allowances auctioned is reduced by a certain withdrawal rate μ of the number of allowances in the bank and these allowances enter the MSR[6]. Within the EU ETS, when there are more allowances banked at the end of a year than the upper threshold of 833,33 million (λ in the general case considered here), then each following year the number of allowances auctioned is decreased by 24 % of the number of allowances in the bank until 2023 and by 12 % after 2023 (generally denoted by μ) (Decision (EU) 2015/1814, 2015; Directive (EU) 2018/410, 2018).

Due to the increase in B_t as a consequence of the climate campaign, the number of allowances withdrawn from auction and put into the MSR increases as well in the next period. This is why it holds both that 1) the auctioned net supply decreases due to $\hat{m} > 0$, i. e. $\hat{N} = -\hat{M}^{IN} = -\mu\hat{B} = \mu\hat{Y}$, and that 2) the number of allowances entering the MSR increases, i. e. $\hat{M}^{IN} = \mu\hat{B} = -\mu\hat{Y}$. Accordingly, $\hat{M} = \hat{M}^{IN} = -\mu\hat{Y}$ is valid as well since the number of allowances in the MSR increases if more allowances enter the MSR and ceteris paribus all other variables determining the size of the MSR are constant.

Whether allowances are canceled due to the climate campaign and if so, how many, depends on the size of the MSR in the next period M_{t+1} as well as on the auctioned net supply N_{t+1}, since if $M_{t+1} > N_{t+1}$, $K_{t+1} = M_{t+1} - N_{t+1}$ holds, i. e. "all these excess allowances are permanently canceled" (Rosendahl, 2019a, p. 3). In the EU ETS case, cancelation will happen from 2023 onwards and allowances will be canceled if they exceed the share of allowances auctioned which is 57 % of the total annual supply, i. e. $\beta=0.57$ (Directive (EU) 2018/410, 2018).

Since in case 1 it is assumed that $M_{t+1} > N_{t+1}$ is valid in the next period $t+1$, ceteris paribus the number of canceled allowances would increase due to 1) the decrease in auctioned net supply N_{t+1} and 2) the increase in the number of allowances in the MSR M_{t+1}, since both effects increase the difference between M_{t+1} and N_{t+1}. Inserting the equations of M_{t+1} and N_{t+1} helps in the next step to differentiate cases 1 a) and 1 b) and yields $M_{t+1} = M_t + M_{t+1}^{IN} - M_{t+1}^{OUT} - K_t > \beta S_{t+1} - M_{t+1}^{IN} + M_{t+1}^{OUT} = N_{t+1}$. Since $B_t > \lambda$ holds, $M_{t+1}^{OUT} = 0$ is

[6] For the purpose of this general analysis, μ instead of μ_t is written here since it is assumed here that the withdrawal rate μ is constant in all periods.

valid, leading to $M_t + M_{t+1}^{IN} - K_t > \beta S_{t+1} - M_{t+1}^{IN}$. Further, the intake into the MSR in period *t+1*, M_{t+1}^{IN}, is ceteris paribus composed of the intake into the MSR in the previous period *t*, M_t^{IN}, and the change due to the campaign $\hat{M}^{IN}$, i. e. $M_{t+1}^{IN} = M_t^{IN} + \hat{M}^{IN}$. Inserting this leads to $M_{t+1} = M_t + M_t^{IN} + \hat{M}^{IN} - K_t > \beta S_{t+1} - M_t^{IN} - \hat{M}^{IN} = N_{t+1}$.

If it is assumed that **a) $M_{t+1} > N_{t+1}$ would apply also without the changes due to the campaign**, i. e. $M_t + M_t^{IN} - K_t > \beta S_{t+1} - M_t^{IN}$, then because $K_{t+1} = M_{t+1} - N_{t+1}$ and hence $\hat{K} = \hat{M} - \hat{N}$ is valid and since $\hat{M} = \hat{M}^{IN} = -\mu\hat{Y}$ and $\hat{N} = -\hat{M}^{IN} = \mu\hat{Y}$ hold, $\hat{K} = -2\mu\hat{Y}$ can be deduced. In *t+2*, K_{t+1} is deducted from M_{t+2} due to $M_{t+2} = M_{t+1} + M_{t+2}^{IN} - M_{t+2}^{OUT} - K_{t+1}$. Therefore, in this case and considering the time interval *t* to *t+2*, emissions in Sector *Y* decrease due to the climate campaign, namely $\hat{C}_y = -\hat{K} = 2\mu\hat{Y}$ holds. The intuition behind this is that because the demand and output decreases in sector *Y*, there are more allowances unused, i. e. banked, in *t*, which is why in *t+1* there is a higher intake into the MSR and a lower number of allowances auctioned which leads to a higher number canceled in *t+2*.

However, the allowances that have been added to the allowances in circulation due to the climate campaign probably stay in the bank afterwards while the bank might still be sufficiently large that allowances are withdrawn from auction and put into the MSR. This is why in addition, these allowances can have an effect even in the following years. Precisely, how long they stay in the bank before the bank falls below the threshold λ determines how big the cumulative effect of the abatement due to the climate campaign is, i. e. how many allowances are withdrawn from auction volume and enter the MSR due to the campaign in total. Whereby of course it is valid that the more years the allowances due to the campaign are in circulation and $B_t > \lambda$ holds, the bigger the cumulative effect of the campaign on emissions. This is because the more allowances enter the MSR due to the campaign, the more allowances are canceled since in case 1 it is assumed that $M_{t+1} > N_{t+1}$ is valid in the next period *t+1*. Note that for a simplified notation, this is to be seen as a reiterating scheme, i. e. in each year *t*, whether there is an intake depends on whether $B_t > \lambda$ holds, and in each following year *t+1*, whether there is cancelation depends on whether $M_{t+1} > N_{t+1}$ holds. Applied on the EU ETS, Perino (2018) used the following formula for this cumulative effect: "1 - $(1 - 0.24)^x (1 - 0.12)^y$ where *x* and *y* are the number of years between the time of abatement and the year the 833,33 million threshold is passed with intake rates of 24% and 12%, respectively" (p. 263). Utilizing this for the general case yields $\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y}$ for case 1 a), where z is the number of years between the year where additional allowances entered the bank due to the climate campaign and the year where the bank falls below the upper threshold λ, assuming that the intake rate μ is constant for the years z considered[7]. Because of that, not only the magnitude of the output change and the intake rate is decisive but also the number of years the additional allowances stay in the bank before the bank falls below the threshold. In short, the larger z, the greater the long-term effect on emissions. Therefore, for a given effect of a climate campaign on the bank (denoted $\hat{B} = -\hat{Y}$ in the case considered here), only a certain number of allowances, corresponding only to a certain percentage of the effect, enter the MSR and can be canceled each year. Hence, it takes a certain number of years for the campaign to make its impact. A summary of this mechanism leading to the emission change in sector Y due to the climate campaign in case 1 a) is displayed in the table below:

<table>
<tr><th>effects</th><th>related equations and remarks</th></tr>
<tr><td>m ↑</td><td>exogenous increase in the utility parameter m (impact of climate campaign)</td></tr>
<tr><td>Y ↓</td><td>decrease in demand and output for good y due to $\hat{m} > 0$</td></tr>
<tr><td>X ↑</td><td>increase in demand for good x due to $\hat{m} > 0$</td></tr>
<tr><td>B_t ↑</td><td>$\hat{B} = -\hat{Y}$</td></tr>
<tr><td colspan="2" align="center">if $B_t > \lambda$</td></tr>
<tr><td>M_{t+1}^{IN} ↑</td><td>$\hat{M}^{IN} = \mu\hat{B} = -\mu\hat{Y}$</td></tr>
<tr><td>N_{t+1} ↓</td><td>$\hat{N} = -\hat{M}^{IN} = \mu\hat{Y}$
since $N_{t+1} = \beta S_{t+1} - M_{t+1}^{IN} + M_{t+1}^{OUT}$ and $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$ and βS_{t+1} is fixed</td></tr>
<tr><td>M_{t+1} ↑</td><td>$\hat{M} = \hat{M}^{IN} = -\mu\hat{Y}$
since $M_{t+1} = M_t + M_{t+1}^{IN} - M_{t+1}^{OUT} - K_t$ and $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$ and M_t and K_t are constant</td></tr>
<tr><td colspan="2" align="center">if $M_{t+1} > N_{t+1}$
and if $M_t + M_t^{IN} - K_t > \beta S_{t+1} - M_t^{IN}$ holds without the changes due to $\hat{m}$ (a)),
since $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$ and since $M_{t+1}^{IN} = M_t^{IN} + \hat{M}^{IN}$</td></tr>
</table>

[7] This formula can be deduced with the assumption that ceteris paribus, since the net auctioned supply N_{t+1} is reduced in $t+1$, B_{t+1} is reduced by the same amount that is withdrawn from auction volume and put into the MSR.

K_{t+1} ↑	$\hat{K} = \hat{M} - \hat{N} = \hat{M}^{IN} - (-\hat{M}^{IN}) = 2\hat{M}^{IN} = -2\mu\hat{Y}$ or since $K_{t+1} = M_{t+1} - N_{t+1} = (M_t + M_{t+1}^{IN} - M_{t+1}^{OUT} - K_t) - (\beta S_{t+1} - M_{t+1}^{IN} + M_{t+1}^{OUT})$, hence $K_{t+1} = M_t + 2M_{t+1}^{IN} - 2M_{t+1}^{OUT} - K_t - \beta S_{t+1}$ and again, $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$, and M_t and K_t are constant and βS_{t+1} is fixed
M_{t+2} ↓	$M_{t+2} = M_{t+1} + M_{t+2}^{IN} - M_{t+2}^{OUT} - K_{t+1}$ (K_{t+1} gets canceled in period $t+2$)
C_{yt+2} ↓	$\hat{C}_y = -\hat{K} = 2\mu\hat{Y}$ (emission change in sector Y in $t+2$)
C_{yt+z+2} ↓ (long-term)	$\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y}$ (emission change in sector Y in $t+z+2$) since $\hat{M}^{IN} = -\left(1-(1-\mu)^z\right)\hat{Y}$, where z is the number of years between the year where B_t increases due to the climate campaign and the year where B_{t+z} falls below the upper threshold λ, i. e. when $B_t \leq \lambda$ happens

Therefore, considering long-term emissions, case 1 a) refers to the scenario where $M_{t+1} > N_{t+1}$ would apply each year also without the changes due to a campaign and hence, where the additional allowances in the MSR due to a campaign are canceled completely, i. e. $\hat{K} = 2\hat{M}^{IN} = -\left(1-(1-2\mu)^z\right)\hat{Y}$ holds, and therefore the long-term emissions in Y decrease accordingly, i. e. $\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y}$.

However, it might also happen that the additional allowances in the MSR due to a campaign are not canceled completely, but only partially, since **b) $M_{t+1} > N_{t+1}$ holds only with the changes due to the campaign**, i. e. without them, $M_t + M_t^{IN} - K_t < \beta S_{t+1} - M_t^{IN}$ and hence $M_{t+1} < N_{t+1}$ would be valid. In this case, some of these additional allowances might contribute that M_{t+1} reaches the threshold of N_{t+1} and only a certain number of them will be excess allowances above the threshold of N_{t+1} that are canceled. Analogous to case 1 a), this would imply $\hat{C}_y = -\hat{K} = 2\mu\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ in $t+2$, where the term in square brackets corresponds to the difference between M_{t+1} and N_{t+1} that exists without the campaign. When considering long-term effects, case 1 b) refers to the scenario where only some of the total number of additional allowances which entered the MSR due to a campaign until a certain year are canceled, i. e. only a part of this total number is canceled. A simplified representation of the case where additional certificates are only partially deleted in one year and the remaining certificates from this year are not deleted later is $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$. Note that if this happens in more than one year, there would be a corresponding number of additional summands like the one in square brackets. Therefore, in case 1 b), emissions in sector Y decrease due to the climate campaign although not as much as in case 1 a). The derivation of these solutions, analogous to the derivation for case 1 a) above, can be found in the appendix (see “Derivation Analytical Solution Case 1 b)”).

Regarding M^{OUT}, since the additional allowances in the MSR due to the climate campaign are completely canceled in case 1 a), these allowances cannot leave the MSR and enter the market again when $B_x > \eta$ holds in a future period x, i. e. $\hat{M}^{OUT} = 0$. However, in case 1 b), because only a part of these allowances is canceled, some might leave the MSR and increase the net auctioned supply in a future period x, i. e. $\hat{M}^{OUT} > 0$, but this has no effect on total long-term emissions, rather amounts to a delay of the supply of these allowances. Note that if the other part of the allowances due to the climate campaign is also canceled in a future period, this eventually corresponds to case 1 a) as well since the focus is on the long-term effects. Of course, if $M_{t+1} = N_{t+1}$ or $M_{t+1} < N_{t+1}$ holds after the changes due to the campaign, then case 2 applies.

5.1.2 Cases 2 a), b) and c)

In case 2, again, $B_t > \lambda$ holds but $M_{t+1} \leq N_{t+1}$ is assumed. As a consequence, the additional allowances in the MSR due to $\hat{m} > 0$ are not canceled immediately in the next period since the number of allowances in the MSR is below the total number of allowances auctioned in the last period. However, they still raise the number of allowances in the MSR M_{t+1} and decrease the auctioned net supply N_{t+1} which is why due to the campaign there might be more allowances canceled later on if $M_{t+x} > N_{t+x}$ holds in a future period $t+x$. Analogous to case 1, but now only focusing on long-term effects, in this case two different scenarios need to be differentiated again: **If a) $M_{t+x} > N_{t+x}$ holds in a future period $t+x$ also without the changes due to the campaign**, e. g. if any sufficiently large additional abatement leads to a sufficiently high M_{t+x}, then, analogous to case 1 a) and considering the long-term effects, $\hat{K} = 2\hat{M}^{IN} = -\left(1-(1-2\mu)^z\right)\hat{Y}$ will be canceled completely in the future period $t+x$. Therefore, in this case, emissions in Sector Y still decrease by $\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y}$ more than without the campaign and $\hat{M}^{OUT} = 0$ holds. Hence, case 2 a) refers to the scenario that in at least one year cancelation is delayed but the additional allowances in the MSR due to a campaign are canceled completely.

However, it might also happen that in at least one year cancelation is delayed and the total number of additional allowances in the MSR due to a campaign is not canceled completely, but only partially, since **b) at least in one year $M_{t+x} > N_{t+x}$ holds only with the changes due to the campaign**. A simplified representation yields that in this case, $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+x} - M_{t+x-1}^{IN}\right) - \left(M_{t+x-1} + M_{t+x-1}^{IN} - K_{t+x-1}\right)\right]$ will be canceled and $\hat{M}^{OUT} > 0$ holds. Again, if this would happen in more than one year, there would be a corresponding number of additional summands like the one in square brackets. Further, remaining allowances that are not canceled in one year might be canceled later on, possibly leading to complete cancelation of the total number of additional allowances, which then corresponds to case 2 a).

Otherwise, i. e. **if c) $M_x \leq N_x$ holds in all future periods x**, then the long run cap would not change due to $\hat{m} > 0$ which is why $\hat{C}_y = 0$ and Perino's (2015) Proposition 2 would hold again. Thus, since in case 2 c) the additional allowances in the MSR due to the campaign are not deleted in any of the future periods, they are all part of the outtake from the MSR, i. e. $\hat{M}^{OUT} > 0$ and the supply of these allowances will only be delayed.

5.1.3 Case 3

In case 3, $B_t \leq \lambda$ holds in all periods. This implies $M_{t+1}^{IN} = 0$ and hence $\hat{K} = 0$, i. e. since the number of allowances in circulation is below the upper threshold λ, there is no intake of allowances in the MSR and hence, no allowances can be canceled or leave the MSR again due to the climate campaign**.** Still, there might be some indirect effects leading to more cancelation due to $\hat{m} > 0$ since the change in m still increases B_t which 1) might contribute to reach $B_x > \lambda$ in a future period x, e. g. due to other "demand shocks that might reverse the trend of a declining number of banked allowances" (Perino, 2018, p. 263). Further, it 2) might contribute that $B_t > \eta$ happens later which might lead to more cancelation since according to Perino (2018) "the later the bank passes the 400 million threshold, the more allowances are cancelled" (p. 263). However, due to Perino (2018), the latter indirect effect 2) is comparatively small which is why he ignored it as well as possible demand shocks leading to indirect effect 1). If $B_t \leq \lambda$ and both possible indirect effects are ignored, the waterbed effect is fully operational which is why $\hat{C}_y = 0$ is valid and Perino's (2015) Proposition 2 holds again in this case.

5.2 Emission Changes in Sector *X*

If $\hat{C}_y = 0$ can no longer be assumed, using Perino's proof of Proposition 2 yields that the term $-(\hat{C}_y)(1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC})$ has to be added in the numerator of the original $\hat{C}_x$-term, hence:

$$\hat{C}_x = \frac{\sigma_u \hat{m} - (\hat{C}_y)(1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC})}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}$$

Rearranging terms shows more clearly that the change in emissions in sector *X* now not only depends on the change in preferences due to the climate campaign represented by $\hat{m} > 0$ but also on $\hat{C}_y$, i. e. the change in emissions in sector *Y*:

$$\hat{C}_x = \frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC}}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{C}_y$$

The proof for this is provided in the appendix.

5.3 Updated Versions of Proposition 2

When considering the long-term effects, the result of the change in emissions in case 1 a) corresponds to the result in case 2 a), the results of cases 1 b) and 2 b) are equivalent and the result of case 2 c) corresponds to the result of case 3, which is why in the following three updated versions of Proposition 2 with their respective conditions and a short interpretation are stated.

5.3.1 Case 1 a) and 2 a)

If sector *X* is regulated by a carbon tax and sector *Y* by a cap-and-trade scheme with a market stability reserve and a cancelation mechanism, if $B_t > \lambda$ and $M_{t+1} > N_{t+1}$ hold (case 1a)) or $M_{t+x} > N_{t+x}$ holds in a future period $t+x$ (case 2a)) also without the changes due to the campaign, and given conditions (1)–(7) and (9) of Perino's (2015) model and (1)–(6) of Rosendahl's (2019a) model, then a climate campaign represented by an increase in the utility parameter *m* induces the following changes in emissions:

- Sector X:

$$\hat{C}_x = \frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC}}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{C}_y,$$

- Sector Y: $\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y}$
- Total emissions:

$$\hat{C} = \varepsilon_x \hat{C}_x + \varepsilon_y \hat{C}_y$$

$$= \varepsilon_x \left[\frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{(1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC})}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\left(1-(1-2\mu)^z\right)\hat{Y} \right] + \varepsilon_y \left(1-(1-2\mu)^z\right)\hat{Y},$$

where $\varepsilon_i = C_i / C$.

Note again that α_i denotes the share of the clean input used in sector i and Θ_{ij} is the share of income used on input j in the production of good i. Further, σ_i corresponds to the elasticity of substitution of the input factors in the production of i, σ_u is the elasticity of substitution in consumption between x and y and μ is the MSR intake rate. Also, these variables are all strictly positive by definition or assumption. Therefore, as a result of an exogenous increase in m it holds that $\hat{C}_x > 0$ and $\hat{C}_y < 0$. Hence, this analytical model can only show an **ambiguous overall effect on total emissions** and yet no statements can be made about the magnitude of the respective effects. The overall effect depends on the specific market values of the relevant variables, for which assumptions are made in the following numerical section to be able to exemplarily estimate the magnitude of changes in emissions due to a climate campaign.

5.3.2 Case 1 b) and 2 b)

If sector X is regulated by a carbon tax and sector Y by a cap-and-trade scheme with a market stability reserve and a cancelation mechanism, if $B_t > \lambda$ and $M_{t+1} > N_{t+1}$ hold (case 1b)) or $M_{t+x} > N_{t+x}$ holds in a future period $t+x$ (case 2b)) and $M_{t+1} > N_{t+1}$ or $M_{t+x} > N_{t+x}$ hold in at least one year only with the changes due to the campaign, and given conditions (1)–(7) and (9) of Perino's (2015) model and (1)–(6) of Rosendahl's (2019a) model, then a climate campaign represented by an increase in the utility parameter *m* induces the following changes in emissions:

- Sector *X*:

$$\hat{C}_x = \frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC}}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{C}_y,$$

- Sector *Y*: $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$

  (in case 1 b))

  $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+x} - M_{t+x-1}^{IN}\right) - \left(M_{t+x-1} + M_{t+x-1}^{IN} - K_{t+x-1}\right)\right]$

  (in case 2 b))

- Total emissions in case 1b) (analogous in case 2 b)[8]):

  $\hat{C} = \varepsilon_x \hat{C}_x + \varepsilon_y \hat{C}_y$

$$= \varepsilon_x \left[\frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{(1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC})}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\left(\left(1-(1-2\mu)^z\right)\hat{Y} + \beta S_{t+1} - 2M_t^{IN} - M_t + K_t\right) \right]$$

$$+ \varepsilon_y \left(\left(1-(1-2\mu)^z\right)\hat{Y} + \beta S_{t+1} - 2M_t^{IN} - M_t + K_t\right),$$

$$= \varepsilon_x \left(\frac{\sigma_u}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} \right) + \left[\varepsilon_y - \varepsilon_x \frac{(1+\theta_{YL}+\frac{\sigma_u}{\sigma_y}\theta_{YC})}{1+\frac{\alpha_x}{\alpha_y}\theta_{YL}+\frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}} \right] \left(\left(1-(1-2\mu)^z\right)\hat{Y} + \beta S_{t+1} - 2M_t^{IN} - M_t + K_t\right),$$

  where $\varepsilon_i = C_i / C$.

Note that this is only a simplified representation of the case where additional certificates are only partially deleted in one year and the remaining certificates are not deleted later and that if this happens in more than one year, there would be a corresponding number of additional summands like the one in square brackets. Like in the cases 1 a) and 2 a), this analytical model can only show an **ambiguous overall effect on total emissions**. The

[8] The only difference in the solution of cases 1 b) and 2 b) is in the different periods. More precisely, *t* in case 1 b) corresponds to *t+x-1* in case 2 b) and *t+1* in 1 b) to *t+x* in 2 b).

difference to cases 1 a) and 2 a) is that there is at least one year where the additional certificates due to a campaign are only partially canceled and the remaining certificates are not canceled later.

5.3.3 Case 2 c) and 3

As already explained above, if $M_{t+1} \leq N_{t+1}$ and $M_x \leq N_x$ holds in all future periods x (case 2 c)) or if $B_t \leq \lambda$ (case 3), then, apart from small possible indirect effects mentioned above, there is no cancelation of allowances due to the increase in *m* and hence the long run cap will not change due to a climate campaign which is why in these cases, $\hat{C}_y = 0$ and **Perino's Proposition 2** hold again (see Perino 2015, p. 479).

While the advantages of this analytical analysis are that it shows the relation with and dependence from the different variables and claims a certain universal validity under the assumptions made, limitations will be discussed later on. To conclude, the results suggests that a campaign that aims at a demand reduction in the capped sector is not advisable if the number of allowances in circulation is and probably remains below the upper threshold and if there is no cancelation of allowances in the MSR in the foreseeable future. This is because in these cases, the cap is fixed and hence a campaign might increase total emissions as Perino (2015) showed. The intuition behind is that if e. g. a campaign advises consumers to save electricity, they might spend the money they saved on electricity on goods and services in sectors outside the cap, e. g. on more fuel for their car, food or long-distance flights. Further, the capped sector uses less clean input which might leak into the uncapped sector, leading to more production there. With this unintended leakage of demand and clean input into the uncapped sector, the emissions of the uncapped sector increase while the emissions of the capped sector cannot decrease but stay constant due to the fixed cap and the waterbed effect, leading to overall increasing total emissions. However, due to the latest reform of the EU ETS and in contrast to the results by Perino (2015), if the number of allowances banked is above the upper threshold and cancelation is likely, it might be possible that total emissions are decreasing if the emission decreasing effect in sector *Y* dominates the leakage effect. To evaluate whether this is likely in reality, the next section illustrates these analytical results numerically.

6 Numerical Illustration for the EU ETS

To assess the magnitude of these emission effects and hence their policy relevance, in the following, the likelihood of occurrence of the six cases analyzed above is discussed, the upper results are parameterized for the EU ETS context, the assumptions made and the numerical solutions are explained before the sensitivity to parameter changes is analyzed. The calculations behind the numerical values used are either explained within this section or can be found in the appendix. Note that this section aims at illustrating the magnitudes of the previous shown analytical results exemplarily using projections, parameters, and assumptions for the EU ETS but it is not claimed to give accurate values since this is beyond the scope of this thesis. Further, the focus is on the effects of temporary, sector-specific campaigns, effects of permanent or general campaigns will be discussed later on.

6.1 Relevance of the analyzed cases in the EU ETS

The current projections for EU ETS and MSR development by Osorio et al. (2020) provide some indications of how likely the occurrence of each of the six cases is under the current rules of regulation. The time period from 2017 to 2057 is considered here for direct effects of abatements on the total number of allowances in circulation. This is because the "MSR will take in allowances for the first time in 2019 based on the total number of allowances that were in circulation at the end of 2017" (Perino, 2018, p. 263). However, it should be noted that abatements and hence also climate campaigns before 2017, namely from 2008 to 2017, might also have contributed to a higher number of allowances banked than without them and with this, indirectly also to a higher number of allowances in the MSR that potentially gets canceled (Perino, 2018). Further, following to Osorio et al. (2020), when assuming the current linear reduction factor of 2.2 % also after 2030, in 2057 the last allowances will be issued and additionally, it is assumed that banking is not possible after 2057. For their projections, Osorio et al. use "the highly detailed electricity sector and industry model LIMES-EU with an endogenous representation of the MSR mechanism" (ibid., p. 4). Projections of when each case might occur are shown below in Figure 2. Note that since cancelation is starting only 2023, case 2, i. e. no cancelation, applies from 2019 to 2022 independently of whether $M_{t+1} \leq N_{t+1}$ is valid in this time or not. However, abatements from 2017 to 2020 might lead to cancelation of allowances later on, namely in cases 2 a) and b).

Looking at the projections, when intake into the MSR is possible, in 22 of the 39 years from 2019 to 2057, allowances are likely to be withdrawn from auction and to enter the MSR. From 2019 to 2042 (except 2023 and 2025) it is expected that $B_t > \lambda$ will be the case, i. e. the number of allowances banked will be greater than the upper threshold λ which corresponds to 833,33 million allowances in the EU ETS (Osorio et al., 2020). This is why most likely in the next years, additional abatements will lead to additional allowances in the MSR, hence probably cases 1 or 2 will be the case in the next years. In contrast, $B_t \leq \lambda$ will apply in the next few years, if at all, probably only for a short time in between due to initial fluctuations, e.g. like Osorio et al. (2020) calculated in 2023 and 2025, and may then only be relevant again from 2043 until 2057 (ibid.).

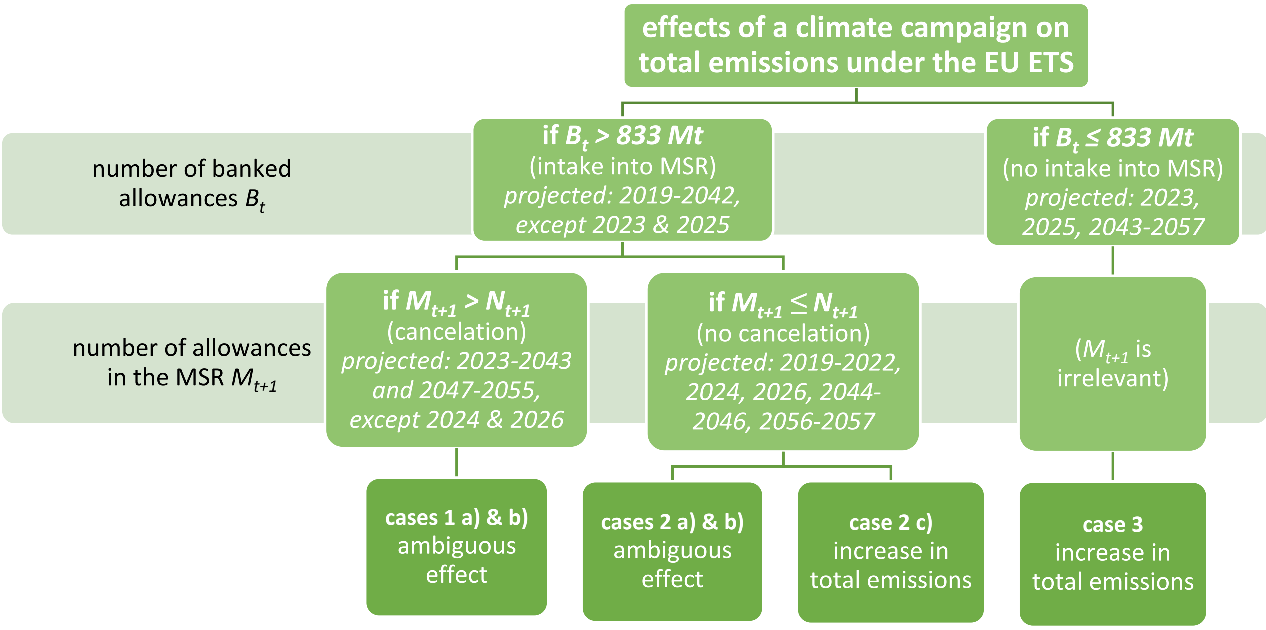

Figure 2: Visualization of the distinct cases, related projections (Osorio et al., 2020), and analytical results.

Further, when cancelation is possible from 2023 onwards until 2057 as assumed above, in 28 of the 35 years, allowances in the MSR are projected to be canceled, i. e. $M_{t+1} > N_{t+1}$ will probably hold (ibid.). Cancelation is projected to take place from 2023 until 2043 (except 2024 and 2026) and from 2047 to 2055 (ibid.) while after cancelation starts in 2023, there will be only short time periods when no allowances are canceled (ibid.). This shows that it is quite likely that additional allowances that are in the MSR due to a campaign are completely canceled like in cases 1 a) and 2 a).

Cases 2 c) and 3 will have a lower probability in the short- and medium- term. Case 3 will first take place in 2023 and 2025 (ibid.), but then a campaign would still increase the allowances in circulation, and very likely some might decrease the auction volume and enter the MSR in the next years and will probably also get canceled. Later, according to Osorio et al. (2020), case 3 might be relevant from 2043 to 2057. This means that under the current rules of regulation, climate campaigns might even increase overall greenhouse gas emissions from 2043 onwards. However, taking the uncertainty of the projections and the varying estimates into account, this could also become relevant far earlier, e. g. starting in 2030 as indicated by Quemin (2020). The most unlikely scenario considering the recent projections is case 2 c) because it is defined under the condition that $M_x \leq N_x$ holds in all future periods x and this is only projected in 2056 and 2057 (ibid.).

Therefore, a climate campaign successfully encouraging consumers to change their demand in the next years would likely lead to more allowances withdrawn from auction volume and put into the MSR. Simultaneously, also the auctioned net supply determining how much allowances are canceled decreases additionally to the linear reduction factor. Overall, according to Osorio et al. (2020), probably there will be only a small outtake from the MSR and the majority of allowances in the MSR will get deleted, namely "from the 5243 MtCO2 certificates withdrawn from the market […], 5143 MtCO2 are cancelled, i.e., 98%" (p. 13). Therefore, although the actual development will depend on many factors, including possible regulatory changes, cases 1 a) and 2 a) can be called the most relevant scenarios in the next years and hence the focus will be on them in the following.

6.2 Cases 1 a) and 2 a)

Most of Perino's calculations of parameters with data on the EU ETS from 2011 were reconstructed and updated with new data sets from 2018. This was done using data from the European Environment Agency (2020a, 2020b) on GHG emissions in all EU Member states and in the EU ETS sectors as well as from Eurostat (2020a, 2020b) on GDP and the amount of non-GHG inputs in different sectors and data from EMBER (2020) on the average allowance price 2018.[9] Although aviation was added as another sector covered by the EU ETS in 2012 (European Commission, 2020b), it was not included in the present analysis since as the aviation sector has a separate cap (European Commission, n.d.–a) and aviation allowances do not add to the total number of allowances in circulation (European Commission, 2020c), they also do not have an effect on the functioning of the MSR which is the focus here. The exact data sources and calculations can be found in the appendix (see "Calculations Parameter Values"). The parameters used by Perino (2015), based on 2011 data, and in this simulation, based on 2018 data, are shown in table 1.

[9] In contrast to Perino (2015), the data used here is specified for 27 instead of 28 EU countries, i. e. excluding Great Britain, since according to the European Commission (2020d), after the end of the transition period on the 31st of December 2020, "the emissions from stationary installations in the United Kingdom are no longer within the scope of Union law and the EU ETS" (p. 3). Further, the data refers to CO_2 equivalents due to the fact that the EU ETS covers emissions of carbon dioxide, nitrous oxide and perfluorocarbons since 2013 (Directive 2009/29/EC, 2009).

Parameter	Definition	2011 Value	2018 Value	Description
α_y	L_y/L	.145	.1175	Share of non-GHG inputs in *Y*
α_x	L_x/L	.855	.8825	Share of non-GHG inputs in *X*
ε_y	C_y/C	.413	.4056	Share of GHG emissions in *Y*
ε_x	C_x/C	.587	.5944	Share of GHG emissions in *X*
Θ_{YC}	$t_y C_y/p_y Y$	.011	.0453	Share of sector's GDP spend on GHG emissions
Θ_{YL}	$wL_y/p_y Y$	.989	.9547	1 - Θ_{YC}
μ_1	-	-	0.24	Withdrawal / intake rate of the MSR 2019-2023
μ_2	-	-	0.12	Withdrawal / intake rate of the MSR 2024 onwards

Table 1: Parameters Used for Numerical Calculations. Source rows 1-6 and columns 1-3, 5: Perino, 2015. Source rows 1-6 and column 4 (2018 value): own calculations, for details and sources see appendix. Source rows 7, 8: Decision (EU) 2015/1814, 2015; Directive (EU) 2018/410, 2018.

Whereas in 2011, 41,3 % of total EU GHG emissions were covered by the EU ETS, in 2018, EU ETS coverage amounted to 40,6 % (denoted by ε_y). This might be due to the fact that from 2011 to 2018 the emissions covered by the EU ETS declined more (13 %) than the emissions of all EU industries (8 %) (own calculations based on European Environment Agency, 2020a, 2020b). Furthermore, the share of non-GHG emissions inputs used by EU ETS sectors decreased from 14,5 % in 2011 to 11,8 % in 2018 (denoted by α_y) because most of the industries covered by the EU ETS used fewer gross values added components, i. e. clean inputs, in total in 2018 than in 2011 (Eurostat, 2020b) and the industries not covered might have used the same or a larger amount of clean inputs in total. Above, the share of the EU ETS sectors' GDP spend on GHG emissions increased from 1,1 % in 2011 to 4,5 % in 2018 (denoted by Θ_{YC}) which might be due to the fact that the average allowance price in 2018 (16,03 €) was higher than in 2011 (12,59 €) (own calculations based on EMBER, 2020). Above, due to the extension of Perino's (2015) model with the MSR and cancelation mechanism, in this simulation, the parameter values for the withdrawal or intake rates of the MSR are needed as well, namely μ_1=24 % from 2019 to 2023, and μ_2=12 % from 2024 onwards (Decision (EU) 2015/1814, 2015; Directive (EU) 2018/410, 2018).

For the goal of assessing the scope of emission effects in the most realistic case possible, in addition to these parameter values, assumptions had to be made which are shown in table 2 and explained in the following. However, since these values are uncertain, the sensitivity of the solution to changes in these assumptions will be analyzed later on.

Parameter	Range	Assumption	Description
$\hat{m}$	-	0.02	Proportional change in utility parameter *m* representing the climate campaign
$\hat{Y}$	-	-0.02	Proportional change in aggregate output quantity of sector *Y*
σ_y	[0, 2]	1	Elasticity of substitution of inputs in *Y*, definition: *(MRTS/dMRTS)(L_y/C_y)*
σ_u	[0, 2]	1	Elasticity of substitution in consumption, definition: *(MRS/dMRS)(X/Y)*
v	[0, 4]	2	Number of years between the year when the effect of a campaign comes into place, i. e. additional allowances are left in the bank (2021**,** own assumption), and the year the upper threshold is passed (2042, reference scenario by Osorio et al. (2020)) with 24 % and 12 % intake rate, respectively
z	[0, 33]	19	

Table 2: Assumptions Made for Numerical Calculations. Source row 1, 3, 4: Perino, 2015. Source row 2: own assumption. Source rows 5, 6: own calculations based on projections by Osorio et al., 2020.

Like Perino (2015) did, the effects of a campaign "with a small intended effect on emissions" (p. 480) will be analyzed, namely $\hat{m}$ = 2 % is assumed, because since "the model equations are differentiated to obtain and solve a set of linear equations in the changes, these simulations are strictly valid only for small changes" (ibid.). That is why possible leakage effects are also limited to a small scale (ibid.). Furthermore, it is assumed that the proportional change in *m* is translated one to one into the change of *Y*, i. e. the shift in the marginal rate of substitution between *x* and *y* is as big as the proportional change in the aggregate output quantity of sector Y. However, the change in output in *Y* has a different sign, namely $\hat{Y} = -\hat{m} = -2$ %, since according to Perino's (2015) definition, "an increase in m ($\hat{m} > 0$) represents a campaign that […], at constant prices, […] reduces demand for good *y*" (p. 475). Concerning the elasticity of substitution of inputs in *Y*, σ_y, and the elasticity of substitution in consumption σ_u, analogous to Perino (2015), unit substitution elasticity is assumed for both, i. e. $\sigma_y = \sigma_u = 1$. Further, in addition to the parameter *z*, defined above as the number of years between the year where additional allowances entered the bank due to the climate campaign and the year where the bank falls below the upper threshold, the parameter *v* is introduced. Adding *v* is necessary since the intake rate μ is not constant for the years considered like in the general case. To be precise, *v* refers to the number of years between the effect on the bank and the year the upper threshold is passed when the withdrawal rate μ_1 = 24 % applies from 2019 to 2023 whereas *z* refers to the period between these events when μ_2 = 12 % applies from 2024 onwards. Therefore, the analytical result for sector *Y* presented in the last section changes slightly to

- Sector *Y*: $\hat{C}_y = \left(1-(1-2\mu_1)^v(1-2\mu_2)^z\right)\hat{Y}$

The possible range for the values of *v* and *z* is derived from their period of validity and the assumption that 2057 will be the year when the last allowances are distributed. To be able to make assumptions for the values of *v* and *z*, a start and an end time for the effect of the additional banked allowances on the MSR intake must be assumed. First, as an example, it is assumed that the year when the effect of a campaign comes into place, i. e. when there are more allowances in the bank than without the campaign, is 2021. This assumption contributes to a realistic and illustrative example of a direct, undelayed emission reducing effect since the first allowances will be canceled in 2023 and due to the MSR functioning, cancelation can occur at the earliest two years after the additional allowances were left unused in the bank. Second, it is assumed that in 2042 the number of allowances banked will fall below the upper threshold of 833,33 million allowances in circulation which is based on the projection by Osorio et al. (2020). From this it follows that *v* = 2 since after the abatement happened and therefore there are more allowances in circulation in 2021, in the following year 2022 and in 2023, a number of allowances corresponding to μ_1 = 24 % of the size of the bank are withdrawn from the auction volume and put into the MSR. From 2024 onwards up to and including 2042 when the bank passes the upper threshold, μ_2 = 12 % applies and therefore *z* = 19 holds.

If one now inserts the parameter and assumption values into the analytical results of the last section, the following results are obtained in cases 1 a) and 2 a):

- Sector *X*: $\hat{C}_x$ = 0,7044 %
- Sector *Y*: $\hat{C}_y$ = -1,9971 %
- Total emissions: $\hat{C} = \varepsilon_x\hat{C}_x + \varepsilon_y\hat{C}_y$

  $\hat{C}$ = -0,3912 %

From this it appears that the demand reduction for good *y* and the effect of the consequent proportional change in the aggregate output quantity of sector *Y*, which was assumed to be $\hat{Y}$ = - 2 %, has been reflected in the emission change in sector *Y* at nearly the same magnitude since there is a decrease in emissions of 1,9971 %. While the waterbed effect was unmitigated in Perino's (2015) model where $\hat{C}_y = 0$ was assumed, meaning that a climate campaign had no effects on emissions in sector *Y*, the result obtained here makes it evident that the waterbed effect is almost completely eliminated in this case and under the assumptions made, which can obviously be attributed to the MSR and the cancelation mechanism. Hence, in the case of the current EU ETS with the MSR, a campaign aiming at convincing consumers to reduce the demand for a certain good can reduce emissions in the specific sector. As noted above, due to the MSR, it takes a certain number of years for the campaign to make its impact. To illustrate this under the assumptions made above, if one considers a campaign that affects the bank in 2021, it takes six years until 2027 for a number of additional allowances to enter the MSR that corresponds to about 90 % of the effect of the campaign (own calculation, $v = 2$, $z = 4$). This is why the values assumed for v and z are essential and the sensitivity of the result to them will be analyzed later.

However, due to the decrease in output, there is also a decrease in the amount of clean input used, and due to that a higher amount of the clean input can be used in the uncapped sector *X*. Hence, sector *X* increases the aggregate output quantity and emissions proportionately, leading to an unintended carbon leakage which amount to an increase in emissions of 0,70 % in sector *X*. This is a higher leakage effect than in Perino's (2015) model, where emissions in sector *X* increased by 0,29 %, because how much the use of the clean input is reduced in *Y* depends no longer only on the change in the output or in the price but also on the change in emissions in *Y* (see "Proof Sector *X*" in the appendix). Apparently, the primary effect of emission reduction dominates the secondary leakage effect. But since the share of emissions in sector *X* on total emissions ($\varepsilon_x = 0.5944$) is higher than the share of emissions in sector *Y* on total emissions ($\varepsilon_y = 0.4056$), the leakage reduces the emission reduction effect in total substantially to -0,39 %. Rosendahl (2019a) looked i. a. at "the effect on cumulative emissions as a percentage of the abatement effort in year *t*" (p. 11), which amounts to -0,3912 % : (-2 %) = 19,5603 % in the case discussed here. Hence, it follows that the leakage rate equals 80,4397 %. Therefore, the aim of a climate campaign to reduce emissions by reducing demand in EU ETS sectors can be achieved, but the effect is not as strong as the "naïve projection of a typical campaign message" (Perino, 2015, p. 482) since only about 20 % of the demand reduction actually result in emission reduction and there is a relatively high leakage rate of approximately 80 %.

However, the crucial point of the analysis is the comparison of the total emission effects of a climate campaign, that shifts demand from sector *X* to sector *Y*, in two different regulatory environments. Using Perino’s (2015) assumptions introduced above, the case of exogenous carbon taxes in both sectors *X* and *Y*, namely $t_x \geq 0$, $t_y > 0$, serves as a reference scenario (tax-tax regime) which can be compared to the scenario discussed above where sector *Y* is regulated by a cap-and-trade system and sector *X* is regulated by a carbon tax (cap-tax regime). Table 3 summarizes the numerical results in both regimes.

	Perino (2015)		own results	
	tax-tax regime	cap-tax regime	tax-tax regime	cap-tax regime
$\hat{C}_x$	+ 0,29 %	+ 0,29 %[10]	+ 0,24 %	+ 0,70 %
$\hat{C}_y$	- 1,71 %	0 %	- 1,77 %	- 2,00 %
$\hat{C}$	- 0,54 %	+ 0,17 %	- 0,58 %	- 0,39 %

Table 3: Summary of emission effects of a climate campaign with a small intended effect of =2 % in two regulatory regimes. Source rows 3 and 4, columns 2 and 3: own calculations, see appendix. Source last row, columns 2 and 3: Perino, 2015. Source other fields: own calculations, based on parameter and assumption values above as well as updated Proposition 2 above and Proposition 1 by Perino (2015).

According to Perino (2015) and therefore considering data from 2011, a climate campaign in a tax-tax regime would have reduced total emissions by 0,54 % while in a cap-tax regime like the EU ETS without the MSR, emissions would have increased by 0,17 % as a consequence of a campaign. Although, according to Perino (2015), “the absolute difference is small by design, under cap and trade the total effect is due to leakage, which is a full one-third of the effect in the tax regime and does not have the intended sign“ (p. 480). Using data from 2018, the effect in the tax-tax regime is similar to Perino’s (2015) results since a climate campaign with a small intended effect of $\hat{m}$ = 2 % would reduce total emissions by 0,58 % in this scenario. This means that 28,81 % of the demand reduction actually result in emission reduction and the leakage rate is 71,19 %. However, in the cap-tax regime referring to the EU ETS and considering the new rules including the MSR and the cancelation mechanism, there is a significant difference compared to Perino's results, since the effect now has the intended sign, namely emissions are reduced by 0,39 %, which corresponds to approximately two thirds (67,88 %) of the effect in the tax-tax

[10] With a view to Figure 2 in Perino’s (2015) paper, $\hat{C}_x$ = 0,17 % seems to be valid instead in both regimes, assumed that $\sigma_y = \sigma_u = 1$. However, this is contradictory to the statement on p. 480 that $\hat{C}$ = 0,17 % holds in the cap-tax case since Proposition 2 states that $\hat{C} = \varepsilon_x \hat{C}_x$ is valid which is why when using the parameter values given in Table 1 of Perino’s (2015) paper, $\hat{C}_x$ = 0,29 % has to hold. This and the statement on p. 480, that “even at σ_y = 0.1 the difference between the two changes in emissions is only 0.0133% of *total emissions* [emphasis of the author]”, points to an inaccurate axis labeling of the y-axis, which therefore is assumed here to actually have to be “Change in emissions relative to total emissions” like in Figure 1 of Perino (2015).

regime. It is therefore apparent that climate campaigns and individual reductions can have the intended effect due to the MSR and the cancelation mechanism. This can be intuitively explained by the fact that due to the campaign and the related demand reduction of good *y*, less output is produced in sector *Y* and more allowances are in circulation or unused which is why more allowances lose their validity, i. e. are permanently canceled. Hence, the long-term cap decreases. Although there is some leakage of the clean input and of demand into sector *X* leading to rising emissions in *X*, the emission reduction effect in *Y* dominates and that is why under the above explained conditions, long-term emissions decrease due to a climate campaign. However, the reduction effect is significantly smaller in the cap-tax than in the tax-tax scenario as the leakage effect is significantly greater in the cap-tax scenario. This might be explained with the fact that the assumptions for *v* and *z* for the calculation of the emission changes in the cap-tax case were related to the time horizon in which the campaign will probably have an impact due to the functioning of the MSR, which was assumed to be 21 years. In contrast, in the tax-tax case only the direct effect and no long time horizon is relevant since there are no future impacts expected as there is no MSR mechanism. This is why in the cap-tax case the emission change in *Y* but also in *X* is higher, as the former directly affects the latter. Mathematically, this is due to the fact that since $\hat{C}_y = 0$ can no longer be assumed, the change in emissions in sector *X* not only depends on the change in $\hat{m}$ but also on $\hat{C}_y$, i. e. since due to the MSR there is an emission reduction in *Y*, there is also more leakage than without MSR.

As assumptions had to be made for some of the decisive parameter values used in the calculation of the results due to their uncertainness, in the following, the sensitivity of the solutions to changes in these assumptions will be analyzed.

First, it will be answered how the result for the change in total emissions $\hat{C}$ changes if alternative values for $\hat{Y}$ are assumed. Figure 3 presents the impact of different values of $\hat{Y}$, i. e. the change in the aggregate output of sector *Y* due to the climate campaign, on the change in total emissions $\hat{C}$ and illustrates that the higher the output reduction in *Y*, the higher the total emissions reduction. This is a

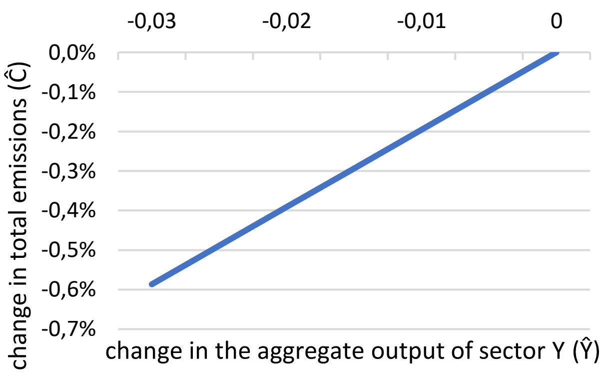

Figure 3: Change in total emissions as a function of the change in the aggregate output of sector *Y* ($\hat{Y}$) ($\hat{m}$ =0,02, σ_u=σ_y=1, v=2, z=19)

very intuitive insight since it points out that the higher $\hat{m}$, i. e. the stronger a campaign, or the higher the resulting $\hat{Y}$, i. e. the larger the output reduction and change in the bank, the higher the total emissions reducing effect. Perino's (2015) results conversely showed that the higher the intended emissions effect of a campaign, the higher the leakage effect and therefore the higher the unintended increase in total emissions. This is why the results here indicate once more that the MSR can be called an improvement to the EU ETS.

In case of elasticity of substitution in consumption σ_u, the greater σ_u, i. e. the more the goods *x* and *y* are substitutable, the higher the leakage effect, i. e. the more emissions in sector *X* increase. Intuitively, this is due to the fact that the easier it is to substitute one good for the other, the higher is the demand increase for good *x* as a consequence of the demand reduction for good *y* and therefore the leakage effect. Hence, as figure 4 shows, the greater σ_u, the smaller the total emission reduction, since a higher leakage effect decreases the reduction of total emissions.

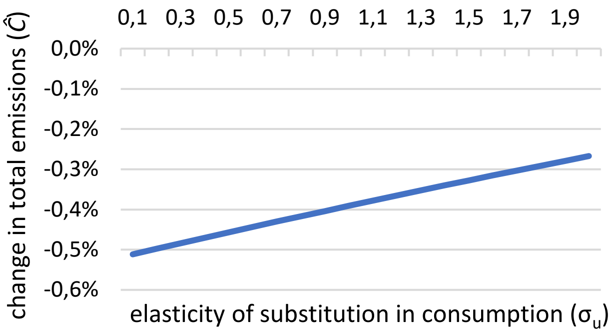

Figure 4: Change in total emissions as a function of the elasticity of substitution in consumption σ_u ($\hat{m}$ =- $\hat{Y}$ =0,02, σ_y=1, v=2, z=19)

Regarding the elasticity of substitution in the production of sector *Y*, σ_y, the reasoning is very similar to the above case of the elasticity of substitution in consumption but it is smaller. Figure 5 shows that the higher the substitution elasticity in the production of good *y*, the smaller the reduction in total emissions, which is also grounded in the fact that the leakage rate increases with a rising σ_y.

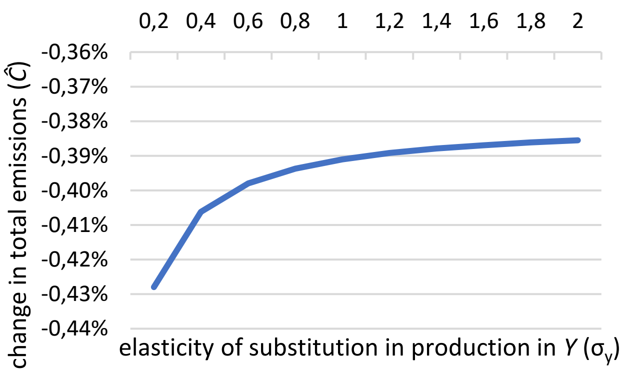

Figure 5: Change in total emissions as a function of the elasticity of substitution in production in sector Y (σ_y) ($\hat{m}$ =- $\hat{Y}$ =0,02, σ_u=1, v=2, z=19)

Further assumptions made where that of *v* and *z*. As explained above, based on the projections by Osorio et al. (2020), the possible range of *v* is zero to four years and the range of *z* is zero to 33 years. While *v* = 2 and *z* = 19 was assumed above, the result of the change in total emissions depends on the point in time of abatement as well as on the year the upper threshold is passed which is exogenously given but uncertain. However, when considering cases 1 a) and 2 a) where allowances in the MSR due to the campaign get canceled completely sooner or later, at least one of both parameters need to be strictly positive by definition. Figure 6 illustrates that in these cases, the change in total emissions is varying from + 0,0121 % (v = 0, z = 1) to - 0,3920 % (v = 4, z = 33). Regarding the latter, it is apparent that although in this case the allowances are 16 years more in the bank influencing the auction volume and the MSR due to a campaign than in the previous assumed case, the reduction of total emissions is only slightly higher than the result of the previous assumed case (- 0,3912 %), which suggests that the marginal effect of an additional year in the MSR before the threshold is passed is decreasing. Also, even if assuming that the upper threshold is passed earlier, e. g. already in 2030, like projected by Rosendahl (2019a) or Quemin (2020), then the change in total emissions still amounts to -0,3709 % (v = 2, z = 7), which is only about 0,02 % smaller although the difference of the projection is twelve years.

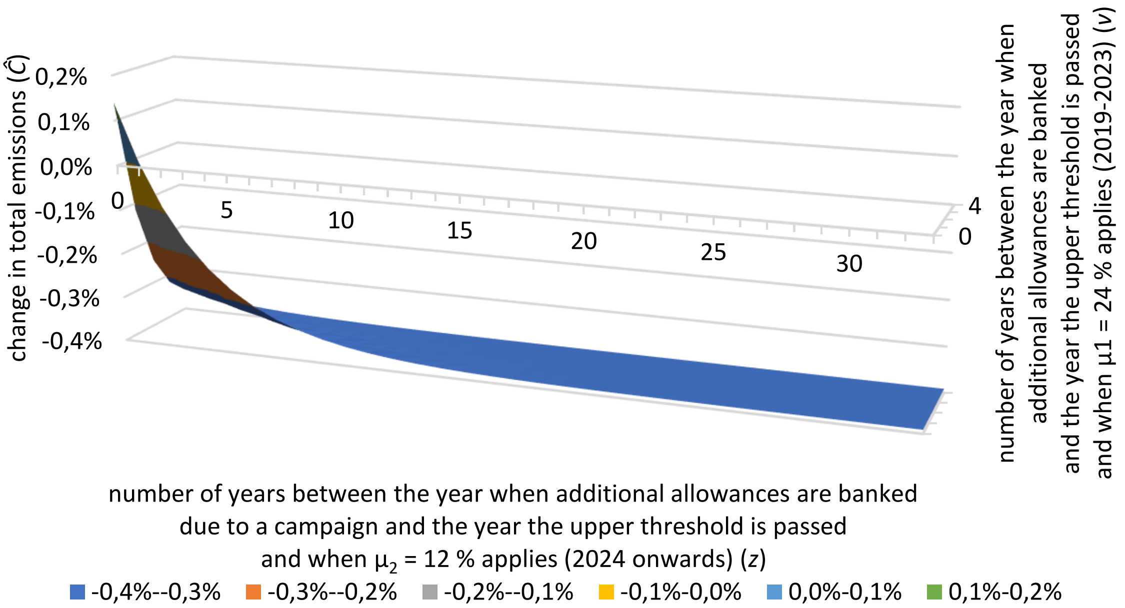

Figure 6: Change in total emissions as a function of v and z ($\hat{m}$ =- $\hat{Y}$ =0,02, σ_u=1, v=2, z=19)

Furthermore, the result in the case where v = 0 and z = 1 are valid shows that it is theoretically possible that even in this scenario, total emissions increase, as figure 6 illustrates. However, the effect is comparatively small, the case where v = 0 and z = 1 hold is the only possible strictly positive result of 169 possible results for cases 1 a) and 2 a) and as already briefly illustrated based on the projections by Osorio et al. (2020), the probability for this case is rather low. The complete table of all 169 possible results for cases 1 a) and 2 a) can be found in the appendix (see “Sensitivity v & z”).

6.3 Cases 1 b) and 2 b)

In cases 1 b) and 2 b), still $B_t > \lambda$ and $M_{t+1} > N_{t+1}$ are valid, i. e. a certain number of allowances get into the MSR and a certain number gets deleted due to the climate campaign. However, as explained above, not all allowances that entered the MSR due to the campaign get deleted since at least once, without the campaign, the number of allowances in the MSR would be less than the auctioned net supply and hence the cancelation threshold is only reached with the allowances that enter the MSR due to the campaign. For simplicity, now N_t and M_{t+1} are considered instead of $\beta S_t - M_{t-1}^{IN}$ and $M_t + M_t^{IN} - K_t$ and hence, the upper equations can be combined and simplified to $\hat{C}_y = \left(1-(1-2\mu_1)^v(1-2\mu_2)^z\right)\hat{Y} + \left[N_t - M_{t+1}\right]$.

Using the parameter values and assumptions like above, and if assuming that M_{2046} = 300 Mt CO_2 and N_{2045} = 300,005 Mt CO_2 hold as exemplary values based on Figure 1 by Osorio et al. (2020), $M_{2046} < N_{2045}$ would be valid and therefore no cancelation would happen without an additional abatement effect like a campaign. In this example, long-term total emissions would be reduced by 0,2583 % as explained in detail in the appendix (see “Numerical Example Cases 1 b) and 2 b)”). As this example illustrates, the effect in cases 1 b) and 2 b) might be similar but smaller compared to cases 1 a) and 2 a). However, this might not always be the case since under the above assumptions, if the complete emission reduction effect in sector Y (denoted by the term $\left(1-(1-2\mu_1)^v(1-2\mu_2)^z\right)\hat{Y}$) is only 1 % or smaller or if the difference between N_t and M_{t+1} amounts to 0,015 Mt CO_2 or more, the leakage effect dominates and total emissions increase due to the campaign (own calculations). Nevertheless, cases 1 b) and 2 b) seem to be rather unlikely since due to the projections by Osorio et al. (2020), allowances will probably be canceled from 2023 to 2042, except 2024 and 2026, i. e. $M_{t+1} > N_{t+1}$ will in these years probably also hold without the changes due to the campaign. However, 1 b) or 2 b) could occur, potentially raising the number of allowances in the MSR above the cancelation threshold which might also be a reasonable goal of a campaign.

6.4 Cases 2 c) and 3

In cases 2 c) and 3, additional allowances due to a campaign are not canceled and hence the long run cap will not change due to a climate campaign, which is why $\hat{C}_y = 0$ and Perino’s Proposition 2 hold again (see Perino 2015, p. 479). For the EU ETS without MSR and with data from 2011 Perino calculated an increase in sector X emissions of 0,29

% and a total emissions increase of 0,17 % due to the leakage effect. Using data from 2018 like introduced above, the increase in sector *X* emissions of 0,2350 % and in total emissions of 0,1397 % is slightly smaller which is due to small changes in the factor shares (α_x, α_y) and in the share of sector's GDP spend on emissions (Θ_{YC}) or the clean input (Θ_{YL}). As noted above, in these cases, the waterbed effect and the leakage effect are responsible for the unintended increase in total emissions. Hence the result of Perino (2015), that a climate campaign can have an unintended emission increasing effect, is still relevant, although probably only in future years.

7 Discussion

Within this section, the results until now are shortly summarized before their limitations, their relevance and resulting recommendations and effects of possible future rule changes are discussed.

To briefly recap the results up to this point: First, six cases were differentiated whereby case 1 refers to the case where additional allowances enter the MSR and get directly deleted due to a campaign, and case 2 where additional allowances enter the MSR but cancelation is delayed at least once and case 3 where allowances do not enter the MSR. Considering the further differentiation, in case 2 c) the allowances that are in the MSR due to the campaign get never canceled whereas in cases 2 a) and 2 b) they are canceled later on. In cases 1 a) and 2 a) the total number of additional allowances that entered the MSR due to the campaign get cancelled completely and in cases 1 b) and 2 b) they only get partly canceled since the cancelation threshold is at least once only reached with these allowances. Second, for cases 1 a) and b) and 2 a) and b) ambiguous effects were derived analytically while in cases 2 c) and 3 an increase in total emissions was found. Third, the numerical illustration showed for the EU ETS that in cases 1 a) and 2 a) a campaign can have the intended total emission reducing effect, which is also possible in cases 1 b) and 2 b) although the effect might be smaller, and that in cases 2 c) and 3 there can be an increase in total emissions. Taking the reference scenario by Osorio et al. (2020) into account, it was deduced that cases 1 a) and 2 a) can be called the most relevant scenarios in the next few years while 1 b) and 2 b) might also occur and cases 2 c) and 3 are likely to become relevant for longer periods from 2030 at the earliest, excluding possible short-term fluctuations in the meantime (ibid.; Quemin, 2020; Rosendahl, 2019a), unless there are rule changes by then. The main results of the analytical analysis and numerical calculations for the different cases are illustrated in Figure 7. However, note again that the numerical results are only exemplary and aim at illustrating magnitudes but do not give accurate values for each possible case.

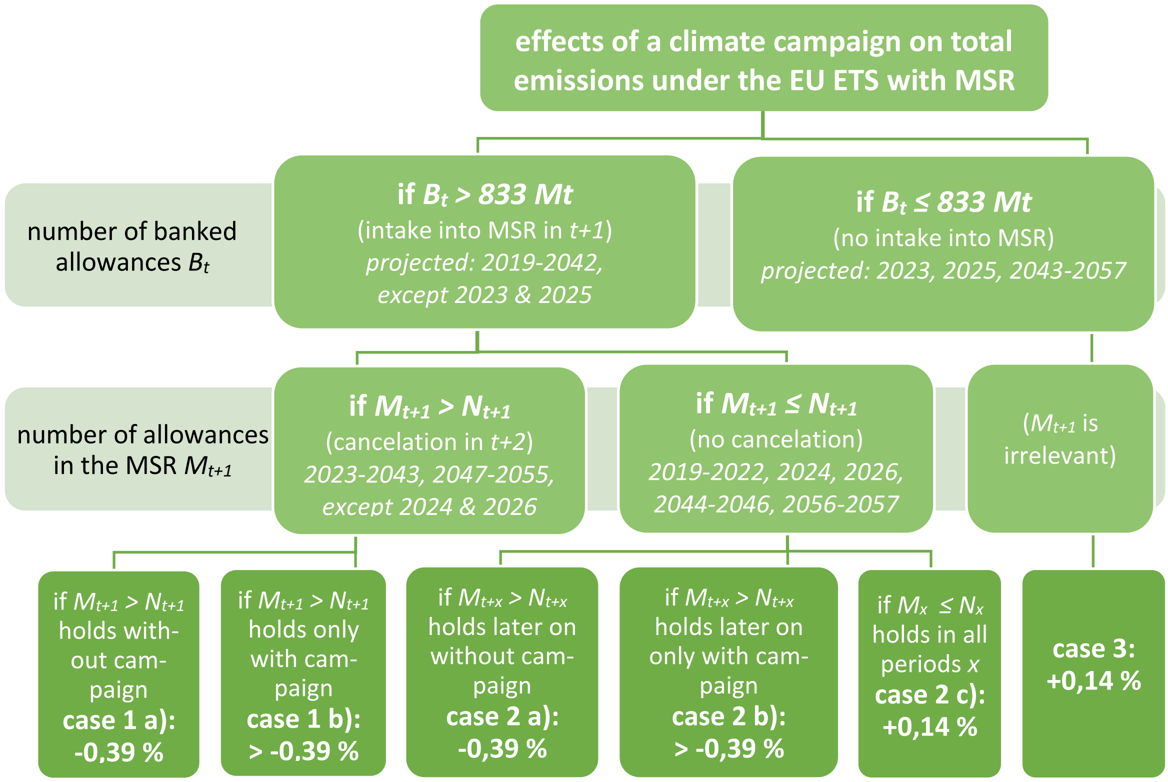

Figure 7: Visualization of the distinct cases, related projections (Osorio et al., 2020), and numerical results.

If practitioners like campaigners are considering whether it would be goal-oriented in terms of climate change mitigation and emissions reduction to launch a campaign aiming at demand reduction in a particular sector covered by an emissions trading scheme in e. g. 2021, they should first look at the projections in this figure 7 to find out whether it is likely that the bank in t = 2021 will be larger than the upper limit of 833 million allowances. This is the case if an intake into the MSR is projected in $t+1$ = 2022. Since this appears to be the case, the campaign is likely to contribute to a higher intake in 2022. Following this path further in the figure, they should look at the projections to see if it is likely that in $t+1$ = 2022 the number of allowances in the MSR will be greater than the auction volume which is true if cancelation is projected in $t+2$ = 2023. Since this is likely to be the case according to the projections even without the campaign, they will arrive at case 1 a) and in $t+2$ = 2023 additional allowances will probably be canceled due to the campaign. Next, to determine the long-term effects, since the additional allowances due to the campaign are assumed to stay in the bank and have an effect on the intake also in the following years, they should additionally look if B_t > 833 Mt and $M_{t+1} > N_{t+1}$ also apply in the next years, i. e. if t = 2022, and if t = 2023 and so on. Since this is the case with small exceptions for cancelation in 2024 and 2026 that only correspond to short delays, it is likely that they will arrive at case 2 a), i. e. although cancelation will probably not happen in all relevant years and might be delayed once or twice, all allowances that entered the MSR due to the campaign would probably be completely canceled. Hence, such a campaign would probably have a total emission reducing effect.

Hence, campaigns or individuals aiming at reducing demand in the EU ETS sectors, e. g. via saving electricity, will, in the next twenty years, likely contribute to reducing total emissions, unless there are significant rule changes. This is even the case despite the occurring leakage effect, meaning despite the fact that more inputs other than GHG emissions can be used outside the EU ETS and the saved budget is then spend in a sector outside the EU ETS instead, e. g. for food, clothing, furniture or gasoline. However, as shown above, a demand shift in between uncapped sectors is more efficient and recommendable since the leakage rate is lower. An example considering the current regulation would be to reduce or restrain from long-distance flights and make more car trips instead. Although this would lead to a higher demand for gasoline, in the demonstrated numerical example, the emission reduction effect due to less flights would dominate the emission increasing effect due to more car rides. Yet, market developments and possible rule changes should be carefully observed and campaign strategies should be adjusted if necessary, in order to exclude that the cap becomes fixed again since in this case there would be a risk that a campaign could have an emission-increasing effect, as in cases 2 c) and 3.

7.1 Limitations

These results have a number of limitations. First, limitations associated with Perino's (2015) model are addressed and critically examined, and then additional points are discussed. Considering Perino's (2015) model and hence also the setup used in the present thesis, it is apparent that in reality there are more than two inputs, goods and sectors which of course is a helpful simplification within the model. Due to the assumption that there are only two goods and preferences are non-satiated, in Perino's (2015) model, consumers can not reduce their demand in both sectors unless they also adjust the "supply of labor, capital, and other inputs by households" (p. 477). Since in reality there are more than two goods, consumers can of course have non-satiated preferences and reduce their demand for two goods simultaneously, but not the demand for all goods in the long-term without adjustment of the supply of labor, capital and other household inputs (ibid.). This shows exemplarily that the results often can be transferred to real world problems. However, in reality, "campaigns would plausibly also affect relative demand for specific industries or firms" (ibid., p. 488), e. g. they advise consumers to fly less and to use the train instead for traveling, which depends on electricity and is therefore also covered by the cap-and-trade scheme (ibid.). In this case, demand would shift within the capped sectors from one more emission-intensive sector to a less emission-intensive sector which uses less of the emission input and more of the clean input (ibid.). Hence, the overall demand of the capped sectors for the clean input would rise, leading to less clean input for the non-capped sectors and because of constant returns to scale also to less output of these non-capped sectors (ibid.). In turn, the overall demand of the capped sectors for allowances might fall and hence more allowances might be unused and banked in the capped sectors. Considering the MSR and cancelation mechanism, this might lead to more cancelation and a lower cap and hence a campaign shifting demand within the capped sectors might reduce total emissions as well. However, in this case, as Perino (2015) indicated, his results concerning the effects of climate campaigns under partial cap-and-trade schemes "would no longer hold qualitatively" (p. 489) and "to identify the exact effects one would need to consider the substitution patterns, emission intensities, and regulatory environment for each specific case" (ibid.) which holds for this thesis as well.

Similarly, the scenario that demand shifts from an uncapped to a capped sector is also not covered here since due to the fact that real world cap-and-trade schemes usually cover the more emission-intensive sectors (Perino, 2015), demand would shift to the more emission-intensive sectors, which might be the less relevant case if assuming the goal is to reduce total emissions. Perino (2015) did also not focus on this case and only mentioned briefly that a general campaign "reduces total emissions in the partial cap-and-trade regime if the sector not covered by the cap is the more emission intensive one" (p. 485). Assuming the latter, however, if a campaign would try to reduce demand in the more emission-intensive, uncapped sector, there would probably be some leakage into the capped sector. In the EU ETS, as a consequence, probably more banked allowances would be used than without the campaign, leading to a decrease of the bank and with that, less intake into the MSR and hence less cancelation than without this campaign. The whole effect of such a campaign would depend on which effect dominates and cannot be evaluated here. Hence, the results presented within this thesis are limited to demand shifts from the capped to the non-capped sector as a whole and between two non-capped sectors in the reference tax-tax scenario and do not account for demand shifts in-between the capped sector or from an uncapped to a capped sector. However, there are also relevant campaigns for the latter cases, e. g. they might aim at shifting demand from gasoline or diesel cars to electric cars or from flights to journeys with electrically powered trains. Therefore, it would be desirable that future research covers the effects in these cases.

It is important to note that climate campaigns and individual behavior changes aiming at personal carbon footprint reductions can have other indirect effects on total emissions beyond the effects covered here, including e. g. raising awareness or the role model function of individuals aiming at reducing their carbon footprint. Above, like Perino (2015) stated, the model does not account for “effects that might arise from interactions between climate campaigns and the political process of setting future caps” (p. 471) although “[c]ampaigns might trigger preference changes that affect future elections and might induce household or energy-sector investments that make ambitious targets easier to achieve” (ibid.). Therefore, even climate campaigns or personal carbon footprint reduction attempts that lead under the specific regulatory environment to an increase in total emissions might have a positive impact on societal change towards a low-carbon economy which is why it might not be necessarily appropriate to advise against them. However, any climate campaign that aims at changing the behavior of consumers in the direction, which is the most effective under the regulations in force, contributes to an efficient reduction of overall emissions beyond these indirect effects and is therefore preferable.

Further it should be noted that the linear reduction factor of the cap is assumed to be constant or not explicitly included in the model used here, as well as any effects on the price or the potential impact of the price development. In the EU ETS, expectations of market participants about future allowance supply and price development are decisive for their behavior and the market development, which also could not be accounted for in the model. A further limitation is that the simplifying assumption is made that due to a campaign, the number of allowances banked increases by the same amount that the demand for good y decreases, namely $\hat{B} = -\hat{Y}$, although the exact effect on the bank might depend on many factors. For example, Jarke-Neuert and Perino (2020) pointed out that “a reduction in the demand for electricity does not directly translate into an increase in the total number of banked allowances, as this depends on the precise response of the electricity market and the timing of the reduction in demand“ (para. 7). However, the sensitivity of a change in $\hat{Y}$ or also in $\hat{B}$ was analyzed above.

Moreover, many campaigns advocating for a behavioral change for climate change mitigation try at the same time also to sensitize and educate consumers about other social and environmental problems related to their consumption, e. g. child labor or loss of biodiversity. Although other challenges related to sustainable development are not less important in comparison to climate change, the focus here is on climate change mitigation effects, which is why effects on other aspects of society can unfortunately not be included here. However, they should also be considered for a holistic decision making.

Regarding the numerical illustration, it is explicitly not claimed to give accurate values but the focus is rather to exemplarily illustrate the magnitudes of the analytical results. This is especially important to note since the point in time when the number of allowances banked falls below the upper threshold is determined by the market which depends also on "the (unpredictable) *expectations* of market actors about future CO_2 prices and costs" (Osorio et al., 2020, p. 28). Further, in reality it apparently cannot be said exactly when which certificates will be deleted. However, this is not the decisive question, but rather which long-term effects climate campaigns can have on total emissions and therefore it is important that more allowances in the bank can contribute to more allowances in the MSR and thus potentially to more cancelation and a tighter cap. Furthermore, it can be critically noted that due to simplicity, the updated parameters were calculated based on data sets from 2018 but these parameters were used to calculate results for the whole time period from 2017 to 2057. However, comparing the updated parameters based on 2018 values with the parameters used by Perino based on 2011 values shows that the orders of magnitude are relatively similar and do not fluctuate too much. Also, the withdrawal or intake rate of the MSR is assumed to stay constant from 2024 onwards and in a similar manner, Osorio et al. (2020) "set all ETS parameters to their current values and assume that they remain at these values after 2030 (current regulation only defines values until 2030)" (p. 9). Another objection is that mainly Osorio et al. (2020) is used for projections although the estimates about the future EU ETS development partly vary significantly. However, this estimates by Osorio et al. (2020) are recent, based on a detailed model and should only give indications. A detailed review of methods and results regarding current projections and trends of the EU ETS is beyond the scope of this thesis.

Importantly, Directive (EU) 2018/410 states that the cancelation mechanism will start in 2023 only "unless otherwise decided in the first review in accordance with Article 3 of Decision (EU) 2015/1814" (p. L 76/8) which will take place starting in 2022 and a rule change is considered to be "quite likely" (Perino, 2018, p. 264). However, the present model might still be helpful, e. g. if the rule changes only consist in changes of the parameters values, which will be discussed later on in the outlook section.

As pointed out before, the focus of the analysis was on the effects of temporary, sector-specific climate campaigns. However, general climate campaigns or campaigns that have permanent effects also have a high relevance which is why their possible effects will be discussed in the following.

To analyze the effects of a general climate campaign, that focuses on personal carbon footprint reductions of consumers instead of demand reductions for specific products or sectors, Perino (2015) extended the model by using a utility function that does not only include consumption but also a term representing the intrinsic motivation for personal carbon footprint reduction. From this utility function he deduced another marginal rate of substitution and the "partial derivative with respect to *m*" (ibid., p. 484) from which he then derived that the effect of a campaign depends on "the relative carbon intensity of the capped and the uncapped sectors" (ibid., p. 485). This is not a surprising result, since the emission intensities of the goods are part of the intrinsic motivation term. He found that a general campaign would reduce total emissions in the tax-tax case but increases total emissions under a partial cap-and-trade system with a fixed cap, if the capped sectors are more emission intensive than the uncapped sectors, as it is the case with the EU ETS and other real-world cap-and-trade schemes (ibid.). Hence, the effects of sector-specific and general campaigns are qualitatively the same within this model which is not surprising either since there are only two goods and sectors in the model and therefore it is not relevant at first sight whether consumers follow a sector-specific campaign and shift their demand away from one good or sector to another or do the same because a campaign tells them to reduce their carbon footprint. However, differences lie in the starting point, the exact mathematical results and the dependence on the emission intensities or which sectors are covered by a cap. The exact mathematical and numerical results differ due to the different utility functions and hence also different marginal rate of substitution, although Perino (2015) did not calculate them but only indicated when total emissions are reduced or increased. The starting point is different since the sector-specific campaign recommends reducing the demand for a certain good and hence it sets the direction of the demand change while in the general case, in which the campaign suggests reducing the personal carbon footprint but not how this should be done, and the consumers decide the direction based on the emission intensities of the goods and sectors. This is also why when looking at Perino's (2015) results it becomes apparent that the size of the effects of a sector-specific campaign in the tax-tax case depends on whether demand shifts to the sector which is more or less emission-intensive while the effects of a general campaign in the cap-tax case depend on whether the more emission-intensive sector is capped or not. Although one could have assumed that both campaigners and consumers that want to reduce their personal carbon footprint will decide to aim for a demand reduction in the more emission-intensive sector, which would have made the differentiation in the case of a sector-specific campaign in a tax-tax environment redundant and the extension of the utility function by an intrinsic motivation term unnecessary, this assumption would have been another issue since in the real world, people might estimate these intensities wrong. This might be especially relevant since products might consist out of some components from EU ETS and some from non-EU ETS sectors, where it is even more complex to determine which effects a demand shift would have. Hence, to analyze effects when people shift demand from less to more emission-intensive industries is still important. To conclude, the effects of general and sector-specific campaigns are likely to be qualitatively the same, although the magnitudes might differ.

To consider permanent behavior changes as a consequence of campaigns instead of only temporary demand changes is relevant since short-term behavior changes will not be sufficient to limit global warming to 1.5°C and hence permanent behavior changes are necessary (Dubois et al., 2019). In this case, one would intuitively expect a higher emission reduction effect. However, Rosendahl (2019a, 2019b) found that within the EU ETS sectors, cumulative emissions may rise as a consequence of an additional, anticipated permanent abatement. The intuition according to Rosendahl (2019a, 2019b) is that if market participants expect a future or permanent abatement and because of that a lower future price than before, banking of allowances is less lucrative and due to less banking, less allowances enter the MSR and get canceled. In contrast to Rosendahl's (2019a, 2019b) results, Perino (2019) assumed that these effects are "highly uncertain and potentially quite small" (p. 736). Notably, Rosendahl's (2019a) analysis focused on greater abatement effects that are expected already today whereas the focus in the present thesis is on rather small abatements that are probably not anticipated by market participants since they are often highly uncertain and not enshrined in laws. Still, this indicates that permanent abatement effects have to be considered separately and future research on them is desirable since they are both relevant and might be more complex. However, it can be briefly estimated that the effect on total emissions depends on when the demand change starts and what the market situation looks like. Considering estimates about the EU ETS development, campaigns with a small but permanent effect starting in the next years ahead will probably reduce total emissions in the first years like analyzed above but with a significantly higher magnitude due to the summation. Later on, it might also be possible that they have a total emission increasing effect. This is due to the fact that cases 2 c) and 3 are more likely in future years. Which effect predominates in the bottom line therefore clearly depends on the timing of the abatement and the market situation. Unfortunately, a detailed analysis of climate campaigns leading to permanent behavior changes is beyond the scope of this thesis since it requires additional extensions to the model used.

7.2 Relevance

Despite these limitations, the results are of relevance, which will now be briefly discussed. First, it can be noted that the main result, that due to the MSR and the cancelation mechanism, campaigns can reduce overall emissions, could be expected from and is consistent with the literature on the reform of the EU ETS and its effects, especially regarding the effects of overlapping policies. However, there are several contributions beyond this, e. g. it was argued with the help of the legal bases that Rosendahl's (2019a) mathematical representation of the cancelation mechanism is not accurate since he used the gross auctioned supply instead of the auctioned net supply as the cancelation threshold, which is decisive for the magnitude of the analyzed effect. Furthermore, a differentiation into six cases based on the functioning of the MSR and the cancelation mechanism was undertaken, which may also be helpful as a framework for other investigations on the EU ETS. Especially important, the definitions and results for these cases as well as the recommendations that will be given later provide useful guidelines for practitioners working with climate campaigns in the EU but also elsewhere where other partial cap-and-trade systems are operating since they facilitate the estimation of effects on emissions.

This is particularly essential since there seems to be a lack of campaigner and consumer awareness about possible interaction effects with the regulations in place. This becomes apparent as most real world campaigns like the campaign of the Earth Overshoot Day (Global Footprint Network, 2020), carbon footprint calculators, e. g. by the German Federal Environment Agency (2020), or lists of actions to reduce the individual carbon footprint, e. g. by NGOs as the World Wide Fund For Nature (2020), seem to not take the regulatory environment into account and do not inform consumers about them. However, the present results indicate for the EU ETS that the effects of campaigns turn out according to or contrary to the intentions of a campaign and also the consumers depending on the state of the MSR. This shows that this lack of awareness about regulations and possible interaction effects with them is problematic since as emission reductions in the household area are indispensable for achieving the 1.5 °C target, it is decisive that campaigners are informed about the possible effects of their campaigns and encourage consumers accordingly so that they are able to effectively contribute to climate change mitigation. Otherwise, they might support the misconception of consumers about the impact of their behavior on total emissions (Perino, 2015). Hence, a consideration of the regulations and possible interaction effects, as analyzed and explained in the present thesis, is highly recommended if a total emission reducing effect of a specific campaign is intended and generally indispensable if households should contribute sufficiently to emission reductions.

Regarding the current design of the EU ETS with the MSR, in light of the results of this thesis, it can be stated that the MSR with the cancelation mechanism brought improvements since additional abatements, like climate campaigns, can have the intended total emission reducing effect under certain circumstances, even if they are small. This is especially apparent in contrast to Perino's (2015) analysis of the EU ETS before the reform which showed that these campaigns tend to increase total emissions. However, the reform also changed effects of abatements in the past retrospectively and made the rules even more complex so that their impacts and the market development are hard to understand and predict and future rule changes with retrospective impacts might be expected. One consequence might be that the potential of reducing emissions with the help of the MSR and the cancelation mechanism might not be fully utilized as there is hardly any planning security. Another consequence of the complexity is that it is likely to further support the lack of awareness for and understanding of the EU ETS. This is problematic, since the EU ETS is an important, but not the only policy instrument and if awareness is lacking, the effects of additional or overlapping abatements, like individual changes in consumption behavior, may conflict with the intentions and even increase emissions. Therefore, regarding future reforms, it is advisable that the complexity of the rules should not be further increased but rather reduced and long-term the aim should be to make the rules as understandable and durable as possible so that as many people as possible can understand them, rely on their longer-term validity, and react to them appropriately. Or as Perino (2018) puts it, "the rules should be simple and stable and their impacts predictable" (p. 264). If this could be realized, many more campaigns, as well as unilateral and overlapping policies, could be designed much more effectively and make a real contribution to climate protection and societal transformation.

7.3 Recommendations

Further, some recommendations can be derived. In general, meaning independent of the specific regulations, practitioners working with climate campaigns or thinking about starting one should be advised to be aware of the regulatory environment and its interactions with the effects of their campaign. Further, they should be aware that probably the consumer demand is not only reduced in one sector without further effects but likely at least partly shifted to another sector. Generally, both facts need to be considered when designing a campaign to be able to guide consumer demand in the right direction so that the campaign can contribute to reduce total long-term emissions. The same holds true for intrinsically motivated consumers who aim to reduce their personal carbon footprint.

Generally, in the case of a carbon tax in all sectors, a campaign should aim to shift demand from the more emission-intensive sector to one with a lower emission intensity to reduce total emissions. If a cap-and-trade scheme is operational in any sector of the economy, it is crucial to include potential interactions with it in the considerations when designing a campaign since it is possible that traditional campaign messages, aiming at reducing demand of emission-intensive industries, lead to an increase in total emissions. In the case of a partial cap-and-trade scheme, focusing a campaign on a demand shift between sectors that are not covered by the cap is the safer option to avoid possible waterbed effects and unintended emission increases. Or as Perino (2015) puts it, “campaigns should target goods and services produced by industries whose emissions are not capped or stimulate consumers to buy and retire emission allowances” (p. 489). The latter will be discussed later. Further, another possible concept of campaigns might be to aim more at educating consumers that one approach for a personal contribution to climate change mitigation can also involve working less, e. g. part-time, and thus earning and consuming less.

Considering the EU ETS with the rules for the fourth trading period including the MSR and the cancelation mechanism, what is recommendable depends on the market situation, since the reform replaced the fixed cap with one that is a result of the market outcome. Since under the above assumptions and in the case of campaigns that shift demand from EU ETS to uncapped sectors, only about 20 % of the demand change result in a total emissions reduction while this amounts to about 30 % in the case of a campaign that shifts demand from an uncapped to another uncapped sector, the latter option is even more recommended due to the higher effectiveness. Hence, following the presented results, it is more recommendable that a campaign focusses on a demand shift within the uncapped sectors, e. g. from long-distance flights to bus journeys or from meat consumption to plant based food. If the bank is above the upper threshold and the number of allowances in the MSR is sufficiently large so that it is likely that allowances in the MSR are canceled and if it is projected that this will be the case in the next years, like in cases 1 a) and b), it is also advisable that a campaign aims at a demand shift from the capped to the uncapped sectors. Examples might be demand shifts from electricity to clothing or food or from products containing a high share of ingredients produced by EU ETS sectors like steel, metals or oil to alternative products made out of other components. This is also the case if currently the bank is below the upper threshold or currently the number of allowances in the MSR is smaller than the auctioned net supply of the previous year but it is projected that they will be above the threshold in the future, like in cases 2 a) and b).

As discussed above, regarding a campaign that shifts demand between the capped sectors, i. e. from one emission-intensive capped sector to a less emission-intensive sector, there might be total emissions-reducing effects but the effects cannot be definitively evaluated here. Similarly, the net emission effect of a campaign aiming at reducing demand from the uncapped sectors, leading to some leakage to EU ETS sectors, cannot be conclusively assessed here. However, in theory such a campaign might be advantageous if the cap is fixed, since then the emission in the uncapped sector would decrease due to the campaign, while the possible leakage into the capped sectors would not lead to higher emissions due to the fixed cap. In the EU ETS, this could be the case if the bank is projected to stay below the upper threshold in the future and hence there will be no intake in the MSR. Nevertheless, in practice, this might not be advisable as further market developments are difficult to predict and rules can also be changed retrospectively.

Like explained above, in case 3, which might happen from 2030 onwards at the earliest (Quemin, 2020), campaigns that shift demand from capped to uncapped sectors would increase total emissions and hence should be avoided. Instead, it is recommended that campaigns should focus on demand changes within the uncapped sectors to avoid the waterbed effect. Since cancelation can occur at the earliest two years after the abatement effect, this holds also true if the bank is above the upper threshold or the MSR is above the cancelation threshold at the starting date of the campaign but is projected that they will be below the threshold in the next two years and in the future, since then the additional allowances in the bank will not lead to more intake or cancelation in the MSR.

One problem, however, is the uncertainty of projections and the development of the EU ETS allowance market due to dependence on expectations which are unpredictable (Osorio et al., 2020) as well as due to the limited resilience to greater demand shocks (Quemin, 2020). Further, as discussed above, rule changes are likely which might change the results retroactively. Due to that, a campaign focusing on a demand shift within the uncapped sectors is recommended as the safer option since it contributes to total emission reduction independent of the size and development of the bank and the MSR. However, as all climate change mitigation and emission reduction options available should be used, campaigns that target the uncapped sectors should also not be neglected but practitioners need to be careful designing these, observe the development of the EU ETS market and adjust their campaigns if necessary.

Further, apart from reducing their demand for a specific good, consumers can also compensate emissions via voluntary carbon offsetting, e. g. for air travel (Tyers, 2018). Thereby, a carbon offset can be defined as “a quantified reduction in emissions of greenhouse gases made in order to compensate for – to offset – an emission made elsewhere” (ibid., p. 2), here referring to “the voluntary market by […] individual customers” (ibid.). In the context of a cap-and-trade scheme, Perino (2015) stated that “consumers can in principle buy and retire emission allowances” (p. 486) which are in this way “permanently withheld from the market and therefore reduce the amount available to participating firms” (ibid.). However, the effects on total emissions are decisive. Considering the EU ETS before the latest reform, Perino (2015) concluded that “consumers can […] reduce aggregate GHG emissions by retiring allowances” (p. 487). However, this concept which is also known as allowance burning or “buy and burn” (Gerlagh & Heijmans, 2019, p. 342) got significantly less effective due to the new rules for phase 4 (ibid.) This is because canceling one allowance decreases the bank by one allowance and with this, in the next period the auction volume is higher and the intake into the MSR is smaller and hence there are probably less allowances in the MSR canceled via the cancelation mechanism than without the allowance burning. Gerlagh and Heijmans (2019) calculated that “if an agent were to burn one ton of emissions (worth in allowances) […], this would reduce emissions in the aggregate only by one third of a ton” (p. 432). Therefore, organizations that were offering the service of buying and retiring allowances to individuals, like TheCompensators or Sandbag, stopped their operations after the publication of the EU reform (Perino, 2018; Sandbag, n. d.). However, Gerlagh and Heijmans (2019) stated that “smart use of the new rules can make allowance burning much more efficient than ever before” (p. 432) and introduced a new method called “the buy, bank, burn program where, as the name suggests, one buys and banks allowances to be burned only in the future, once the emission cap has become exogenous; that is, when emission flows into the MSR end” (ibid.). Hence, since the allowances bought by nongovernmental organizations are not directly canceled like before but banked, they are not withdrawn from the market but count as banked instead which is why they do not reduce but might even increase the intake into the MSR and with that the potential cancelation via the cancelation mechanism (ibid.). The point in time when the bought allowances are burned is decisive since before burning them, the allowances are a part of the bank and it depends on the size of the bank whether there is an intake in the MSR in the next year. Since it might be the case that the size of the bank fluctuates around the threshold value, i. e. falls below it several times and rises above it again, like estimated by Osorio et al. (2020), the allowances should only be irreversibly cancelled if it is safe to expect that the threshold value will not be exceeded again. With this “buy, bank and burn” method, “[p]arties outside EU ETS can burn allowances at more than 100% efficiency, partly paid for by regulated industries” (ibid., p. 433) since “[i]n order to offset 1 ton of emissions, an agent need only buy and bank 3/5 tons worth of allowances” (ibid.). This is why today a new service to buy, bank and later burn EU ETS allowances is offered by organizations like Compensators*, 50ZERO or ForTomorrow (Compensators* e.V., 2020a). As an advantage of their offsetting service, they emphasize that emissions are avoided within Europe where per capita emissions are comparatively high and with this the incentives for European industries to reduce emissions are strengthened whereas other offsetting organizations focus rather on projects in the global south (ibid.). Some of them directly work together with scientists, e. g. Grischa Perino controls the operations of the Compensators* organization as an additional authorized account holder of the allowance account (Compensators* e.V., 2020b). To conclude, consumers can use these services to buy, bank and later burn allowances to contribute to a reduction of total emissions in the EU and campaigns might hence also recommend this option. Compared to campaigns aiming at a demand reduction where consumers might spend their money elsewhere and the clean input might leak to other sectors, campaigns recommending to donate to a buy, bank and burn program seem to not face these leakage effects.

Another important contribution of citizens apart from demand changes and offsets can be political engagement. Currently, the parties to the Paris Agreement neither have Nationally Determined Contribution goals and plans that are ambitious enough to limit global warming to 1.5°C, nor are they on track to achieve their goals (Pauw & Klein, 2020; Sachs, 2019). However, climate policy can only get more ambitious if more people demand it and get engaged in the political process which is why intrinsically motivated individuals should not only change their demand and buy allowances as consumers but also get involved in the political process and demand political changes as citizens and voters. Therefore, these actions are rather complements than substitutes and should also be promoted by climate campaigns.

Nevertheless, as noted above, most real world campaigns do not take the regulatory environment into account and do not inform consumers about them. Additionally, options to buy, bank and burn EU ETS allowances, to work and consume less or to engage politically are rarely mentioned. However, this is advisable and could improve the impact of efforts by individuals substantially.

Apart from the recommendations for practitioners, suggestions for improvement of the EU ETS for politicians would be to reduce the complexity of the rules, since as explained above this would remove barriers and facilitate that additional abatement measures like overlapping policies as well as campaigns can be designed effectively. Further suggestions for improvement would follow the already mentioned recommendations of the scholars, like e. g. a carbon price floor (Edenhofer et al., 2017; Flachsland et al., 2020; Newbery et al., 2018) or a price stability reserve (Osorio et al., 2020) which might also be options to reduce complexity.

7.4 Outlook

Next, it will be briefly discussed whether possible future rule changes and potential additional measures that are debated in the context of the upcoming review starting in 2022 might affect the results presented. One option is that the MSR parameters for the upper and the lower threshold, the intake rate and the auction share are adjusted (Osorio et al., 2020). In this case, the numerical results would no longer be valid but they could be recalculated using the analytical results that would still hold. More precisely, a change in the thresholds would only change projections used here to estimate the relevance of the six cases analyzed and a change in the auction share would only change the numerical results in cases 1 b) and 2 b). In cases 1 a) and 2 a), an intake rate lower than the currently set 12 % from 2024 onwards would led to a smaller emission reducing effect and a higher intake rate would lead to a higher emission reduction, but the increase would be very small since the difference only amounts to 0,0008 % for intake rates in the range from 18

% to 50 % (see “Sensitivity μ_2” in the appendix). This coincides with the results by Osorio et al. (2020) who stated that “intake rates above 12% only have a small additional effect [on cancellation]” (p. 27). Note that with a view to the results by Osorio et al. (2020), it is assumed that the intake rate will probably not be set to 0 % or above 50 %, since this “may induce some instability” (p. 18).

Another possibility is a sectoral expansion of the EU ETS, e. g. by including road transport into the system (Achtnicht et al., 2019). If only some sectors are added, the results are still valid, but the scope for campaigns which want to avoid EU ETS sectors and focus on sectors outside is smaller and the numerical values of the parameters would differ. If all sectors are added, which currently seems to be not a likely scenario, then the impact of campaigns would be demand shifts between capped sectors which might be total emissions-reducing as discussed above but cannot be definitively evaluated here. Further, the option of a carbon border adjustment is debated which would probably have no direct effects on the present results unless it would replace the current free allocation system (Mehling & Ritz, 2020). If the latter would be the case, the auction volume and with this the threshold for cancelation would become substantially higher and if all other rules would stay the same, this would probably lead to less cancelation. Therefore, considering the effects of campaigns, cases 1 a), b) and 2 a), b) would become less likely and hence the probability that campaigns would reduce total emissions might decrease.

Above, the recently in light of the EU Green Deal agreed increase in the EU GHG emission reduction target by 2030, from - 40 % to - 55 % compared to 1990 (Sánchez Nicolás, 2020), might probably lead to an increase of the linear reduction factor (LRF). According to Osorio et al. (2020), raising the LRF to 2,6 % would suffice to reach the -55 % reduction goal. Although the LRF is assumed to be constant and hence its potential change is not explicitly taken into account in the present model, it can be stated that a higher LRF would result in a lower allowance supply and hence probably a lower auction volume which constitutes the threshold for cancelation. Therefore, ceteris paribus, this would lead to more cancelation and hence the probability that campaigns would reduce total emissions might increase.

8 Conclusion

The present thesis pursued the question, what the effects of temporary, sector-specific climate campaigns on long-term total emissions under a partial cap-and-trade scheme with a market stability mechanism are, particularly investigating the example of the EU ETS including the market stability reserve (MSR) and the cancelation mechanism.

Independent of specific regulations, the results indicate the importance of being aware of the regulatory environment and possible interaction effects with climate campaigns as well as of the fact that probably the consumer demand is not only reduced in one sector but at least partly shifted to another sector. Further, in the case of an existing partial cap-and-trade scheme, focusing a campaign on a demand shift between sectors that are both not covered by a cap-and-trade scheme is the safer option to avoid possible waterbed effects and unintended emission increasing effects.

Considering the current rules of the EU ETS and the most likely scenarios of its development for the next years, climate campaigns that aim at reducing demand from the more emission-intensive capped sector *Y* and lead to some leakage to the uncapped sector *X* can reduce total emissions. However, the analysis suggests a high leakage rate of about 80 % and hence only about 20 % of the abatement lead to a total emission reduction. Therefore, in contrast to Perino's (2015) results, it is apparent that climate campaigns can have a total emissions reducing effect due to the MSR and the cancelation mechanism, although the size of the effect is smaller than probably expected by consumers due to the framing of many climate campaigns. In comparison, in the scenario of a carbon tax in both sectors or in the case of a campaign that shifts demand from one uncapped, more emission-intensive industry to another uncapped, less emission-intensive industry, there is a lower leakage rate of about 70 %. Further, there are still also cases where Perino's (2015) results hold again and a climate campaign might even increase aggregate emissions. This is the case if the number of allowances in circulation stays below the upper threshold in the future, since then the MSR does not take in allowances, or if the number of allowances in the MSR is smaller than the net auction volume of the previous year, since then there are no allowances canceled and hence the cap is fixed again. There are varying estimates about when this might happen, but it is not likely in the next years until 2030. Hence, within the EU, shifting demand between sectors that are not regulated by the EU ETS but e. g. by a carbon tax is the safer option and also more effective than shifting demand from an emission-intensive EU ETS sector to an uncapped sector. Other complementary options for climate campaigns are to encourage consumers to use a service to buy, bank and later burn allowances and to inspire them as citizens and voters to get involved in the political process.

Note that these results face a number of other limitations that are discussed in detail in the discussion section above. However, the presented analytical results might still be useful if future EU ETS reforms change parameters. Further, they might be expandable or adaptable to analyze permanent changes due to campaigns as well as overlapping policies and effects in other cap-and-trade systems with mechanisms similar to the MSR. This is especially relevant since market stability mechanisms "will likely receive growing attention as systems move to stricter targets in line with long-term decarbonization plans" (International Carbon Action Partnership, 2020b, p. 16). Further research on the effects of permanent behavior changes induced by campaigns as well as on the effects of campaigns that shift demand between capped sectors or from uncapped to capped sectors would be desirable to give more detailed recommendations.

Although the main result could be expected from and is consistent with the literature on the reform of the EU ETS and its effects, the results contribute useful guidelines and recommendations for practitioners and consumers working with climate campaigns as well as a framework for the differentiation of six cases based on the functioning of the MSR which might be helpful for other investigations on the EU ETS. Additionally, although the MSR improved the direct emission effect of campaigns, it was criticized that the reform changed effects of abatements in the past retrospectively and made the rules even more complex, which is why it is suggested that future reforms should aim at reducing complexity to facilitate an effective design of unilateral or overlapping policies as well as campaigns.

References

Achtnicht, M., Graevenitz, K. von, Koesler, S., Löschel, A., Schoeman, B., & Tovar Reaños, M. A. (2019). Road Transport and Its Potential Inclusion in the EU ETS. In E. Gawel, S. Strunz, P. Lehmann, & A. Purkus (Eds.), *The European Dimension of Germany's Energy Transition* (pp. 493–508). Springer International Publishing. https://doi.org/10.1007/978-3-030-03374-3_28

Anderson, A. (2011). Sources, media, and modes of climate change communication: the role of celebrities. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(4), 535–546. https://doi.org/10.1002/wcc.119

Baylis, K., Fullerton, D., & Karney, D. H. (2013). Leakage, Welfare, and Cost-Effectiveness of Carbon Policy. *American Economic Review*, *103*(3), 332–337. https://doi.org/10.1257/aer.103.3.332

Baylis, K., Fullerton, D., & Karney, D. H. (2014). Negative Leakage. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 51–73. https://doi.org/10.1086/676449

Beck, U., & Kruse-Andersen, P. K. (2020). Endogenizing the Cap in a Cap-and-Trade System: Assessing the Agreement on EU ETS Phase 4. *Environmental and Resource Economics*, *77*(4), 781–811. https://doi.org/10.1007/s10640-020-00518-w

Bocklet, J., Hintermayer, M., Schmidt, L., & Wildgrube, T. (2019). The reformed EU ETS - Intertemporal emission trading with restricted banking. *Energy Economics*, *84*, 104486. https://doi.org/10.1016/j.eneco.2019.104486

Böhringer, C. (2014). Two Decades of European Climate Policy: A Critical Appraisal. *Review of Environmental Economics and Policy*, *8*(1), 1–17. https://doi.org/10.1093/reep/ret018

Böhringer, C., & Fischer, C. (2020). *Kill Bill or Tax: An Analysis of Alternative CO2 Price Floor Options for EU Member States* (Oldenburg Discussion Papers in Economics V-432-20). Oldenburg. Retrieved November 29, 2020, from https://www.econstor.eu/bitstream/10419/225287/1/1736486624.pdf

Böhringer, C., Keller, A., Bortolamedi, M., & Rahmeier Seyffarth, A. (2016). Good things do not always come in threes: On the excess cost of overlapping regulation in

EU climate policy. *Energy Policy*, *94*, 502–508. https://doi.org/10.1016/j.enpol.2015.12.034

Böhringer, C., & Rosendahl, K. E. (2010). Green promotes the dirtiest: on the interaction between black and green quotas in energy markets. *Journal of Regulatory Economics*, *37*(3), 316–325. https://doi.org/10.1007/s11149-010-9116-1

Bruninx, K., Ovaere, M., & Delarue, E. (2020). The long-term impact of the market stability reserve on the EU emission trading system. *Energy Economics*, *89*, 104746. https://doi.org/10.1016/j.eneco.2020.104746

Bruninx, K., Ovaere, M., Gillingham, K., & Delarue, E. (2019). *The unintended consequences of the EU ETS cancellation policy* (Munich Personal RePEc Archive No. 96437). Munich. Retrieved November 28, 2020, from https://mpra.ub.uni-muenchen.de/96437/1/MPRA_paper_96437.pdf

Bruns, H., & Perino, G. (2019). The Role of Autonomy and Reactance for Nudging - Experimentally Comparing Defaults to Recommendations and Mandates. *SSRN Electronic Journal.* Advance online publication. https://doi.org/10.2139/ssrn.3442465

Calel, R. (2013). Carbon markets: a historical overview. *Wiley Interdisciplinary Reviews: Climate Change*, *4*(2), 107–119. https://doi.org/10.1002/wcc.208

Compensators* e.V. (2020a). *Compensators* Methoden-Papier.* Retrieved December 9, 2020, from https://www.compensators.org/wp-content/uploads/2020/09/compensators-stategiepapier.pdf

Compensators* e.V. (2020b, July 28). *Professor Perino kontrolliert Compensators.* Retrieved December 9, 2020, from https://www.compensators.org/professor-perino-kontrolliert-compensators/

Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J., & Vignati, E. (2019). *Fossil CO2 and GHG emissions of all world countries: 2019 Report* (Vol. 29849). Publications Office of the European Union. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/fossil-co2-and-ghg-emissions-all-world-countries-0

Detenber, B. H., Rosenthal, S., Liao, Y., & Ho, S. S. (2016). Audience Segmentation for Campaign Design: Addressing Climate Change in Singapore. *International Journal of Communication*(10), 4736–4758.

Dubois, G., Sovacool, B., Aall, C., Nilsson, M., Barbier, C., Herrmann, A., Bruyère, S., Andersson, C., Skold, B., Nadaud, F., Dorner, F., Moberg, K. R., Ceron, J. P., Fischer, H., Amelung, D., Baltruszewicz, M., Fischer, J., Benevise, F., Louis, V. R., & Sauerborn, R. (2019). It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures. *Energy Research & Social Science*, *52*, 144–158. https://doi.org/10.1016/j.erss.2019.02.001

Edenhofer, O., Flachsland, C., Wolff, C., Schmid, L. K., Leipprand, A., Koch, N., Kornek, U., & Pahle, M. (2017). *Decarbonization and EU ETS Reform: Introducing a price floor to drive low-carbon investments: Policy Paper.* Mercator Research Institute on Global Commons and Climate Change (MCC) gGmbH. Retrieved November 29, 2020, from https://www.mcc-berlin.net/fileadmin/data/C18_MCC_Publications/Decarbonization_EU_ETS_Reform_Policy_Paper.pdf

Eichner, T., & Pethig, R. (2019). EU-type carbon regulation and the waterbed effect of green energy promotion. *Energy Economics*, *80*, 656–679. https://doi.org/10.1016/j.eneco.2019.01.019

EMBER. (2020). *EUA Price.* Retrieved October 3, 2020, from https://ember-climate.org/data/carbon-price-viewer/

European Commission. (n.d.–a). *Allocation to aviation.* Retrieved November 11, 2020, from https://ec.europa.eu/clima/policies/ets/allowances/aviation_en

European Commission. (n. d.–b). *Market Stability Reserve.* Retrieved November 28, 2020, from https://ec.europa.eu/clima/policies/ets/reform_en

European Commission. (n. d.–c). *Phases 1 and 2 (2005-2012).* Retrieved November 25, 2020, from https://ec.europa.eu/clima/policies/ets/pre2013_en

European Commission. (2020a). *EU Emissions Trading System (EU ETS).* Retrieved November 10, 2020, from https://ec.europa.eu/clima/policies/ets_en

European Commission. (2020b). *Reducing emissions from aviation.* Retrieved November 11, 2020, from https://ec.europa.eu/clima/policies/transport/aviation_en

European Commission. (2020c). *Report on the functioning of the European carbon market* (COM(2019) 557 final/2). Brussels. Retrieved November 10, 2020, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0557R(01)&from=EN

European Commission. (2020d). *Withdrawal of the United Kingdom and EU Emissions Trading System (EU ETS)*. Brussels. Retrieved November 18, 2020, from https://ec.europa.eu/info/sites/info/files/brexit_files/info_site/emissions-trading-system_en_0.pdf

European Environment Agency. (2020a). *EEA greenhouse gas - data viewer.* Retrieved November 8, 2020, from https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

European Environment Agency. (2020b). *EU Emissions Trading System (ETS) data viewer.* Retrieved November 8, 2020, from https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, Official Journal of the European Union L 275/32-L 275/46 (2003). Retrieved November 29, 2020, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003L0087&from=EN

Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community, Official Journal of the European Union L 140/63-L140/87 (2009). Retrieved November 18, 2020, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0029&from=EN

Decision (EU) 2015/1814 of the European Parliament and of the Council of 6 October 2015 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC, Official Journal of the European Union L 264/1-L 264/5 (2015). Retrieved November 10, 2020, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015D1814&from=EN

Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814, Official Journal of the European Union L 76/3-L 76/27 (2018). Retrieved November 10, 2020, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0410&from=EN

Eurostat. (2020a). *National accounts aggregates by industry (up to NACE A*64).* Retrieved November 8, 2020.

Eurostat. (2020b). *Use table at basic prices.* Retrieved November 8, 2020, from https://ec.europa.eu/eurostat/databrowser/view/NAIO_10_CP1610__custom_174544/default/table?lang=en

Flachsland, C., Pahle, M., Burtraw, D., Edenhofer, O., Elkerbout, M., Fischer, C., Tietjen, O., & Zetterberg, L. (2020). How to avoid history repeating itself: the case for an EU Emissions Trading System (EU ETS) price floor revisited. *Climate Policy*, *20*(1), 133–142. https://doi.org/10.1080/14693062.2019.1682494

Fullerton, D. (2011). Six distributional effects of environmental policy. *Risk Analysis : An Official Publication of the Society for Risk Analysis*, *31*(6), 923–929. https://doi.org/10.1111/j.1539-6924.2011.01628.x

Fullerton, D., & Metcalf, G. E. (2002). Chapter 26 Tax incidence. In A. J. Auerbach & M. Feldstein (Eds.), *Handbook of Public Economics* (pp. 1787–1872). Elsevier. https://doi.org/10.1016/S1573-4420(02)80005-2

Fuss, S., Flachsland, C., Koch, N., Kornek, U., Knopf, B., & Edenhofer, O. (2018). A Framework for Assessing the Performance of Cap-and-Trade Systems: Insights from the European Union Emissions Trading System. *Review of Environmental Economics and Policy*, *12*(2), 220–241. https://doi.org/10.1093/reep/rey010

Gerlagh, R., & Heijmans, R. J. R. K. (2019). Climate-conscious consumers and the buy, bank, burn program. *Nature Climate Change*, *9*(6), 431–433. https://doi.org/10.1038/s41558-019-0482-0

Gerlagh, R., Heijmans, R., & Rosendahl, K. E. (2019). *Endogenous Emission Caps Always Induce a Green Paradox* (CESifo Working Paper No. 7862). Munich. Center for Economic Studies and ifo Institute (CESifo). Retrieved November 10, 2020, from https://www.econstor.eu/bitstream/10419/207253/1/cesifo1_wp7862.pdf

German Federal Environment Agency. (2020). *UBA Carbon Calculator: Life in Germany: keeping an eye on your carbon balance.* Retrieved December 15, 2020, from https://uba.co2-rechner.de/en_GB

Global Footprint Network. (2020). *Earth Overshoot Day 2020 fell on August 22.* Retrieved December 15, 2020, from https://www.overshootday.org/

Harberger, A. C. (1962). The Incidence of the Corporation Income Tax. *Journal of Political Economy*, *70*(3), 215–240. https://doi.org/10.1086/258636

Hintermayer, M. (2020). A carbon price floor in the reformed EU ETS: Design matters! *Energy Policy*, *147*. https://doi.org/10.1016/j.enpol.2020.111905

Intergovernmental Panel on Climate Change (IPCC). (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global warming of 1.5 °C: An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*.

International Carbon Action Partnership. (2020a). *Emissions Trading Worldwide: Status Report 2020*. Berlin. Retrieved November 23, 2020, from https://icapcarbonaction.com/en/?option=com_attach&task=download&id=677

International Carbon Action Partnership. (2020b). *Market Stability Mechanisms in Emissions Trading Systems*. Berlin. Retrieved December 11, 2020, from https://icapcarbonaction.com/en/?option=com_attach&task=download&id=669

International Organization for Standardization. (2018). *ISO 14067:2018: Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification.* Retrieved November 14, 2020, from https://www.iso.org/standard/71206.html

International Organization for Standardization. (2020a). *ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework.* Retrieved November 14, 2020, from https://www.iso.org/standard/37456.html

International Organization for Standardization. (2020b). *ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines.* Retrieved November 14, 2020, from https://www.iso.org/standard/38498.html

Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M., & Creutzig, F. (2020). Quantifying the potential for climate change mitigation of consumption options. *Environmental Research Letters*, *15*(9), 1–19.

Jarke, J., & Perino, G. (2017). Do renewable energy policies reduce carbon emissions? On caps and inter-industry leakage. *Journal of Environmental Economics and Management*, *84*, 102–124. https://doi.org/10.1016/j.jeem.2017.01.004

Jarke-Neuert, J., & Perino, G. (2019). Understanding Sector Coupling: The General Equilibrium Emissions Effects of Electro-Technology and Renewables Deployment.

SSRN Electronic Journal. Advance online publication. https://doi.org/10.2139/ssrn.3326407

Jarke-Neuert, J., & Perino, G. (2020). *When power saving harms the climate*. Sustainable Future Policy Lab: Analyses. Retrieved December 6, 2020, from https://sfplab.org/?p=884

Koch, N., Fuss, S., Grosjean, G., & Edenhofer, O. (2014). Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. *Energy Policy*, *73*, 676–685. https://doi.org/10.1016/j.enpol.2014.06.024

Kollenberg, S., & Taschini, L. (2019). Dynamic supply adjustment and banking under uncertainty in an emission trading scheme: The market stability reserve. *European Economic Review*, *118*, 213–226. https://doi.org/10.1016/j.euroecorev.2019.05.013

Kotchen, M. J. (2013). Voluntary- and Information-Based Approaches to Environmental Management: A Public Economics Perspective. *Review of Environmental Economics and Policy*, *7*(2), 276–295. https://doi.org/10.1093/reep/ret012

Mehling, M. A., & Ritz, R. A. (September 2020). *Going beyond default intensities in an EU carbon border adjustment mechanism* (Cambridge Working Paper in Economics No. 2087). Retrieved December 9, 2020, from https://www.repository.cam.ac.uk/bitstream/handle/1810/314742/cwpe2087.pdf?sequence=1&isAllowed=y https://doi.org/10.17863/CAM.61848

Michaelowa, A., Shishlov, I., & Brescia, D. (2019). Evolution of international carbon markets: lessons for the Paris Agreement. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(6). https://doi.org/10.1002/wcc.613

Moser, S. C. (2010). Communicating climate change: history, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 31–53. https://doi.org/10.1002/wcc.11

Moser, S. C., & Dilling, L. (2012). Communicating Climate Change: Closing the Science-Action Gap. In J. S. Dryzek, R. B. Norgaard, & D. Schlosberg (Eds.), *The Oxford Handbook of Climate Change and Society* (pp. 161–174). Oxford University Press.

Newbery, D. M., Reiner, D. M., & Ritz, R. A. (2018). *When is a carbon price floor desirable?* (Cambridge Working Paper in Economics No. 1833). Retrieved November 29, 2020, from https://www.eprg.group.cam.ac.uk/wp-content/uploads/2018/06/1816-Text.pdf

Osorio, S., Tietjen, O., Pahle, M., Pietzcker, R., & Edenhofer, O. (2020). *Reviewing the Market Stability Reserve in light of more ambitious EU ETS emission targets*. Kiel, Hamburg. ZBW – Leibniz Information Centre for Economics. Retrieved November 10, 2020, from https://www.econstor.eu/bitstream/10419/217240/1/Paper_MSR_Osorio_etal_vf.pdf

Pauw, W. P., & Klein, R. J. (2020). Beyond ambition: increasing the transparency, coherence and implementability of Nationally Determined Contributions. *Climate Policy, 20*(4), 405–414. https://doi.org/10.1080/14693062.2020.1722607

Perino, G. (2015). Climate Campaigns, Cap and Trade, and Carbon Leakage: Why Trying to Reduce Your Carbon Footprint Can Harm the Climate. *Journal of the Association of Environmental and Resource Economists, 2*(3), 469–495. https://doi.org/10.1086/682572

Perino, G. (2018). New EU ETS Phase 4 rules temporarily puncture waterbed. *Nature Climate Change*, *8*(4), 262–264. https://doi.org/10.1038/s41558-018-0120-2

Perino, G. (2019). Reply: EU ETS and the waterbed effect. *Nature Climate Change*, *9*(10), 736. https://doi.org/10.1038/s41558-019-0580-z

Perino, G., Ritz, R., & van Benthem, A. (2019). *Understanding Overlapping Policies: Internal Carbon Leakage and the Punctured Waterbed*. Cambridge, MA. https://doi.org/10.3386/w25643

Perino, G., Ritz, R. A., & van Benthem, A. A. (November 2020). *Overlapping Climate Policies* (Cambridge Working Paper in Economics No. 20111). Retrieved November 30, 2020, from http://www.econ.cam.ac.uk/research-files/repec/cam/pdf/cwpe20111.pdf https://doi.org/10.13140/RG.2.2.29523.81448

Perino, G., & Willner, M. (2015). The price and emission effects of a market stability reserve in a competitive allowance market. *WiSO-HH Working Paper Series*(28).

Perino, G., & Willner, M. (2016). Procrastinating reform: The impact of the market stability reserve on the EU ETS. *Journal of Environmental Economics and Management*, *80*, 37–52. https://doi.org/10.1016/j.jeem.2016.09.006

Perino, G., & Willner, M. (2017). EU-ETS Phase IV: allowance prices, design choices and the market stability reserve. *Climate Policy*, *17*(7), 936–946. https://doi.org/10.1080/14693062.2017.1360173

Perino, G., & Willner, M. (2019). Rushing the Impatient: Allowance Reserves and the Time Profile of Low-Carbon Investments. *Environmental and Resource Economics, 74*(2), 845–863. https://doi.org/10.1007/s10640-019-00350-x

Perman, R., Ma, Y., McGilvray, J., & Common, M. (2003). *Natural Resource and Environmental Economics* (3rd edition). Pearson Education Limited.

Phaneuf, D. J., & Requate, T. (2016). *A course in environmental economics: Theory, policy, and practice*. Cambridge University Press.

Quemin, S. (2020). *Using supply-side policies to raise ambition: the case of the EU ETS and the 2021 review* (Centre for Climate Change Economics and Policy Working Paper No. 366). London. London School of Economics and Political Science. Retrieved November 10, 2020, from https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2020/03/working-paper-335-Quemin-1.pdf

Rosendahl, K. E. (2019a). *EU ETS and the New Green Paradox* (CESifo Working Paper No. 7645). Munich. Retrieved November 10, 2020, from https://www.econstor.eu/bitstream/10419/201871/1/cesifo1_wp7645.pdf

Rosendahl, K. E. (2019b). EU ETS and the waterbed effect. *Nature Climate Change, 9*(10), 734–735. https://doi.org/10.1038/s41558-019-0579-5

Sabbadin, D., European Environmental Bureau, Carbon Market Watch, ECOS, Bellona, Bond Beter Leefmilieu, Sandbag, Seas at risk, & Sciaena. (2020). *Industrial Transformation for a More Resilient Future*. Brussels. European Environmental Bureau. Retrieved October 5, 2020, from https://eeb.org/library/industrial-transformation-for-a-more-resilient-future/

Sachs, N. M. (2019). The Paris Agreement in the 2020s: Breakdown or Breakup? *Ecology Law Quarterly*, *46*, 865–909. https://doi.org/10.15779/Z38H708140

Sánchez Nicolás, E. (2020, December 11). EU leaders agree on 55% climate target for 2030. *EUobserver*. https://euobserver.com/green-deal/150364

Sandbag. (n. d.). *Destroy Carbon No longer operational: Why we closed our service cancelling carbon permits from the EU Emissions Trading System.* Retrieved December 9, 2020, from https://sandbag.be/index.php/carbon-destruction-service/

Tietjen, O., Lessmann, K., & Pahle, M. (2019). Hedging and the Temporal Permit Issuance in Cap-and-Trade Programs: The Market Stability Reserve Under Risk Aversion. *SSRN Electronic Journal.* Advance online publication. https://doi.org/10.2139/ssrn.3436736

Tyers, R. (2018). Nudging the jetset to offset: voluntary carbon offsetting and the limits to nudging. *Journal of Sustainable Tourism*, *26*(10), 1668–1686. https://doi.org/10.1080/09669582.2018.1494737

van de Ven, D.-J., González-Eguino, M., & Arto, I. (2018). The potential of behavioural change for climate change mitigation: a case study for the European Union. *Mitigation and Adaptation Strategies for Global Change*, *23*(6), 853–886. https://doi.org/10.1007/s11027-017-9763-y

Wiedmann, T., & Minx, J. (2007). A Definition of 'Carbon Footprint'. In C. C. Pertsova (Ed.), *Ecological economics research trends* (pp. 1–11). Nova Science Publishers.

World Wide Fund For Nature. (2020). *Measure your impact.* Retrieved December 15, 2020, from https://wwf.panda.org/act/live_green/

Appendix

Nomenclature

α_i	$\alpha_i = L_i / L$ is the share of the clean input used in sector *i* and $\alpha_x + \alpha_y = 1$
β	share of supply S_t above which excess allowances are canceled
γ	number of allowances taken out of the MSR and into the market
δ	discount factor, $\delta = 1/(1+r)$
ε_i	share of emissions in sector *i* on total emissions, $\varepsilon_i = C_i / C$
θ_{ij}	share of income used on input *j* in the production of good *i* and $\theta_{iL} + \theta_{iC} = 1$
λ	upper threshold of the number of banked allowances for inflow into MSR
μ_t	withdrawal or intake rate determining intake into MSR, $\mu_t \in (0,1)$ (named α_t by Rosendahl (2019a))
η	threshold of the number of banked allowances for outflow from MSR ($\eta < \lambda$)
σ_i	elasticity of substitution of the input factors in the production of good *i*, $\sigma_i > 0$
σ_u	elasticity of substitution in consumption between *x* and *y*
σ_m	elasticity of the MRS with respect to a change in *m*
B_t	number of allowances banked at the end of period *t*
C	carbon emissions or emissions input
D_t	demand for allowances, depending on allowance price P_t, interpreted as emissions in *t*
K_t	number of allowances permanently canceled (named *C* by Rosendahl (2019a))
L	clean input (fixed in supply)
m	parameter that represents the impact of the climate campaign through shifting the marginal rate of substitution between *x* and *y* up or down
M_t	size of the MSR at the start of period *t*
M_t^{IN}	MSR intake, i. e. allowances withdrawn from the auction volume and put into the MSR
M_t^{OUT}	MSR outtake, i. e. allowances taken out of the MSR into the auction

N_t	auctioned net supply, i. e. share of the annual supply that is auctioned after possible reduction by M_t^{IN} or increase by M_t^{OUT}
p_i	price of good i (good x is the numeraire, i. e. $p_x = 1$)
r	market interest rate
S_t	supply of allowances in each period, initially fixed
t_x	carbon tax, $t_x \geq 0$
t_y	permit price, $t_y > 0$ (or carbon tax $t_y > 0$ in the reference scenario)
$u(X, Y; m)$	utility function (nonsatiated in both goods, decreasing marginal utility, strictly positive demand at finite prices, asymptotic satiation, homo-thetic, budget constraint: $X + p_y Y \leq wL + t_x C_x + t_y C_y$)
v	number of years between the year where additional allowances entered the bank due to the climate campaign and the year where the bank falls below the upper threshold λ; in the EU ETS when the withdrawal rate μ_1 = 24 % applies from 2019 to 2023
w	price for clean input L
X	aggregate output quantity of the sector regulated by a carbon tax
x	good produced in sector X (e. g. "driving")
Y	aggregate output quantity of the sector regulated by cap-and-trade
y	good produced in sector Y (e. g. "electricity")
z	number of years between the year where additional allowances entered the bank due to the climate campaign and the year where the bank falls below the upper threshold λ; in the EU ETS when the withdrawal rate μ_2 = 12 % applies from 2024 onwards

Derivation Analytical Solution Case 1 b)

The fact that in case 1 a), $M_{t+1} > N_{t+1}$ would also apply without a campaign, i. e. without $2\hat{M}^{IN}$, means mathematically that $M_t + M_t^{IN} - K_t > \beta S_{t+1} - M_t^{IN}$ would be valid as well. However, if, all other things being equal, it is assumed that b) $M_{t+1} > N_{t+1}$ holds only with the changes due to the campaign, then without them, $M_t + M_t^{IN} - K_t < \beta S_{t+1} - M_t^{IN}$ and hence $M_{t+1} < N_{t+1}$ would be valid. Therefore, considering the time interval t to t+2, case 1 b) refers to the scenario where the additional allowances which are in the MSR due to a campaign, i. e. $2\mu\hat{Y}$ in period t+2, will only be partially canceled. This is because some of these additional allowances will contribute that M_{t+1} reaches the threshold of N_{t+1} and hence, only a certain number of them will be excess allowances above the threshold of N_{t+1} that are cancelled. In the following, it should be briefly illustrated what these considerations imply mathematically.

Analogous to case 1 a), still $B_t > \lambda$ and $M_{t+1} > N_{t+1}$ are valid, i. e. a certain number of allowances get into the MSR and a certain number gets deleted. However, not all allowances that entered the MSR because of the campaign get deleted since the cancelation threshold is only reached with this campaign allowances. If the difference between the auctioned net supply N_{t+1} and the number of allowances in the MSR M_{t+1} without the changes due to the campaign is smaller than the change in this difference due to the campaign $2\hat{M}^{IN}$, i. e. $\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right) < 2\hat{M}^{IN}$, then some of this change due to the campaign is canceled, namely the part of $2\hat{M}^{IN}$ that is eventually above the threshold value. This amounts to $\hat{K} = 2\hat{M}^{IN} - \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ which gets canceled in period $t+2$. Therefore, in case 1 b) and considering the time interval t to $t+2$, emissions in sector Y decrease due to the climate campaign although not as much as in case 1 a), namely $\hat{C}_y = -\hat{K} = 2\mu\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ since analogous to case 1 a) it holds that $\hat{M}^{IN} = -\mu\hat{Y}$.

Considering long term emissions until a certain year $t+x$, case 1 b) refers to the scenario where only some of the total number of additional allowances which entered the MSR due to a campaign until $t+x$ are canceled, i. e. only a part of this total number is canceled. Note that if in one year, additional campaign allowances in the MSR are canceled only partially, the remaining allowances that are not canceled in this year might be canceled later on, since the number of allowances auctioned in the respective previous year and with this the cancelation threshold also decreases year after year due to the campaign. This might lead to complete cancelation of the total number of additional allowances, which corresponds to case 1 a). Hence, only the overall balance is decisive whether case a) or b) is given. Analogous to case 1 a), a mathematical representation can be derived, i. e. $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$. However, this should be understood as a simplified representation, as it only represents the case where additional certificates are only partially deleted in one year and the remaining certificates from this year are not deleted later. If this would happen in more than one year, there would be a corresponding number of additional summands like the one in square brackets.

Of course, if in one year the above conditions and $\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right) \geq 2\hat{M}^{IN}$ would hold, then nothing would be canceled since then $M_{t+1} \leq N_{t+1}$ would hold and case 2 would apply. Like for case 1 a), the table below shows a summary of the steps in case 1 b) which differ from case 1 a) and lead to the emission change in sector Y in case 1 b):

effects	**related equations and remarks**
	if $B_t > \lambda$
	if $M_{t+1} > N_{t+1}$ and if $M_t + M_t^{IN} - K_t < \beta S_{t+1} - M_t^{IN}$ without the changes due to $\hat{m}$, since $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$ and since $M_{t+1}^{IN} = M_t^{IN} + \hat{M}^{IN}$
	if $\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right) < 2\hat{M}^{IN}$
K_{t+1} ↑	$\hat{K} = 2\hat{M}^{IN} - \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ and since analogous to case 1 a), $\hat{M}^{IN} = \mu\hat{B} = -\mu\hat{Y}$, $\hat{K} = -2\mu\hat{Y} - \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$
M_{t+2}	$M_{t+2} = M_{t+1} + M_{t+2}^{IN} - M_{t+2}^{OUT} - K_{t+1}$ (K_{t+1} gets canceled in period $t+2$)
C_{yt+2} ↓	$\hat{C}_y = -\hat{K} = 2\mu\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ (emission change in Y in $t+2$)
C_{yt+z+2} ↓ (long-term)	$\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$ (emission change in Y in $t+z+2$) rearranging yields $\hat{C}_y = \left(1-(1-2\mu)^z\right)\hat{Y} + \beta S_{t+1} - 2M_t^{IN} - M_t + K_t$, where z is the number of years between the year where B_t increases due to the climate campaign and the year where B_{t+z} falls below the upper threshold λ, i. e. $B_t \leq \lambda$ (derivation analogous to case 1 a))

Proof Sector *X*

This proof for the updated equation for the change in emissions in sector *X* follows the "Proof of Proposition 2" (p. 490) by Perino (2015) except that $\hat{C}_y = 0$ can no longer be assumed. The approach is to replace $\hat{Y}$ and $\hat{p}_y$ in condition (9) as functions of $\hat{X}$, using condition (7) and lemma 3 and 4. Afterwards, $\hat{X}$ can be factored out and due to the assumption of lemma 4 that "inputs and outputs of sector *X* expand or contract proportionally ($\hat{X} = \hat{L}_x = \hat{C}_x$)" (p. 478), this then yields $\hat{C}_x$.

From condition (7) $\hat{C}_y - \hat{L}_y = \sigma_y(\hat{w} - \hat{t}_y)$ and lemma 3 stating $\hat{w} = 0$, it follows that

$$\hat{L}_y = \sigma_y \hat{t}_y + \hat{C}_y$$

Using this and lemma 4 or condition (3) $\hat{Y} = \theta_{YL}\hat{L}_y + \theta_{YC}\hat{C}_y$ results in

$$\hat{Y} = \theta_{YL}(\sigma_y \hat{t}_y + \hat{C}_y) + \theta_{YC}\hat{C}_y$$

Rearranging $\hat{p}_y = \theta_{YC}\hat{t}_y$ from lemma 3 to $\hat{t}_y = \frac{\hat{p}_y}{\theta_{YC}}$ and inserting in the above equation yields

$$\hat{Y} = \theta_{YL}\left(\sigma_y \frac{\hat{p}_y}{\theta_{YC}} + \hat{C}_y\right) + \theta_{YC}\hat{C}_y$$

Rearranging again and factoring out $\hat{C}_y$ results in

$$\hat{Y} = \frac{\theta_{YL}}{\theta_{YC}}\sigma_y \hat{p}_y + \hat{C}_y(\theta_{YL} + \theta_{YC})$$

Since it holds that $\theta_{iL} + \theta_{iC} = 1$, compared to Perino's proof, $\hat{C}_y$ is simply added in **the $\hat{Y}$ equation:**

$$\hat{Y} = \frac{\theta_{YL}}{\theta_{YC}}\sigma_y \hat{p}_y + \hat{C}_y$$

From lemma 4 and $\hat{L}_y = \sigma_y \hat{t}_y + \hat{C}_y$ from above, it follows that

$$\hat{X} = -\frac{\alpha_y}{\alpha_x}(\sigma_y \hat{t}_y + \hat{C}_y)$$

Inserting $\hat{t}_y = \frac{\hat{p}_y}{\theta_{YC}}$ from lemma 3 and rearranging results in

$$\hat{X} + \frac{\alpha_y}{\alpha_x}\hat{C}_y = -\frac{\alpha_y}{\alpha_x}\frac{\sigma_y}{\theta_{YC}}\hat{p}_y$$

Rearranging again yields **the** $\hat{p}_y$ **equation:**

$$\hat{p}_y = -\frac{\theta_{YC}}{\sigma_y}\left(\frac{\alpha_x}{\alpha_y}\hat{X} + \hat{C}_y\right)$$

Inserting $\hat{Y}$ and $\hat{p}_y$ in condition (9) gives

$$\hat{X} - \frac{\theta_{YL}}{\theta_{YC}}\sigma_y\left(-\frac{\theta_{YC}}{\sigma_y}\left(\frac{\alpha_x}{\alpha_y}\hat{X} + \hat{C}_y\right)\right) + \hat{C}_y = \sigma_u\left(-\frac{\theta_{YC}}{\sigma_y}\left(\frac{\alpha_x}{\alpha_y}\hat{X} + \hat{C}_y\right) + \hat{m}\right)$$

Factoring out $\hat{X}$ results in

$$\hat{X}\left(1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}\right) = \sigma_u\hat{m} - \hat{C}_y\left(1 + \theta_{YL} + \frac{\sigma_u}{\sigma_y}\theta_{YC}\right)$$

Rearranging and using $\hat{X} = \hat{L}_x = \hat{C}_x$ yields **the** $\hat{C}_x$ **equation:**

$$\hat{C}_x = \frac{\sigma_u\hat{m} - \hat{C}_y\left(1 + \theta_{YL} + \frac{\sigma_u}{\sigma_y}\theta_{YC}\right)}{1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}$$

Therefore, compared to Perino (2015), the term $-(\hat{C}_y)(1 + \theta_{YL} + \frac{\sigma_u}{\sigma_y}\theta_{YC})$ has to be added in the numerator. Rearranging terms shows more clearly that the change in emissions in sector *X* now not only depends on the change in preferences due to the climate campaign represented by $\hat{m}$ but also on $\hat{C}_y$:

$$\hat{C}_x = \frac{\sigma_u}{1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{m} - \frac{1 + \theta_{YL} + \frac{\sigma_u}{\sigma_y}\theta_{YC}}{1 + \frac{\alpha_x}{\alpha_y}\theta_{YL} + \frac{\alpha_x}{\alpha_y}\frac{\sigma_u}{\sigma_y}\theta_{YC}}\hat{C}_y$$

Calculations Parameter Values

respective share of the clean input used in sectors *X* and *Y* (α_x, α_y)

parameter	2018 value	source	filters
Manufacture of paper and paper products (C17)	121.807,88	Eurostat, 2020b, Use table at basic prices available at: https://ec.europa.eu/eurostat/databrowser/view/NAIO_10_CP1610__custom_174544/default/table?lang=en (last accessed November 08, 2020)	• Unit of measure: "Million euro" • Stock or flow: "Total" • Geopolitical entity: "European Union – 27 countries"
Manufacture of coke and refined petroleum products (C19)	256.720,92 million euro		
Manufacture of chemicals and chemical products (C20)	326.474,98 million euro		
Manufacture of other non-metallic mineral products (C23)	125.003,21 million euro		
Manufacture of basic metals (C24)	259.847,54 million euro		
Electricity, gas, steam and air conditioning supply (D)	386.596,3 million euro		
L_y (sum of the above)	1.476.450,83 million euro		
L (total)	12.563.077,03 million euro		

$$\alpha_y = L_y / L = 0{,}1175 = 11{,}75\ \%$$

$$\alpha_x = 1 - \alpha_y = 0{,}8825 = 88{,}25\ \%$$

respective share of emissions in sectors *X* and *Y* on total emissions (ε_x, ε_y)

parameter	2018 value	source	filters
C (EU emissions 2018)	3763,8677 million tons CO_2 eq	European Environment Agency, 2020a, EEA greenhouse gas - data viewer available at: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (last accessed November 08, 2020)	• Greenhouse gas: "All greenhouse gases - (CO2 equivalent)" • Measures: "Emissions" • Geographic entity: "EU-27 (2020)" • Emission unit: "Tg (million tonnes)" • Emission source – IPCC sector: "Total (without LULUCF)"
C_y (EU ETS emissions 2018)	1526,4798 million tons CO_2 eq	European Environment Agency, 2020b, EU Emissions Trading System (ETS) data viewer available at: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1 (last accessed November 08, 2020)	• Historical emissions • ETS information: "2. Verified emissions" • Emission unit: "Mt CO2-eq" • Activity: "20-99 All stationary installations" • Country: "EU27"

Note that although the EU ETS covers not all GHG emissions but only CO_2, N_2O and PCFs emissions (European Commission, 2020a), the share of all GHG emissions in sector *Y* or the EU ETS on total GHG emissions can still be accurately calculated since the GHG emissions are measured in CO_2 equivalents (CO_2 eq).

$$\varepsilon_y = C_y / C = 0{,}4055 = 40{,}56\ \%$$

$$\varepsilon_x = 1 - \varepsilon_y = 0{,}5945 = 59{,}44\ \%$$

share of income used on the respective input in the production of good *y* ($\boldsymbol{\Theta_{YC}}$, $\boldsymbol{\Theta_{YL}}$)

parameter	2018 value	source	filters
t_y (average EUA price 2018)	16,03 euro	EMBER, 2020, EUA Price Viewer available at: https://ember-climate.org/data/carbon-price-viewer/ (last accessed October 03, 2020)	-
C_y (EU ETS emissions 2018)	1.526.479.757 tons CO_2 eq	European Environment Agency, 2020b, EU Emissions Trading System (ETS) data viewer available at: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1 (last accessed November 08, 2020)	• Historical emissions • ETS information: "2. Verified emissions" • Emission unit: "t CO2-eq" • Activity: "20-99 All stationary installations" • Country: "EU27"
p_yY (GDP of the EU ETS sectors)	$5{,}40683 \cdot 10^{11}$ euro[11]	Eurostat, 2020a, National accounts aggregates by industry (up to NACE A*64)	• Geopolitical entity: "European Union – 27 countries" • Classification of economic activities – NACE

[11] This value is not based on data for 2018 since no data is available yet. Instead, the latest available data for the EU ETS sectors relevant here were used, namely data for 2017 for C17, C19, C23, C24 and D and data for 2014 for C20. If the growth trend in these sectors in the years prior to 2018 continued in 2018, a slightly higher GDP value for these sectors for 2018 is probable and due to that, the 2018 value of Θ_{YC} could therefore be slightly lower.

		available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_a64&lang=en (last accessed November 08, 2020)	Rev. 2: C17, C19, C20, C23, C24, D (selection of six EU ETS sectors like in the above table for α_x, α_y) • National accounts indicator (ESA 2010): “Value added, gross” • Unit of measure: “Current prices, million euro”

$$\Theta_{YC} = t_y C_y \,/\, p_y Y = 0{,}0468 = 4{,}53\ \%$$

$$\Theta_{YL} = 1 - \Theta_{YC} = 0{,}9532 = 95{,}47\ \%$$

Calculations Interim Results by Perino (2015)

From Perino's (2015) statement that in the **tax-tax regime**, according to Proposition 1 (p. 477)

- $\hat{C}_x = \alpha_y \sigma_u \hat{m}$ and
- $\hat{C}_y = -\alpha_x \sigma_u \hat{m}$ hold

and in general,

- α_y = 0,145 and α_x = 0,855 are used according to Table 1 (p. 481) and
- σ_u = 1 and $\hat{m}$ = 2% are assumed according to statements on p. 480,

it follows that

$\hat{C}_x$ = 0,0029 = 0,29 % and $\hat{C}_y$ = - 0,0171 = - 1,71 % are valid.

This can be verified by using the equation $\hat{C} = \varepsilon_x \hat{C}_x + \varepsilon_y \hat{C}_y$ of Proposition 1 (p. 477).

From Perino's (2015) statement that in the **cap-tax regime**,

- $\hat{C} = \varepsilon_x \hat{C}_x$ is valid according to Proposition 2 (p. 479) and
- $\hat{C}$ = 0,17 % = 0,0017 holds (p. 480)

and in general,

- ε_x = 0,587 is used according to Table 1 (p. 481),

it follows that

$\hat{C}_x$ = 0,0029 = 0,29 % is valid.

This can be checked by using the $\hat{C}_x$ definition of Proposition 2 (p. 479).

Sensitivity *v* & *z*

Considering cases 1 a) and 2 a), the following table shows the change in total emissions ($\hat{C}$) for different values of *v* and *z*.

		v				
		0	1	2	3	4
z	0	-	-0,116%	-0,248%	-0,317%	-0,353%
	1	0,012%	-0,182%	-0,283%	-0,335%	-0,362%
	2	-0,085%	-0,232%	-0,309%	-0,349%	-0,370%
	3	-0,159%	-0,271%	-0,329%	-0,359%	-0,375%
	4	-0,215%	-0,300%	-0,344%	-0,367%	-0,379%
	5	-0,257%	-0,322%	-0,356%	-0,373%	-0,382%
	6	-0,290%	-0,339%	-0,364%	-0,378%	-0,384%
	7	-0,314%	-0,351%	-0,371%	-0,381%	-0,386%
	8	-0,333%	-0,361%	-0,376%	-0,384%	-0,388%
	9	-0,347%	-0,369%	-0,380%	-0,386%	-0,389%
	10	-0,358%	-0,374%	-0,383%	-0,387%	-0,389%
	11	-0,366%	-0,378%	-0,385%	-0,388%	-0,390%
	12	-0,372%	-0,382%	-0,387%	-0,389%	-0,391%
	13	-0,377%	-0,384%	-0,388%	-0,390%	-0,391%
	14	-0,381%	-0,386%	-0,389%	-0,390%	-0,391%
	15	-0,383%	-0,387%	-0,390%	-0,391%	-0,391%
	16	-0,385%	-0,389%	-0,390%	-0,391%	-0,392%
	17	-0,387%	-0,389%	-0,391%	-0,391%	-0,392%
	18	-0,388%	-0,390%	-0,391%	-0,391%	-0,392%
	19	-0,389%	-0,390%	-0,391%	-0,392%	-0,392%
	20	-0,390%	-0,391%	-0,391%	-0,392%	-0,392%
	21	-0,390%	-0,391%	-0,392%	-0,392%	-0,392%
	22	-0,391%	-0,391%	-0,392%	-0,392%	-0,392%
	23	-0,391%	-0,391%	-0,392%	-0,392%	-0,392%
	24	-0,391%	-0,392%	-0,392%	-0,392%	-0,392%
	25	-0,391%	-0,392%	-0,392%	-0,392%	-0,392%
	26	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	27	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%

	28	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	29	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	30	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	31	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	32	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%
	33	-0,392%	-0,392%	-0,392%	-0,392%	-0,392%

Numerical Example Cases 1 b) and 2 b)

The analytical result for sector *Y* in cases 1 b) and 2 b) is smaller than in cases 1 a) and 2 a), namely

- Sector *Y*: $\hat{C}_y = \left(1-(1-2\mu_1)^y(1-2\mu_2)^z\right)\hat{Y} + \left[\left(\beta S_{t+1} - M_t^{IN}\right) - \left(M_t + M_t^{IN} - K_t\right)\right]$

  $\hat{C}_y = \left(1-(1-2\mu_1)^y(1-2\mu_2)^z\right)\hat{Y} + \beta S_{t+1} - 2M_t^{IN} - M_t + K_t$,

  where N_{t+1} without the changes due to $\hat{m}$ corresponds to $\beta S_{t+1} - M_t^{IN}$

  and M_{t+1} without the changes due to $\hat{m}$ corresponds to $M_t + M_t^{IN} - K_t$

  since $M_{t+1}^{OUT} = 0$ due to $B_t > \lambda$ and since $M_{t+1}^{IN} = M_t^{IN} + \hat{M}^{IN}$.

Note that in the analytical section above, *M* and *N* where compared regarding the same year (e. g. $M_{t+1} > N_{t+1}$) due to the design of the model by Rosendahl (2019a, see footnote p. 22). However, since "the MSR may hold only as many allowances as were auctioned in the previous year" (Perino, 2018, p. 263), in this numerical section, $M_{t+1} > N_t$ will be applied as the condition for cancelation. Further, for the sake of simplicity, it is assumed that the projections are to be considered without the effect of a climate campaign or that each climate campaign would have an additional effect beyond the projections which is why it is possible to consider N_t and M_{t+1} instead of $\beta S_t - M_{t-1}^{IN}$ and $M_t + M_t^{IN} - K_t$ and hence, the upper equation can be simplified to

- Sector Y: $\hat{C}_y = -\hat{K} = \left(1-(1-2\mu)^z\right)\hat{Y} + \left[N_t - M_{t+1}\right]$.

If one takes the projections by Osorio et al. (2020) again as a basis, it is not possible to use the same example as above in cases 1 a) and 2 a) of an abatement coming into place 2021 since the conditions for cases 1 b) and 2 b) are not fulfilled[12]. However, it is possible to construct a suitable example where these conditions apply, i. e. where without the effect of the campaign, M_{t+1} is only a little bit smaller than the auctioned net supply of the previous year N_t ($M_{t+1} < N_t$), and where the number of allowances that enter the MSR due to the campaign, although small by design, is high enough that eventually $M_{t+1} > N_t$ is valid. Considering the projections by Osorio et al. (2020), this is not often the case but

[12] This is because as the projections displayed in Figure 1 of Osorio et al. (2020) show, in 2023, the number of allowances in the MSR M_{2023} will probably be much higher than the "Final Auction" (ibid., p. 14) or auctioned net supply in the previous year N_{2022}, leading to over 2.000 Mt CO_2 allowances being cancelled in 2023. Hence, $M_{2023} > N_{2022}$ is valid without the climate campaign and therefore the conditions for cases 1 b) and 2 b) are not fulfilled.

might happen e. g. in 2046 where the number of allowances in the MSR is projected to be slightly below the number of allowances in the final auction of the previous year 2045, e. g. M_{2046} = 300 Mt CO_2 and N_{2045} = 300,005 Mt CO_2 hold. Note that these are no accurate numbers but only exemplary values based on Figure 1 by Osorio et al. (2020)[13]. In this case, $N_{2045} > M_{2046}$ would hold and therefore no cancelation would happen without an additional abatement effect leading to a sufficiently high number of additional allowances in the MSR, namely greater than the distance between N_{2045} and M_{2046} which amounts to 0,005 Mt CO_2. Further, if one assumes an additional and sufficiently large abatement effect coming into place 2044 due to a climate campaign with the same parameter and assumption values as in cases 1 a) and 2 a) above, and if one inserts these values into the analytical results above and in the last section, the following results are obtained in cases 1 b) and 2 b) with these exemplary values considering the year 2046:

- Sector *X*: $\hat{C}_x$ = 0,5869 %
- Sector *Y*: $\hat{C}_y$ = - 1,4971 %
- Total emissions: $\hat{C} = \varepsilon_x \hat{C}_x + \varepsilon_y \hat{C}_y$

  $\hat{C}$ = - 0,2583 %

Therefore, with the above assumptions and exemplary values, it would be the case that the additional allowances entering the MSR due to the campaign in 2044 lead to additional allowances in the MSR in 2045 and hence to the fact that $N_{2045} < M_{2046}$ is valid and allowances are canceled in 2046 because of the additional and sufficiently large abatement effect due to the campaign. However, as the analytical result indicated, not all the allowances that entered the MSR due to the campaign are canceled due to the fact that the volume of the MSR would have been smaller than the volume of the auction without the campaign and hence no cancelation would happen without the additional effect due to the campaign. This is illustrated by this numerical example, since the emission reduction in sector *Y* is exactly 0,005 Mt CO_2 or 0,5 % smaller than in cases 1 a) and 2 a). That is because the difference between N_{2045} and M_{2046} without the campaign has to be subtracted

---

[13] The projections shown in Figure 1 by Osorio et al. (2020) are further understood and assumed to correspond to the definitions used here, i. e. it is assumed that the data shown for "MSR" (ibid., p. 14) correspond to the definition of the number of allowances in the MSR M_t, namely $M_t = M_{t-1} + M_t^{IN} - M_t^{OUT} - K_{t-1}$, and that the data for "Final Auction" (ibid.) correspond to the definition of the net supply N_t used here, namely $N_t = \beta S_t - M_t^{IN} + M_t^{OUT}$.

from the emission reduction in sector *Y* and thus from the effect of the campaign in *Y*, since the additional allowances due to the campaign first contribute to reaching the limit value that is required for the deletion. Therefore, as explained above, the effect in cases 1 b) and 2 b) is similar but smaller compared to cases 1 a) and 2 a) which is why the sensitivity analysis would also be similar to that of cases 1 a) and 2 a). However, in the case that the difference between M_{t+1} and N_{t+1} is larger, it is also possible that the leakage effect dominates the smaller reduction effect in sector *Y* and hence total emissions increase. In the above example, this would be the case if e. g. N_{2045} = 300,019 Mt CO_2 would hold since then there would be an increase of total emissions of 0,1139%.

Sensitivity μ_2

Considering cases 1 a) and 2 a), the following table shows the change in total emissions ($\hat{C}$) for different values of the MSR intake rate μ_2.

intake rate μ_2 (from 2024 on)	**change in total emissions ($\hat{C}$) in cases 1 a) and 2 a)**
2%	-0,3258%
4%	-0,3625%
6%	-0,3793%
8%	-0,3868%
10%	-0,3899%
12%	**-0,3912%**
14%	-0,3917%
16%	-0,3919%
18%	-0,3920%
20%	-0,3920%
22%	-0,3920%
24%	-0,3920%
26%	-0,3920%
28%	-0,3920%
30%	-0,3920%
32%	-0,3920%
34%	-0,3920%
36%	-0,3920%
38%	-0,3920%
40%	-0,3920%
42%	-0,3920%
44%	-0,3920%
46%	-0,3920%
48%	-0,3920%
50%	-0,3920%

Eidesstattliche Erklärung

Hiermit versichere ich an Eides statt, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Außerdem versichere ich, dass ich die allgemeinen Prinzipien wissenschaftlicher Arbeit und Veröffentlichung, wie sie in den Leitlinien guter wissenschaftlicher Praxis der Carl von Ossietzky Universität Oldenburg festgelegt sind, befolgt habe.

Oldenburg, 30.12.2020 Laura Schürer