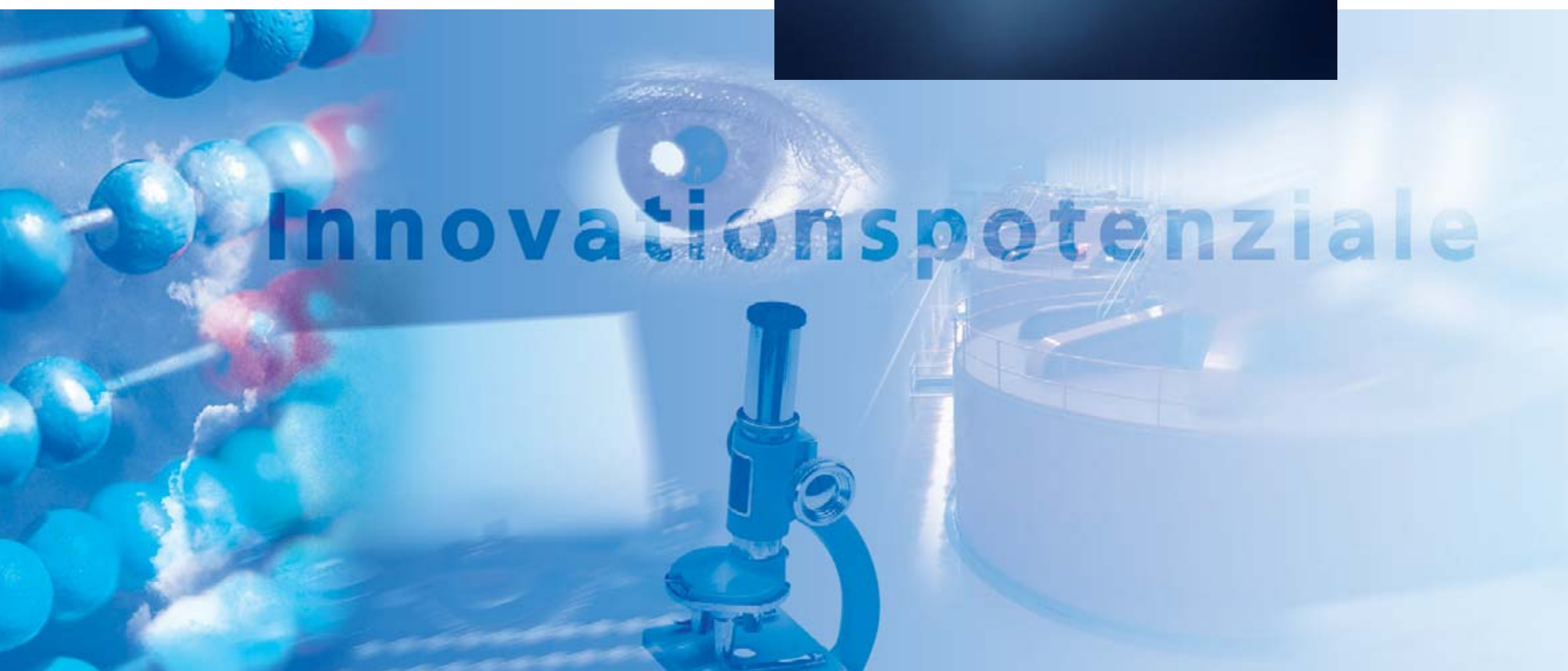
# No-lose targets as an option to integrate non-Annex I countries in global emission reduction efforts

## A game-theoretical analysis

Vicki Duscha



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# No-lose targets as an option to integrate non-Annex I countries in global emission reduction efforts

## A game-theoretical analysis

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# Abstract

Substantial greenhouse gas emission reductions of 50% and more below 1990 levels by 2050 are necessary, to limit mean temperature increase below 2°C above pre-industrial levels. While the Kyoto Protocol foresees emission reduction targets for Annex I countries only, current and projected greenhouse gas emissions, as well as the growing economic importance of emerging economies call for an integration of non-Annex I countries in global reduction efforts.

No-lose targets set emission reduction targets and define incentives for meeting the target, in contrast to binding reduction targets that use penalties to ensure compliance. One form of incentive is the participation in an international emissions trading market. While a few conceptual and quantitative analyses of no-lose targets can be found in the literature, economic analyses have not been carried out so far.

In this thesis, two theoretical frameworks are introduced to analyze the potential of no-lose targets to contribute to global emission reduction efforts. First, a two-player, two-stage model is developed to model a non-Annex I country's participation decision and derive the contribution to global emission reductions. Then a two-player participation game is introduced to analyze the effects that the participation decision of one non-Annex I country has on another non-Annex I country also facing a no-lose target. Two market forms, a perfectly competitive market, and a market with market power on the side of the non-Annex I country are analyzed. In order to complement the highly stylized theoretical frameworks, a quantitative analysis applying marginal abatement cost curves is conducted to estimate the contribution of no-lose targets to reaching the 2°C target.

The analyses show that no-lose targets can result in substantial contributions from non-Annex I countries to global emission reductions, in particular if the reduction potential in the non-Annex I countries is large, compared to that of the Annex I community. Market power on the part of the non-Annex I countries is found to further increase these contributions. Yet large certificate transfers via the carbon market are necessary to make the no-lose targets profitable.

This thesis is based on my research conducted at the Fraunhofer Institute for Systems and Innovation Research (ISI) in Karlsruhe under the supervision of Professor K.-M. Ehrhart at the Karlsruhe Institute of Technology (KIT) and is written in English.

# Zusammenfassung

Eine zentrale Herausforderung für den internationalen Klimaschutz besteht darin, Nicht-Annex-I-Länder in globale Emissionsminderungsanstrengungen einzubeziehen. Im Gegensatz zu bindenden Emissionszielen stellen no-lose-Ziele unverbindliche Emissionsminderungsvorgaben dar, die gleichzeitig Anreize für die Zielerreichung setzen, z.B. durch die Teilnahme am internationalen Emissionshandel.

Anhand von zwei theoretischen Modellen werden die ökonomischen Wirkweisen von no-lose-Zielen und deren potentieller Beitrag zur Erreichung von globalen Emissionszielen untersucht. Zunächst findet die Analyse eines einzelnen Nicht-Annex-I-Landes mit no-lose-Ziel unter der Prämisse von vollkommenem Wettbewerb bzw. Marktmacht des Nicht-Annex-I-Landes statt. Es werden zwei Fälle der Lastenteilung von Minderungszielen (bottom-up und top-down) betrachtet.

Da die Teilnahmeentscheidung eines nicht-Annex I-Landes die Profitabilität des no-lose-Ziels eines anderen Nicht-Annex I-Landes über den Zertifikatpreis beeinflussen kann, wird in einem zweiten Schritt die strategische Situation zweier Nicht-Annex-I-Länder unter Zuhilfenahme einer spieltheoretischen Komponente ("participation game") analysiert. Die Untersuchung wird wiederum für zwei verschiedene Marktformen durchgeführt.

Ergänzt werden die theoretischen Untersuchungen um eine quantitative Analyse basierend auf Grenzvermeidungskostenkurven. Ein speziell dafür entwickelter Algorithmus ermöglicht die Bestimmung von stabilen Marktsituationen, bei denen für alle am Markt teilnehmenden Nicht-Annex-I-Ländern die Erfüllung des no-lose-Ziels einen positiven Gewinn ergibt und gleichzeitig ein möglichst hoher Beitrag von Nicht-Annex-I-Ländern zu globalen Emissionsminderungen erzielt wird. Die quantitative Untersuchung beschränkt sich auf den Wettbewerbsfall.

Die Analysen zeigen, dass no-lose-Ziele einen substantiellen Beitrag von Nicht-Annex-I-Ländern zu globalen Emissionsminderungen insbesondere bei einem hohen Emissionsminderungspotential ermöglichen. Das Vorliegen von Marktmacht steigert diesen Beitrag sogar noch. Allerdings sind große Zertifikattransfers über den Emisssionshandelsmarkt notwendig, um eine Profitabilität der Ziele zu erreichen.

Die Arbeit wurde von Herrn Prof. Dr. K.-M. Ehrhart am Institut für Wirtschaftstheorie und Statistik betreut. Sie ist in englischer Sprache verfasst.

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# List of Abbreviations and Variables

## Abbreviations

| | |
|---|---|
| AAU | Assigned Amount Unit |
| AI | Annex I |
| BIC | Brazil, India, China |
| CAIT | Climate Analysis Indicators Tool |
| CDM | Clean Development Mechanism |
| $CO_2$ | Carbon Dioxid |
| $CO_2e$ | Carbon Dioxid Equivalents |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| Gt | Gigatons |
| Mt | Million tons |
| NAMAs | Nationally Appropriate Mitigation Actions |
| IEA | International Energy Agency |
| IETM | International Emissions Trading Market |
| IPCC | Intergovernmental Panel on Climate Change |
| JI | Joint Implementation |
| LULUCF | Land-Use, Land-Use Change and Forestry |
| NAI | Non-Annex I |
| OM | Offsetting Market |
| POLES | Prospective Outlook on Long-term Energy Systems |
| R&D | Research and Development |
| REDD | Reducing Emissions from Deforestation and Forest Degradation |
| UNFCCC | United Nations Convention on Climate Change |

**Countries**

| | |
|---|---|
| ARG | Argentina |
| BRA | Brazil |
| CHN | China |
| EGY | Egypt |
| IDN | Indonesia |
| IND | India |
| IRN | Iran |
| KAZ | Kazakhstan |
| KOR | Republic of Korea |
| MEX | Mexico |
| MYS | Malaysia |
| NGA | Nigeria |
| PAK | Pakistan |
| SAU | Saudi Arabia |
| THA | Thailand |
| TWN | Taiwan |
| USA | United States of America |
| VNM | Vietnam |
| ZAF | South Africa |

**Variables**

| | |
|---|---|
| $\alpha$ | Annex I community's and non-Annex I country's relative reduction potential |
| $\alpha_A$ | slope of the Annex I community's marginal aggregated abatement costs |
| $\alpha_N$, $\alpha_{N1}$, $\alpha_{N2}$ | slope of the non-Annex I country's marginal abatement costs |
| $\Pi_i$ | non-Annex I country $i$'s payoff |
| $\Pi_N^C$ | non-Annex I country's optimal payoff for one participating non-Annex I country in a competitive market |
| $\widetilde{\Pi}_N^C$ | non-Annex I country's optimal payoff for two participating non-Annex I countries in a competitive market |
| $\Pi_N^P$ | non-Annex I country's optimal payoff for one participating non-Annex I country in case of market power |
| $\widetilde{\Pi}_N^P$ | non-Annex I country's optimal payoff for two participating non-Annex I countries in case of market power |
| $C_A$ | Annex I community's aggregated abatement costs |
| $C_N$, $C_{N1}$, $C_{N2}$ | non-Annex I country's abatement costs |
| $DQ_i$ | Annex I country $i$'s domestic quota |
| $EC_{j,i}$ | emission certificates sold from Annex I country $j$ to Annex I country $i$ |
| $h(r_N)$, $h(r_{N1}, r_{N2})$ | Annex I's reaction to the non-Annex I country's emission reductions for one participating non-Annex I country |
| $\widetilde{h}(r_{N1}, r_{N2})$ | Annex I's reaction to the non-Annex I countries' emission reductions for two participating non-Annex I countries |
| $MC_A$ | Annex I community's marginal aggregated abatement costs |
| $MC_N$, $MC_{N1}$, $MC_{N2}$ | non-Annex I country's marginal abatement costs |
| NAI_NLT | non-Annex I countries facing no-lose targets |
| NAI_REST | non-Annex I countries not facing any emission reduction targets |
| $OL_i$ | Annex I country $i$'s offsetting limit |
| $p$ | market price for emission certificates |
| $p^0$ | market price for emission certificates without non-Annex I country participation for a competitive market |
| $p^C$ | equilibrium market price for emission certificates for one participating non-Annex I country in a competitive market |

| | |
|---|---|
| $\widetilde{p}^C$ | equilibrium market price for emission certificates for two participating non-Annex I countries in a competitive market |
| $p^P$ | equilibrium market price for emission certificates for one participating non-Annex I country in case of market power |
| $\widetilde{p}^P$ | equilibrium market price for emission certificates for two participating non-Annex I countries in case of market power |
| $p^{PC}$ | market price for emission certificates for a global reduction target $T^P$ for one participating non-Annex I country in a competitive market |
| $q^C$ | equilibrium market price for offsetting credits in a competitive market |
| $r_A$ | Annex I community's joint emission reductions below baseline |
| $r_A^0$ | Annex I community's joint emission reductions below baseline without non-Annex I country participation for a competitive market |
| $r_A^*$ | Annex I community's joint optimal emission reductions below baseline |
| $r_A^C$ | Annex I community's joint optimal emission reductions for one participating non-Annex I country in a competitive market |
| $\widetilde{r}_A^C$ | Annex I community's joint optimal emission reductions for two participating non-Annex I countries in a competitive market |
| $r_A^P$ | Annex I community's joint optimal emission reductions for one participating non-Annex I country in case of market power |
| $\widetilde{r}_A^P$ | Annex I community's joint optimal emission reductions for two participating non-Annex I countries in case of market power |
| $r_N$, $r_{N1}$, $r_{N2}$ | non-Annex I country's emission reductions below baseline |
| $r_N^*, r_{N1}^*, r_{N2}^*$ | non-Annex I country's optimal emission reductions below baseline |
| $r_N^C$, $r_i^C$ | non-Annex I country's optimal emission reductions below baseline for one participating non-Annex I country in a competitive market |

| | |
|---|---|
| $\widetilde{r}^C_{N1}$, $\widetilde{r}^C_{N2}$ | non-Annex I country's optimal emission reductions below baseline for two participating non-Annex I countries in a competitive market |
| $r^P_N$,$r^P_i$ | non-Annex I country's optimal emission reductions below baseline for one participating non-Annex I country in case of market power |
| $\widetilde{r}^P_{N1}$, $\widetilde{r}^P_{N2}$ | non-Annex I country's optimal emission reductions below baseline for two participating non-Annex I countries in case of market power |
| $T$ | global emission reduction target for one participating non-Annex I country |
| $\bar{T}$ | exogenous global emission reduction target for one participating non-Annex I country |
| $\widetilde{T}$ | global emission reduction target for two participating non-Annex I countries |
| $T^C$ | global emission reduction target applying the optimal no-lose target for one participating non-Annex I country in a competitive market |
| $\widetilde{T}^C$ | global emission reduction target applying the optimal no-lose target for two participating non-Annex I countries in a competitive market |
| $T^P$ | global emission reduction target applying the optimal no-lose target for one participating non-Annex I country in case of market power |
| $\widetilde{T}^P$ | global emission reduction target applying the optimal no-lose target for two participating non-Annex I countries in case of market power |
| $T_A$ | Annex I community's aggregated emission reduction target |
| $T^C_A$ | endogenous Annex I community's aggregated emission reduction target for one participating non-Annex I country in a competitive market |
| $T^P_A$ | endogenous Annex I community's aggregated emission reduction target for one participating non-Annex I country in case of market power |
| $\bar{T}_A$ | exogenous Annex I community's aggregated emission reduction target |

| | |
|---|---|
| $T_N$, $T_{N1}$, $T_{N2}$ | non-Annex I country's no-lose target |
| $T_N^C$ | non-Annex I country's optimal no-lose target for one participating non-Annex I country in a competitive market |
| $\widetilde{T}_N^C$ | non-Annex I country's optimal no-lose target for two participating non-Annex I countries in a competitive market |
| $T_N^P$ | non-Annex I country's optimal no-lose target for one participating non-Annex I country in case of market power |
| $\widetilde{T}_N^P$ | non-Annex I country's optimal no-lose target for two participating non-Annex I countries in case of market power |
| $TC$ | global total (compliance) costs |
| $TC^0$ | global total (compliance) costs without non-Annex I country participation for a competitive market |
| $TC^{PC}$ | global total (compliance) costs for a global reduction target $T^P$ for one participating non-Annex I country in a competitive market |
| $TC_A$ | Annex I community's aggregated total (compliance) costs |
| $TC_A^0$ | Annex I community's aggregated total (compliance) costs without non-Annex I country participation for a competitive market |
| $TC_A^C$ | Annex I community's aggregated total (compliance) costs for one participating non-Annex I country in a competitive market |
| $TC_A^P$ | Annex I community's aggregated total (compliance) costs for one participating non-Annex I country in case of market power |
| $TC_N$ | non-Annex I country's total (compliance) costs |
| $TC_i$ | country $i$'s total (compliance) costs |

# 1 Introduction

## 1.1 Background

In recent years, climate change has emerged as an important issue, not only in science, but also in politics. Following the European Council and the G8, recent international climate summits in Copenhagen and Cancun have recognized the goal to keep mean temperature increase below 2°C above preindustrial levels (United Nations, 2009, 2010). The international community thereby followed the recommendations of the Intergovernmental Panel on Climate Change (IPCC), which warns that mean temperature changes of more than 2°C "would result in an increasing number of key impacts [...] such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland and West Antarctic" (Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007). According to science, substantial reductions in global greenhouse gas (GHG) emissions of at least 50% below 1990 levels by the middle of the century are necessary to stabilize the concentration of GHGs in the atmosphere at a level compatible with reaching a 2°C target (Rogelj et al., 2010, 2011).[1]

The framework of the Kyoto Protocol foresees emission reduction targets for Annex I countries[2] only (UNFCCC, 1997). In order to achieve cost efficiency, the Kyoto Protocol provides the Annex I countries with three flexible mechanisms that are supposed to help lower the costs for reaching the emission

[1]In order to limit mean temperature increase to 2°C above the pre-industrial level, the concentration of GHGs in the atmosphere needs to be stabilized at around 450ppm $CO_2$e. According to science, that can be achieved if global emissions peak by 2015 and decline thereafter. By 2050 global $CO_2$ emissions need to be 50% to 85% below 2000 levels (Metz, Davidson, Bosch, Dave, & Meyer, 2007).

[2]Annex I countries are all countries listed in Annex I of the UN Framework Convention on Climate Change – mainly industrialized countries and countries in transition. A list of the Annex I countries and their GHG emissions can be found in Appendix A of this thesis.

reduction targets: an international emissions trading market allows Annex I countries to trade emission certificates called Assigned Amount Units (AAUs). Hence, emission reductions should occur in those Annex I countries where emission reductions are least expensive. In addition, the Joint Implementation (JI) allows one Annex I country to finance abatement measures in another Annex I country. As compensation, the financing Annex I country receives AAUs from the Annex I country where the emission reductions occur.

Non-Annex I countries are integrated in the Kyoto Protocol via the third flexible mechanism, the Clean Development Mechanism (CDM). It allows Annex I countries to fulfill part of their emission reductions by financing emission reductions in non-Annex I countries. Own contributions of non-Annex I countries towards reaching the global reduction target do not exist in the Kyoto framework.

Current and projected GHG emissions show, however, that non-Annex I countries, which currently (2010) have a share of 60% in world-wide $CO_2$ emissions (Boden & Blasing, 2011), are becoming increasingly important in reaching global emission reduction targets. Also, the growing importance of non-Annex I countries, in particular emerging economies like China and India, in world trade and in the world financial markets tend to make Annex I countries reluctant to commit to own emission reduction targets. They fear they will become less competitive as long as non-Annex I countries do not agree to similar efforts (T. Stern, 2011).

Emission reduction efforts under the first commitment period of the Kyoto Protocol end in 2012. Recent international negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, Cancun and Durban on finding a follow-up agreement to the Kyoto Protocol showed once more how difficult it is for countries to agree on ambitious national emission reduction targets in the context of an international agreement. One fundamental issue that makes finding an international agreement so difficult is the absence of a supranational institution which could enforce cooperation (Finus, 2002). Instead, an agreement of this kind would have to be self-enforcing. Under self-enforcing conditions, however, agreements that achieve substantial emission reductions over and above the non-cooperative level and that include a large number of countries do not exist as several theoretical studies show (Barrett, 2003; Carraro & Siniscalco, 1993).

Another obstacle to finding an international agreement is that substantial differences exist between nations, a fact that is neglected in many of the theoretical studies. Emerging developing countries fear that binding emission targets will inhibit future economic growth, implying that per capita income will continue to stay substantially below the level observed in industrialized countries. The most common arguments made by non-Annex I countries against own contributions to emission reductions are that binding targets might constrain economic growth and that the larger share of historical emissions stem from today's industrialized nations. Thus, they consider combating climate change predominantly as the responsibility of the industrialized nations (Spence, 2009). Consequently, acknowledging the differences between industrialized and developing nations, the UNFCCC emphasizes the principle of "common but differentiated responsibility" (United Nations, 1992).

Hence, new instruments need to be found to extend the number of countries contributing to global emission reductions beyond the Annex I community. Scientific literature on this topic has emerged over the last decade, which is concerned with the theoretical and - more recently also quantitative - analysis of possible design elements of an international agreement scheme including both Annex I and non-Annex I countries (Carraro & Siniscalco, 1998; Carraro, Eyckmans, & Finus, 2006; Aldey, Barrett, & Stavins, 2003; Aldey & Stavins, 2007; Bosetti & Frankel, 2009; Frankel, 2009). A number of new instruments have been proposed with a special focus on integrating non-Annex I countries and resulting in non-Annex I countries' contributing to global emission reductions. Sector-based approaches propose reduction targets for single sectors, instead of covering the whole economy of a country right from the beginning (Bosi & Ellis, 2005; J. Schmidt, Helme, Lee, & Houdashelt, 2008; Ward et al., 2008; Schneider & Cames, 2009). Concentrating on single sectors might make reduction targets more acceptable (Philibert & Pershing, 2001; J. Schmidt et al., 2008). Relative or intensity-based targets try to overcome the fear of non-Annex I countries that accepting emission reduction targets might constrain economic growth. They do not apply a fixed emission target, but define emission targets based on output levels like production or gross domestic product (GDP) (Ellerman & Wing, 2003; Pizer, 2005; Quirion, 2005). Similarly, "no-lose'" targets try to overcome that fear by refraining from penalties in the case that a target is not met and creating incentives instead (Bodansky, 2003; Philibert, 2000; J. Schmidt et al., 2008). A more direct way to encourage participation of non-Annex I countries in emission reduction efforts are transfer payments, as discussed by Hoel and Schneider (1997), Altamirano-Carbrera and Finus (2006) and Carraro et al. (2006). Issue-linkages between GHG reduction measures and other international topics like technology and R&D cooperation is another approach, also using incentives for non-Annex I countries to participate in emission reduction efforts by offering enhanced co-operation between industrialized and developing countries (Martinot, Sinton, & Haddad, 1997; Barrett, 2002; Viguier, 2004). Instead of defining reduction targets some argue that agreeing to implement certain policies and measures is a better way to include non-Annex I countries (Philibert & Pershing, 2001; Baumert & Winkler, 2005).

In contrast to the binding reduction targets applied under the Kyoto Protocol, some of these newly proposed instruments create incentives for non-Annex I countries to contribute to global emission reductions (Kuik et al., 2008). They thus try to overcome the problem that participation by non-Annex I countries is voluntary in nature. One of these instruments are no-lose targets.

## 1.2 No-lose targets

No-lose targets have been proposed as a possible measure to overcome the dichotomy of Annex I and non-Annex I countries, while at the same time safeguarding non-Annex I countries from emission targets that may inhibit economic development (Philibert, 2000; Philibert & Pershing, 2001). Simultaneously with setting a reduction target, no-lose targets provide incentives for the non-Annex I country to meet the target. In contrast to binding targets, no-lose targets do not use penalties as a threat in case a target is not met. Hence, they offer a safety valve against high costs.

The incentives can take on various forms. J. Schmidt et al. (2008) propose assistance to reach the target through a “Technology Finance and Assistance Package” including assistance in the deployment of advanced technologies, capacity-building activities and financing of pilot and demonstration projects. Help would mainly be provided by financing mechanisms such as soft loans, direct grants and other special lending provisions. The idea is to help cover the incremental costs of applying advanced low-emission technologies instead of conventional technologies.

The analyses in this thesis focus on the idea of an "emission budget" as introduced and discussed by Philibert (2000) and Philibert and Pershing (2001)[3]. The basic idea is to use participation in the international emissions trading market as an incentive for countries to fulfill their no-lose targets. In detail, the emission budget works as follows: a non-Annex I country agrees on a particular emission target. If its actual emissions are above the agreed emission target (e.g. because of strong economic growth or because demand for emission certificates is low relative to supply), it is neither punished nor is it allowed to enter the international emissions trading market. If its actual emissions are below the agreed emission target, however, the non-Annex I country is allowed to enter the emissions trading market as a seller of emission certificates. The number of certificates it can trade if the non-Annex I country manages to over-achieve its reduction target is defined by the difference between its actual emissions and its emission target. These revenues can compensate the non-Annex I country for associated abatement costs.

For a financial net benefit ("profitable no-lose target") the revenues from selling emission certificates need to over-compensate a country's abatement costs. Two effects determine the net benefit. On the one hand, there are the costs incurred for meeting the no-lose target level. A lenient (stringent) no-lose target means low (high) abatement costs and, hence, increases (decreases) the probability that the target is profitable and that the country will decide to participate in the emissions trading market (*cost effect*). On the other hand, there is the revenue from selling emission certificates which is determined by the supply of excess emission certificates and the market price for certificates (*revenue effect*). While lenient targets increase the supply of emission certificates, they lower the market price. Hence, the direction of the revenue effect is ambiguous. For only one non-Annex I country facing a no-lose target, it can determine the market price for certificates and hence decide to participate or not. The revenue effect is of particular interest if more than just one non-Annex I country faces a no-lose target. In that case, a lenient no-lose target of a competing non-Annex I country, while not affecting their own abatement costs, lowers the price as well as the number of certificates to sell for other non-Annex I countries. Hence, in that case the lenient no-lose target of the

[3] Bosi and Ellis (2005), Amatayakul, Berndes, and Fenhann (2008), J. Schmidt et al. (2008), Ward et al. (2008), Schneider and Cames (2009) and Hofmann (2010) discuss a similar approach, which is however limited to certain sectors of the economy.

competing non-Annex I country clearly has a negative effect on the profitability of the other non-Annex I countries' no-lose targets. That is, the market price which affects the revenues links a country's participation decision to the no-lose target and the participation decision of other countries facing no-lose targets.

Two characteristics arise that determine the difference between binding and no-lose targets. First, the decision to accept a no-lose target and the decision to comply with the target are not directly linked. Hence, applying a no-lose target does not guarantee that a given global emission target will be met. Instead, a non-Annex I country will contribute towards reaching the global emission target if it decides to fulfill its no-lose target. Therefore, setting the target level for no-lose targets is crucial. Second, the role of the non-Annex I country facing a no-lose target in the international emissions trading market is determined beforehand. It can only participate in the emissions trading market if it over-achieves its no-lose target. Hence, the non-Annex I country is always a seller of emission certificates.

Analyses of no-lose targets in the literature are limited and can be differentiated into conceptual work and quantitative analyses. Conceptual work by Philibert (2000) introduces the idea of a no-lose target and discusses aspects of integrating no-lose targets in the UNFCCC framework. Among others, the study investigates the practical realization of combining binding and no-lose targets in a single emissions trading market. He finds that, as long as at least one entity facing a binding target is part of the system to act as potential buyer of emission certificates, an integration in a joint market is possible. He further states that no-lose targets have the advantage of easing the target negotiations and preventing the emergence of "tropical hot air"[4].

A central problem discussed by Philibert is how to ensure that only excess certificates are traded to protect the environmental integrity of the trading system. He identifies three options to solve this problem: (i) a no-lose target is treated as a binding target (and ensuing compliance and penalty provisions) once a country starts to trade certificates in the market; (ii) a country can only trade certificates once they are verified, i.e. a country would have to wait

[4]"Hot air" refers to a situation in which the emission target is above the baseline emissions, i.e. excess emission certificates exist without abatement options. This was the case for example for Russia and other states from the former Soviet Union under the first commitment period of the Kyoto Protocol. "Tropical hot air" refers to "hot air" from non-Annex I countries.

until the next period to be able to sell its emission certificates in the market; or (iii) a country would have to buy back the amount of certificates sold up to the no-lose target should the target turn out to be missed ex-post. A fourth option proposed by Philibert is to introduce a dual target instead of a no-lose target, i.e. the target consists of a lower target which, if fulfilled, allows selling of emission certificates (selling target). A second, higher target (buying target) would, if missed, require countries to buy emission certificates up to that target.

Philibert and Pershing (2001) compare non-binding targets with four other instruments proposed to integrate non-Annex I countries in emission reduction efforts. These instruments are binding targets, intensity targets, sectoral targets and policies and measures. They find that, while no-lose targets provide a low certainty of emission reductions, they might be useful to deal with problems of carbon leakage[5] or growth rebound effects. They identify the fact that the danger of constraining economic growth is low as another advantage. For similar reasons, Bodansky (2003) terms no-lose targets a "useful transitional device" while acknowledging that non-Annex I countries will have to commit to binding reduction targets in the long run. He further proposes to combine no-lose targets with other instruments, like intensity targets.

Hofmann (2010) discusses main issues that would arise from implementing sectoral no-lose targets. These are the definition of an emissions baseline, determining an adequate no-lose target and ensuring the environmental integrity by measurement, reporting and verification of emissions. She also tackles questions on the legal and regulatory framework and concludes that a no-lose target framework could build on the existing Kyoto framework.

Quantitative analyses of no-lose targets mostly relate to sectors rather than countries. J. Schmidt et al. (2008) analyze sectoral no-lose targets for the cement, iron and steel and electricity sector. The study applies financing mechanisms while certificate trading by the non-Annex I countries is not considered.

Amatayakul et al. (2008) propose a method for setting the baseline and the target level and estimate the potential for emission reductions applying no-lose targets in the electricity sector for seven large developing countries. Their approach builds on the existing methods for calculating the baseline of

[5]Carbon leakage refers to the effect that GHG emissions in one country increase as a result of emission reductions in another country due to stricter climate policies. For a discussion of carbon leakage, see e.g. Babiker (2004).

a CDM project. They estimate a no-lose reduction target of about 10% below baseline for the electricity sector.

den Elzen, Hoehne, and Moltmann (2010) allow developing countries to participate, among others, in international emissions trading via national no-lose targets prior to accepting an agreement involving binding reduction targets. The no-lose character of the targets is, however, not taken into account in the modeling exercise.

Finally, R. C. Schmidt and Marschinski (2010) explore the potential of a binding national target for China, to result in positive revenues from participation in emissions trading with the USA and the EU. The analyses show that a reduction target of up to 1.5Gt $CO_2$e can be optimal in the case of a link to the EU ETS alone. Widening the emissions trading market to include the USA and an offsetting market, however, results in optimal reduction targets which are higher than China's baseline emissions. Hence, these reduction targets would lead to "hot air" rather than to own contributions from China to global emission reductions.

Economic analyses of no-lose targets based on theoretical frameworks do not exist so far. Hence, the question arises, whether no-lose targets are a suitable economic instrument to integrate non-Annex I countries in global emission reduction efforts. The environmental effectiveness and the economic impacts on the emissions trading market are of particular interest.

## 1.3 Objective and approach

The main objective of this thesis is to determine whether no-lose targets are a suitable instrument to integrate non-Annex I countries in global emission reduction efforts and to explore their economic impacts on the emissions trading market. The analyses focus on no-lose targets using participation in an emissions trading market as incentive system for non-Annex I countries. The main assumption for the following analyses is that a non-Annex I country will decide to fulfill its target and participate in the emissions trading market only if fulfilling the target is profitable. Hence, revenues from selling emission certificates need to be higher than the country's abatement costs.

The analyses focus on applying theoretical economic frameworks to fill the gap that exists in understanding the economic effects of no-lose targets and the impacts on the emissions trading market, in contrast to binding reduction targets. These analyses will help to deepen the economic understanding of on-lose targets and will hence complement the existing conceptual and quantitative work. As the theoretical frameworks present highly stylized models, the analyses will be complemented by analyses with a global partial equilibrium model.

In particular, the analyses focus on three main aspects of no-lose targets. First, they attempt to quantify the contribution of no-lose targets to global emission reduction efforts. In that context, the analyses also consider the effects that the integration of no-lose targets in an international emissions trading market has on the Annex I community's emission reductions and market prices.

Given the fact that non-Annex I countries facing no-lose targets compete as sellers of emission certificates in the market, a second aspect analyzed in more detail in this thesis are the effects that the integration of more than one non-Annex I country applying no-lose targets has. The competition as sellers in the emissions trading market affects the level of the no-lose targets as well as the global emission reduction target. The interaction of non-Annex I countries introduces a game-theoretical aspect into the analysis. Understanding the interaction of non-Annex I countries facing no-lose targets is of particular interest, if no-lose targets are introduced as an instrument in international climate agreements, as this would imply that the instrument is applied for more than just one non-Annex I country.

The third aspect that is of particular interest for this thesis is the market power aspect in the emissions trading market and its effects on no-lose targets. While a competitive market can be assumed for small non-Annex I countries, the countries' GHG emissions vary widely in size. Two large non-Annex I countries in particular, China and India, who are often discussed as potential participants in an international agreement on climate change. They have shares of 25% and 6% respectively in global $CO_2$ emissions in 2010 (Boden & Blasing, 2011) which can be assumed to further increase in the future (International Energy Agency, 2007, 2010). At the same time, China in particular is predicted to have large emission reduction potentials (McKinsey & Company, 2009; Hoehne et al., 2008). It seems reasonable to assume that those countries can act strategically, if integrated in the international emissions trading market. The analyses focus on the effects that market power on the part of a non-Annex I country has in contrast to a competitive market if applying no-lose targets.

This thesis is organized in three main sections. Chapter 2 focuses on quantifying the potential of no-lose targets to contribute to global emission reductions. A two-player, two-stage model is introduced to analyze the decision of one non-Annex I country facing a no-lose target to participate in an international emissions trading market with the Annex I community. The model allows analyses of the non-Annex I country's contribution towards meeting a global reduction target and the effects that the participation of a non-Annex I country has on the Annex I community. Two different paradigms to define emission reduction targets, the bottom-up and the top-down approach, are considered and the model is constructed assuming a perfectly competitive market for emission certificates, as well as an emissions trading market with market power on the part of the non-Annex I country.

In chapter 3, the situation of two non-Annex I countries facing a no-lose target is modeled in a two-player participation game. The interaction with the Annex I community in an international emissions trading market allows us to determine the payoffs of the non-Annex I countries. An analysis of the Nash equilibria of the participation game allows conclusions to be drawn on the effects that the competition of the non-Annex I countries as sellers of emission certificates has on their participation decision. It also allows conclusions regarding the effects of increased participation on global emission reductions. Again, the analysis presents findings for a competitive market as well as for the case of market power, but is restricted to symmetric non-Annex I countries. Hence, the two non-Annex I countries have similar marginal abatement cost curves and face similar no-lose target levels.

A quantitative analysis of no-lose targets is provided in chapter 4. In this chapter the analyses move away from the highly stylized theoretical frameworks used for the analyses in chapters 2 and 3. It presents estimates of the amount of emission reductions that can be generated by applying no-lose targets to the 18 largest non-Annex I countries. Based on marginal abatement cost curves from a global partial equilibrium model and starting with the burden-sharing proposal by the IPCC, contributions from non-Annex I countries to global emission reductions necessary to reach the 2°C target are quantified.

The thesis concludes with a critical reflection on the methodological approaches and the obtained results and an outlook to future research.

# 2 No-lose targets and the participation decision[6]

## 2.1 Introduction

The analyses in this chapter focus on the potential of no-lose targets to act as a suitable instrument to integrate a non-Annex I country in an international agreement on climate change. Suitable means that, on the one hand, it is an instrument that provides an incentive for the non-Annex I country to participate in emission reduction efforts. On the other hand, it is meant to lead to real emission reductions on the part of the non-Annex I countries. Hence, a main goal is to quantify the contribution of no-lose targets to global emission reduction efforts. In addition, the impact of the no-lose target on the emissions trading market will also be analyzed.

The analyses will be based on the simplest constellation of one non-Annex I country facing a no-lose target and interacting with the Annex I community in a joint emissions trading market. Hence, the analyses focus on the definition of an incentive-compatible no-lose target while effects from interaction of more than just one country facing a no-lose target are neglected. This aspect will be introduced to the model and analyzed in a later chapter. The situation of modeling only one non-Annex I country can also be interpreted as modeling the potential of all non-Annex I countries as a group neglecting the differences between the countries that might hinder exploiting the full emission reduction potential from no-lose targets.

A two-player two-stage model will be introduced to model the participation decision of the non-Annex I country facing a no-lose target. In the first stage

[6]This is a preprint of an article submitted for consideration in the Journal of Environmental Economics and Management

of the model, the non-Annex I country decides if it wants to fulfill its no-lose reduction target. If deciding to fulfill its target the non-Annex I country will participate in the emissions trading market with the Annex I community in the second stage. This framework will be used to derive participation conditions for the non-Annex I country based on the assumption that the non-Annex I country will only participate if the no-lose target is profitable. Further taking into account that if a lenient no-lose target is applied, the contribution of the non-Annex I country to global emission reductions is small and the large supply of cheap emission certificates in the emissions trading market may hinder real emission reductions in other parts of the world we propose the definition of an “optimal no-lose target”.

The analyses consider two different paradigms for defining emission reduction targets: the bottom-up and the top-down approach (Criqui et al., 2003). In the bottom-up approach the individual targets are set in the first step, which together add up to the global reduction target. An example are the recent negotiations on a Post-Kyoto agreement on climate change in Copenhagen and Cancun where Annex I as well as non-Annex I countries pledged reduction targets or nationally appropriate mitigation actions (NAMAs). In the top-down approach, first a global reduction target is defined, which is then split-up by an effort-sharing rule. Examples of the top-down approach are the reduction target under the Kyoto Protocol or the effort-sharing of the EU target.

The main difference between the two approaches is which targets are exogenous and which are endogenous. In the bottom-up approach the individual Annex I countries’ targets are assumed to be exogenously given and the no-lose targets are derived endogenously. Thus, the global target is endogenously defined too. In the top-down approach, the global reduction target is set exogenously while the distribution of the global target is derived endogenously. Since the two approaches have different implications for setting the no-lose target, they are analyzed separately.

In addition, two market forms will be considered. First, the market for emission certificates is assumed to be perfectly competitive and the countries act as price takers. In addition, to better model the situation of large developing countries like China and India we will also consider the case of a strategically acting non-Annex I country.

The remainder of this chapter is organized as follows: In Section 2.2, a basic two-player game of emissions trading is adapted to allow modeling of no-lose targets and participation conditions for the competitive market as well as for a non-Annex I country with market power are derived. The definition of the optimal no-lose target and its characteristics follows in Section 2.3. Results for the bottom-up and the top-down approach are presented in Section 2.4 and Section 2.5. To highlight the most important findings and their relevance in the present political situation a small case study is presented in Section 2.7. Section 2.8 concludes.

## 2.2 Theoretical modeling of no-lose targets

### 2.2.1 The basic model

Our model involves two players: first, the community of Annex I countries, and, second, a non-Annex I country. The parameters and variables of the Annex I community are labeled by index $A$, those of the non-Annex I country by $N$.

Each country of the Annex I community is obliged to reach a national reduction target (with respect to baseline emissions) and is allowed to bargain emission certificates on the international emissions trading market.[7] The national reduction targets add up to the joint target $T_A$[8] of the Annex I community, whose joint emission reductions below their baseline emissions are denoted by $r_A$[9]. The marginal (aggregated) abatement costs of the Annex I community are assumed to be linearly increasing with slope $\alpha_A > 0$[10], i.e. $MC_A(r_A) = \alpha_A r_A$. Hence, the (aggregated) abatement costs of the Annex I community (neglecting fixed costs) are of the form[11] $C_A(r_A) = \frac{\alpha_A}{2} r_A^2$.

In the case that the non-Annex I country does not participate, the Annex I community has to achieve its target $T_A$ entirely by own emission reductions, i.e. $r_A^0 = T_A$. We assume that the Annex I countries act as price takers on the

[7] This describes – in simple terms and excluding the CDM – the situation of the Kyoto Protocol where all countries facing targets are allowed to participate in a common emissions trading market.

[8] given in absolute terms below baseline, i.e. in Mt $CO_2$e

[9] given in absolute terms below baseline, i.e. in Mt $CO_2$e

[10] The abatement cost curves concentrate on net investment, operating and maintenance costs. They do not consider positive effects like energy savings or other positive benefits. Hence, it is assumed that abatement costs are always positive. For further discussions on no-regret options see e.g. Bréchet and Jouvet (2009) or Kesicki and Strachan (2011).

[11] Note that all results qualitatively hold even for weaker conditions for the abatement costs $MC > 0$ and $MC' \geq 0$ and also if fixed costs are taken into consideration.

international emissions trading market, which is thus assumed to be perfectly competitive if the non-Annex I country does not participate. In this case, the market price for emission certificates $p^0$ is equal to the marginal abatement costs at the target, i.e.

$$p^0 = MC_A(r_A^0) = \alpha_A T_A \,. \qquad (2.1)$$

For integrating the non-Annex country in an agreement on climate change with an own contribution to emission reductions a no-lose target $T_N \geq 0$ has to be fixed.[12] If the non-Annex country decides to accept the no-lose target and succeeds to reduce its emissions according to its target, it is allowed to interact with the Annex I community in a special type of restricted international emissions trading. More precisely, the following interactions are permitted: if the non-Annex I country's emissions[13] are below the predetermined target, i.e. $r_N > T_N$, the country is rewarded for the additional reductions by emission certificates that it may sell to the Annex I community. The Annex I community, on the other hand, can benefit from buying these certificates if the price is below its own marginal abatement costs. However, in contrast to conventional emissions trading games, the non-Annex I country is not permitted to buy certificates from the Annex I community.[14]

For the non-Annex I country we also assume linearly increasing marginal abatement costs with slope $\alpha_N > 0$, i.e. $MC_N(r_N) = \alpha_n r_N$ and $C_N(r_N) = \frac{\alpha_N}{2} r_N^2$.

In our analyses, we take into account that the Annex I community and the non-Annex I country dispose of different reduction potentials[15]. As a measure of the relative reduction potentials we propose the ratio $\alpha = \alpha_A/\alpha_N$. That is,

[12] For simplicity reasons, the no-lose target is assumed to be given as an absolute target in absolute emission reductions below baseline in Mt $CO_2$e and not a relative one based on efficiency or output. On the analysis of intensity targets see Ellerman and Wing (2003), Quirion (2005) or Marschniski and Edenhofer (2010).

[13] also given in absolute terms below baseline, i.e. in Mt $CO_2$e

[14] For simplicity, the option of buying offsets (e.g. CDM credits) from other countries outside the emissions trading market is not explicitly modeled here. However, including a limit on offsets which was binding due to price restrictions, would result in a lower Annex I community's target and thus lower the price for certificates. Qualitatively, the results would not be affected.

[15] The reduction potential follows the concept of "mitigation potential" as described in the IPCC 2007 assessment report (Metz et al., 2007). It defines mitigation potential as "the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price". In contrast, a technical definition of reduction potential does not take into account the costs but focuses on the amount of emission reductions.

the higher the potential of the non-Annex I country compared to the Annex I community is, the higher is the value of $\alpha$. From $\alpha_A > 0, \alpha_N > 0$ immediately follows $\alpha > 0$.

### 2.2.2 The participation decision of the non-Annex I country

A characteristic of a no-lose target is that the decision to accept a target is not directly linked to complying with the accepted target. In contrast, a country can tentatively accept a no-lose emission reduction target and then decide later whether to comply with the target or not, i.e. to try to reach the target or not. If it reaches the target, it is allowed to enter into a restricted emissions trading market with the Annex I community as described above.

We simplify the decision process of the non-Annex I country by assuming that it does not differentiate between the decision to accept the target and the decision to comply with the target. This simplification is based on the assumption that the non-Annex I country only accepts the target if complying with it is profitable. Accordingly, we introduce a two-stage decision model for the non-Annex I country, in which the two sequent decisions of accepting and complying are combined to the decision of accepting the target. That is, on the first stage, the non-Annex I country faces the two strategic options of accepting the no-lose target or not accepting it. Accepting the target automatically implies that the non-Annex I country complies with the target and, thus, enters second stage, where it reduces its emissions and is allowed to sell certificates to the Annex I community. Hence, on the second stage both players decide on the amount of emissions to reduce domestically and thus determine the number of certificates traded in the market.

The first stage of the non-Annex I country's two-stage decision process is described by two conditions, which take the no-lose characteristic of the reduction target into account. With the first condition

$$p(r_A^*, r_N^*)(r_N^* - T_N) - C_N(r_N^*) \geq 0, \tag{2.2}$$

the non-Annex I country checks whether the no-lose target $T_N$ is profitable or not. For this purpose, it compares the costs $C_N(r_N^*)$ of reducing its emissions by the optimal amount $r_N^*$, which is together with $r_A^*$ determined on the second stage in the emissions trading market, with the revenues from selling the emission certificates on the emissions market at market price $p(r_A^*, r_N^*)$.[16] The non-Annex I country will only accept the no-lose target if it suffers no financial loss from participating in the emissions trading market. We therefore call condition (2.2) the *participation constraint*. Since the non-Annex I country is only allowed to sell certificates on the market, condition

$$r_N^* - T_N \geq 0 \tag{2.3}$$

has to be fulfilled in any cases for the non-Annex I country to accept the target. For deriving more precise conditions for participation, we have to consider the decision problem on the second stage.

In the second stage, the countries interact in an emissions trading market and thereby decide on their emission reductions by minimizing their total costs from emissions reduction and trading for achieving their target, i.e.

$$TC_k = C_k(r_k) + p(r_A, r_N) \cdot (T_k - r_k) \rightarrow \min_{r_k} \tag{2.4}$$

for $k \in \{A, N\}$. The target function of the non-Annex I country $N$ is denoted as its *incentive compatibility condition*.

The optimization problem has to be amended by the market clearing conditions. If the non-Annex I country decides to accept the no-lose target and participate in the market, the market clearing condition

$$r_A + r_N = T_A + T_N \tag{2.5}$$

has to be fulfilled, i.e. total emission reductions of all market participants have to match the global reduction target. However, if the non-Annex I country does not accept the no-lose target on the first stage, $r_N = 0$ holds and (2.5) is replaced by

$$r_A = T_A. \tag{2.6}$$

[16]The environmental benefits resulting from global emission reductions are neglected in this model for the purpose of focusing on an economic analysis of no-lose targets and are therefore not included in the optimization problem. For estimations on damage/social costs see e.g. N. Stern (2007) or Tol (2009).

In this case the non-Annex I country does not reduce its emissions compared to baseline and, thus, does not sell certificates to the Annex I community.

The interaction of the cost-minimizing countries in the emissions trading market, according to (2.4), determine their individually optimal reductions $r_A^*$ and $r_N^*$ and the market price $p(r_A^*, r_N^*)$.

The two-stage decision process is solved by backwards induction. Anticipating the outcome of emissions trading on the second stage, the non-Annex I country decides on its behavior on the first stage, i.e. to accept the no-lose target if the total costs in the second stage are non-positive or reject it otherwise.[17]

In the remainder of this section, we solve the optimization problem of the non-Annex I country and derive the participation conditions under which this country has an incentive to accept the no-lose target $T_N$ and, thus, participate in the emissions trading market. In Section 2.2.3 we consider the case of a competitive emissions trading market, which represents the situation of a small non-Annex I country acting as a price taker on the emissions trading market. This applies for most non-Annex I countries, which have a rather low share of world GHG emissions. However, there is a small number of countries, including China and India, that account for a large share of the world-wide GHG emissions. We therefore assume that those countries may not simply act as price takers but may decide strategically on the international emissions trading market. Hence, in Section 2.2.4 we consider the case of a non-Annex I country with market power in the emissions trading market.

### 2.2.3 Participation conditions in a competitive market

In the competitive market framework, endogenously determined variables are labeled by $C$. In the competitive market all countries act as price takers. Therefore, the first order conditions of the minimization problem (2.4) yield a certificate market price equal to the marginal abatement costs,

$$p^C = MC_A(r_A^C) = \alpha_A r_A = MC_N(r_N^C) = \alpha_N r_N \,. \tag{2.7}$$

The combination of (2.7) and the market clearing condition (2.5) then determines the non-Annex I country's optimal amount of emission reductions in the

[17]This kind of anticipatory behavior of a country seems to be in line with what can be expected from a country within a negotiation process.

case of participation

$$r_N^C - T_N = \frac{\alpha_A T_A - \alpha_N T_N}{\alpha_A + \alpha_N} = \frac{\alpha T_A - T_N}{1+\alpha}\,. \tag{2.8}$$

This condition generally applies to competitive emissions trading markets. That is, the optimal emission reductions by the non-Annex I country depend on the ambition level of both targets as well as the slope of the marginal abatement cost curves, but are independent of the emission reductions realized by the Annex I community. Rearranging (2.8) to solve for $r_N^C$,

$$r_N^C = \frac{\alpha(T_A + T_N)}{1+\alpha} = \frac{\alpha T}{1+\alpha}\,, \tag{2.9}$$

confirms that the optimal amount of emission reductions in a competitive market is only depending on the total amount of emission reductions $T = T_A + T_N$, but not on the reduction targets of the countries (Hahn, 1984).

By deciding on accepting the no-lose target on the first stage of the game, the non-Annex I country takes the expected outcome of the second stage into account, i.e. the market price (2.7) and its optimal emissions (2.9) in case of accepting the no-lose target and participating in emissions trading.

We have to consider the fact that the non-Annex I country may only sell certificates on the emissions trading market. Combining (2.3) and (2.8) yields

$$\alpha_N T_N \leq \alpha_A T_A \tag{2.10}$$

as a necessary condition for participation. For the non-Annex I country to act as a seller, the marginal abatement costs at the target of the non-Annex I country need to be lower than of the Annex I community. That is, the Annex I community will only buy emission certificates if they are less expensive than emission reductions at home.

For deriving a more precise condition for participation, we apply (2.7) to the participation constraint (2.2), which leads to

$$r_N^C\left(\alpha_N(r_N - T_N) - \frac{\alpha_N}{2}r_N\right) \geq 0. \tag{2.11}$$

Since $r_N^C \geq 0$, the expression in brackets needs to be greater than zero, which together with (2.8) yields

$$\frac{T_N}{T_A} \leq \frac{\alpha_A}{\alpha_A + 2\alpha_N} = \frac{\alpha}{2 + \alpha} \tag{2.12}$$

as necessary and sufficient participation condition. According to this condition, the ratio of burden-sharing $T_N/T_A$ is restricted by an upper bound, which is determined by the slopes of the marginal abatement cost curves of the two countries. It is obvious that condition (2.12) is more restrictive than (2.10). That is, for the non-Annex I country to participate, its marginal abatement costs need be lower than the half of the Annex I community's marginal abatement costs at their respective targets. Moreover, since the term on the right-hand side of (2.12) is smaller than one, the absolute amount of the no-lose target $T_N$ has to be strictly smaller than the Annex I community's target $T_A$ and is independent of the values of $\alpha_A$ and $\alpha_N$. Thus, for the non-Annex I country to accept the no-lose target, this has to be less strict than the Annex I community's target.

Condition (2.12) allows us to calculate the ratio of burden sharing in dependence of the relative reduction potentials of the two countries. For comparability, we first consider the symmetric case $\alpha = 1$ ($\alpha_A = \alpha_N$). The right-hand side of (2.12) then becomes 1/3. That is, in order to induce the non-Annex I country to accept the no-lose target, it can carry not more than 25% of the total emission reduction burden and, thus, the Annex I community has to carry at least 75%, although both dispose of the same emission reduction potential. For the asymmetric cases, let us first consider the case of $\alpha < 1$ ($\alpha_A < \alpha_N$) in which the Annex I community has a higher emission reduction potential than the non-Annex I country. This can in particular be the case for small and least developed non-Annex I countries. Here, the steeper the marginal abatement cost curve of the non-Annex I country is (compared to this of the Annex I community), the smaller is its maximal share of emission reductions. In the other case of $\alpha > 1$ ($\alpha_A > \alpha_N$), the non-Annex I country is willing to carry more than 25% of the reduction burden without loosing the incentive to participate. This case applies to large non-Annex I countries which have already reached a certain economic development standard. In general, the maximum ratio of the targets $T_N/T_A$ for a non-Annex I country accepting the no-lose target and participating in emissions trading continuously increases in $\alpha$ with

$$\frac{T_N}{T_A} \leq \begin{cases} 1 & \text{for } \alpha \to \infty \\ \frac{1}{3} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} . \tag{2.13}$$

### 2.2.4 Participation conditions in the case of market power

Instead of a competitive emissions trading market, we now assume that the non-Annex I country disposes of market power. Endogenously determined variables are labeled by $P$.

As discussed before, this constellation is considered to be relevant for large developing countries like China or India, which produce a large share of worldwide GHG emissions. Both countries are feasible candidates for an inclusion in an international agreement on climate change due to the size of their emissions and the state of their economic development.

The non-Annex I country with market power takes the Annex I community's price-taking behavior into account when deciding on its emission reductions $r_N$ and thus the number of certificates to be sold. The Annex I community's "reaction" to $r_N$ is described by the functional relation $r_A = h(r_N)$ with

$$h(r_N) = T_A - (r_N - T_N) = T - r_N \,. \tag{2.14}$$

The solution of the non-Annex I country's minimization problem (2.4) then leads to

$$p^P = MC_A(r_A^P) = \alpha_A r_A^P > MC_N(r_N^P) = \alpha_N r_N^P \tag{2.15}$$

as condition for the market price $p^P$ and results in the non-Annex I country's optimal emission reductions

$$r_N^P - T_N = \frac{\alpha_A T_A - \alpha_N T_N}{2\alpha_A + \alpha_N} = \frac{\alpha T_A - T_N}{1 + 2\alpha} \tag{2.16}$$

and

$$r_N^P = \frac{\alpha(T_A + 2T_N)}{1 + 2a} = \frac{\alpha(T + T_N)}{1 + 2a} \,. \tag{2.17}$$

Note that other than in the case of a competitive market (2.9), where the emissions reductions $r_N^C$ only depend on the global target $T$, in the case ofmarket power, the no-lose target has an additional impact on non-Annex I's emissions reductions (Hahn, 1984).

By considering the first stage of the decision process, let us first apply the optimal emissions in the case of market power (2.16) to condition (2.3). As in the case of a competitive market, this also yields condition (2.10) as a necessary condition for the non-Annex I country to participate in the emissions trading market. That is, for the non-Annex I country to be able to sell emission certificates to the Annex I community, its marginal abatement costs at the no-lose reduction target $T_N$ need to be lower than the Annex I community's abatement costs at the reduction target $T_A$.

Applying condition (2.16) to condition (2.2) yields

$$\frac{T_N}{T_A} \leq \sqrt{\frac{1}{4} + \frac{\alpha_A^2 + \frac{1}{2}\alpha_A\alpha_N}{\alpha_N^2 + 2\alpha_A\alpha_N}} - \frac{1}{2} = \frac{\sqrt{1+2\alpha} - 1}{2} \tag{2.18}$$

as a necessary and sufficient participation condition for the non-Annex I country under a no-lose target in the case of market power. As before, the condition only includes the slopes of the marginal abatement cost curves of the two countries.

Obviously, condition (2.18) differs from the corresponding competitive market condition (2.12). In the symmetric case $\alpha = 1$ ($\alpha_A = \alpha_N$), the burden sharing ratio $T_N/T_A$ may not exceed $(\sqrt{3}-1)/2 \approx 0.366$ in order to provide the non-Annex I country an incentive to participate, which is slightly higher than in the symmetric competitive market case, where it is equal to 1/3. Hence, this implies that in the case of market power, the non-Annex I country can carry a higher share of the emission reduction burden.

As in the competitive market case, the upper bound of the burden sharing ratio continuously increases in $\alpha$ with

$$\frac{T_N}{T_A} = \begin{cases} \infty & \text{for } \alpha \to \infty \\ \frac{\sqrt{3}-1}{2} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} . \tag{2.19}$$

## 2.3 The optimal no-lose target

Before analyzing the effects of a no-lose target in the two considered target-setting approaches of bottom-up and top-down (Section 2.4 and 2.5), we first discuss the "correct" stetting of a no-lose target and on this basis propose the "optimal" no-lose target.

The participation conditions derived in Section 2.2 define a range for applicable no-lose targets rather than one precise target. For a more distinguished analysis of the no-lose reduction targets we want to propose, in a first step, a precise no-lose target, i.e. "optimal" no-lose target, by taking two major aspects of the concept of the no-lose target within the framework of international climate protection agreements into consideration. First, the no-lose target representing the non-Annex I country's contribution to emission reductions should be as large as possible. Second, the idea of the no-lose target is that the costs of emission reductions are carried solely by the countries of the Annex I community. Therefore, financial transfers to the non-Annex I country via the carbon market should only be used to finance the emission reductions in the non-Annex I country. Accordingly, we propose the following definition for the optimal no-lose target:

**Definition 1.** *A no-lose target is called* optimal *if it meets the following two requirements:*

*(i) The no-lose target is as ambitious as possible.*

*(ii) The sum of the non-Annex I country's costs and revenues from emission reduction and trading are zero.*

It is easy to see that the upper limit for the no-lose target meets these requirements.

**Proposition 1.** *The optimal no-lose target $T_N^C$ in a competitive market is determined by the upper limit of* (2.13) *and the optimal no-lose target $T_N^P$ in the case of market power of the non-Annex I country is determined by the upper limit of* (2.19).

*Proof.* The upper limit of the no-lose target is the highest no-lose target that the non-Annex I country accepts and, thus, requirement (i) is met. Since the upper limit of the no-lose target is determined by the zero-profit condition, requirement (ii) is fulfilled. □

In general, the two characteristics that define the optimal no-lose target play an important role in making an integration of non-Annex I countries using no-lose targets politically more acceptable for Annex I countries. Although the nature of the no-lose target implies that all costs have to be carried by the countries of the Annex I community, setting the no-lose target optimally guarantees that, on the one hand, the non-Annex I country's contribution to emission reductions is as large as possible. Hence, the no-lose target fulfills the Annex I countries' call for own contributions by non-Annex I countries. On the other hand, the zero-profit condition prevents that large financial profits can be generated by the non-Annex I country via the carbon market.[18] Thus, the two characteristics provide good reasons that if a no-lose target is to be defined it is set as close as possible to the optimal no-lose target.

## 2.4 The no-lose target in a bottom-up environment

In our framework, the bottom-up environment is characterized by an exogenous Annex I community's target $\bar{T}_A$ and an endogenous no-lose target and, thus, an endogenous global target. According to Proposition 1 together with (2.12) and (2.18), the optimal no-lose target in the competitive case is then given by

$$T_N^C = \frac{\alpha}{2+\alpha}\bar{T}_A \tag{2.20}$$

and in the market power case by

$$T_N^P = \frac{\sqrt{1+2\alpha}-1}{2}\bar{T}_A\,. \tag{2.21}$$

Hence, the respective global targets are

$$T^C = \bar{T}_A + T_N^C\,, \tag{2.22}$$

$$T^P = \bar{T}_A + T_N^P\,. \tag{2.23}$$

The comparison of the two considered competition levels with respect to the optimal no-lose target and the global target yields the following result.

[18] Alternative (market or non-market-based) mechanisms could be used to generate additional monetary transfers for e.g. adaptation or as compensation for damages from climate change.

**Proposition 2.** *In the bottom-up approach with a fixed Annex I community's target $\bar{T}_A$ and under the condition of an optimal no-lose target the following holds:*

*(i) The optimal no-lose target (and thus the global target) positively depends on $\alpha$ in the case of a competitive market as well as in the case of market power of the non-Annex I country.*

*(ii) The optimal no-lose target (and thus the global target) in the market power case is always higher than in the competitive market case, i.e. $T_N^P > T_N^C$ for every $\alpha > 0$, and the ratio $T_N^P/T_N^C$ increases with $\alpha$.*

*Proof.* For a fixed Annex I community's target $\bar{T}_A$, the derivatives of the optimal no-lose targets (2.20) and (2.21) with respect to $\alpha$ are

$$\frac{dT_N^C}{d\alpha} = \frac{2}{(2+\alpha)^2}\bar{T}_A > 0 \tag{2.24}$$

$$\frac{dT_N^P}{d\alpha} = \frac{1}{2\sqrt{1+2\alpha}}\bar{T}_A > 0 \tag{2.25}$$

which are also the derivatives of the global targets (2.22) and (2.23) with respect to $\alpha$. Thus, (i) is proved.

For the first part of (ii) with (2.20) and (2.21) we have to show

$$\frac{\sqrt{1+2\alpha}-1}{2} > \frac{\alpha}{2+\alpha}$$

for all $\alpha > 0$. This leads to

$$\begin{aligned}
& & (2+\alpha)\sqrt{1+2\alpha} &> 2+3\alpha \\
&\Leftrightarrow & (2+\alpha)^2(1+2\alpha) &> (2+3\alpha)^2 \\
&\Leftrightarrow & 4+12\alpha+9\alpha^2+2\alpha^3 &> 4+12\alpha+9\alpha^2 \\
&\Leftrightarrow & 2\alpha^3 &> 0
\end{aligned}$$

which is true because of $\alpha > 0$. For the second part of (ii) we have to prove

$$\frac{d\left(\frac{T_N^P}{T_N^C}\right)}{d\alpha} = \frac{\frac{dT_N^P}{d\alpha}T_N^C - T_N^P\frac{dT_N^C}{d\alpha}}{(T_N^C)^2} > 0$$

which with (2.24) and (2.25) leads to

$$
\begin{aligned}
& & \frac{\alpha}{2(2+\alpha)\sqrt{1+2\alpha}} &> \frac{2(\sqrt{1+2\alpha}-1)}{2(2+\alpha)^2} \\
&\Leftrightarrow & \alpha(2+\alpha) &> 2(1+2\alpha) - 2\sqrt{1+2\alpha} \\
&\Leftrightarrow & \alpha^2 + 2\sqrt{1+2\alpha} &> 2(1+\alpha) \\
&\Leftrightarrow & \alpha^4 + 4\alpha^2\sqrt{1+2\alpha} + 4(1+2\alpha) &> 4 + 8\alpha + 4\alpha^2 \\
&\Leftrightarrow & \alpha^2(\alpha^2 + 4(\sqrt{1+2\alpha}-1)) &> 0
\end{aligned}
$$

which is true because of $\alpha > 0$ and, thus, the second part of (ii) is proved. □

The first part of statement (ii) has its origin in the fact that in the market power case the non-Annex I country can profit from its dominant position in the emissions trading market. Hence, the ability of the non-Annex I country to sell its certificates at a high price and thus increase its revenue can be used to increase its contribution to emission reductions. The optimal no-lose target accounts for this by capturing all revenues from emissions trading and thus preventing the non-Annex I country to benefit from its market position by increasing the ambition of the target. That is, the benefits from market power are used to force higher global emission reductions. The reason for the second part of statement (ii) is that the impact of $\alpha = \alpha_A/\alpha_N$ on the optimal target in the case of market power is stronger than in the case of a competitive market. Hence, for significantly larger reduction potentials in the non-Annex I country compared to the Annex I community's the no-lose target in the case of market power can be more ambitious compared to the optimal no-lose target in a competitive market than for similar reduction potentials or if reduction potential in the Annex I community is larger than in the non-Annex I country. This is of particular interest for countries like China or India with high emissions and large reduction potential. It implies that the market power can be used to significantly increase the contribution from these countries to global reduction efforts (see Figure 2.1).

We now consider the effect of the optimal no-lose target on actual emission reductions in the bottom-up setting. In the competitive market case with (2.9) and (2.20), the emission reductions of the non-Annex I country under

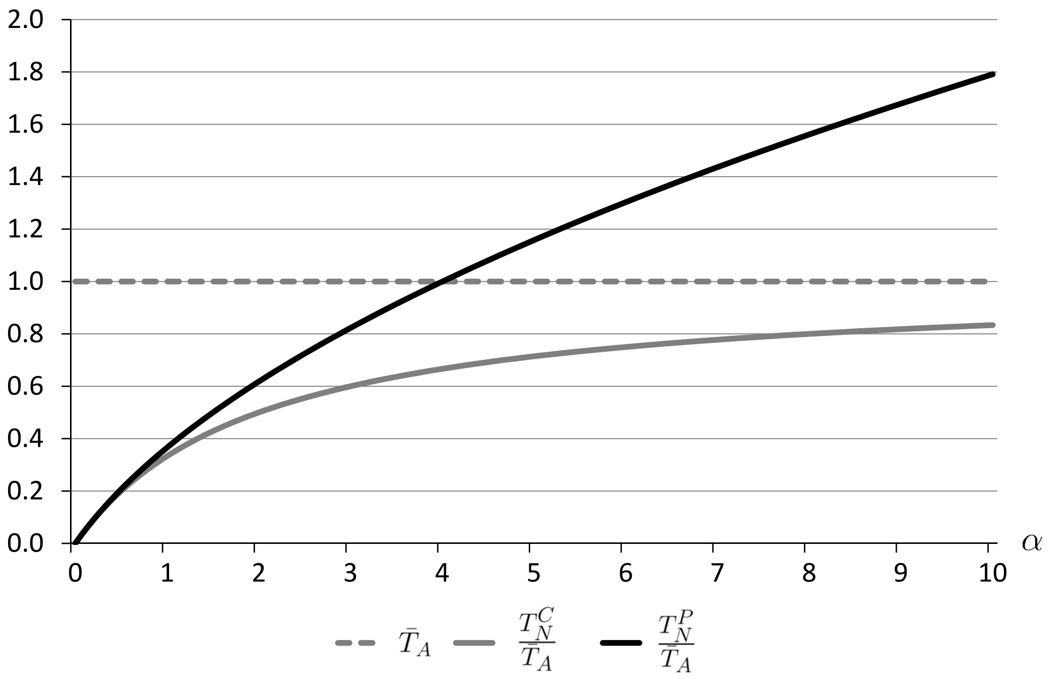


Figure 2.1: Optimal no-lose targets under a bottom-up target-setting approach

the optimal no-lose target yields

$$r_N^C = \frac{2\alpha}{2+\alpha}\,\bar{T}_A \tag{2.26}$$

and in the market power case with (2.17) and (2.21)

$$r_N^P = \frac{\alpha}{\sqrt{1+2\alpha}}\,\bar{T}_A\,. \tag{2.27}$$

The following proposition states interesting properties of non-Annex I country's emission reductions induced by the optimal no-lose target.

**Proposition 3.** *In the bottom-up approach with a fixed Annex I community's target $\bar{T}_A$ and under the condition of an optimal no-lose target, the actual emission reductions of the non-Annex I country both in the competitive market case $r_N^C$ and in the market power case $r_N^P$ positively depend on $\alpha$ with*

$$r_N^P \gtreqless r_N^C \;\; \textit{for} \;\; \alpha \gtreqless 4\,.$$

*Proof.* The derivatives of (2.26) and (2.27) with respect to $\alpha$ are

$$\begin{aligned} \frac{dr_N^C}{d\alpha} &= \frac{4}{(2+\alpha)^2}\,\bar{T}_A > 0 \\ \frac{dr_N^P}{d\alpha} &= \frac{2+3\alpha}{2\sqrt{(1+2\alpha)^3}}\,\bar{T}_A > 0 \end{aligned}$$

which proves the first part of the proposition.

For proving the second part of the proposition we compare (2.26) and (2.27). Hence, $r_N^P \gtreqless r_N^C$ is fulfilled if and only if

$$\begin{aligned} && 2+\alpha &\gtreqless 2\sqrt{1+2\alpha} \\ \Leftrightarrow && 4+4\alpha+a^2 &\gtreqless 4+8\alpha \\ \Leftrightarrow && \alpha(\alpha-4) &\gtreqless 0 \\ \Leftrightarrow && \alpha &\gtreqless 4 \end{aligned}$$

which completes the proof. □

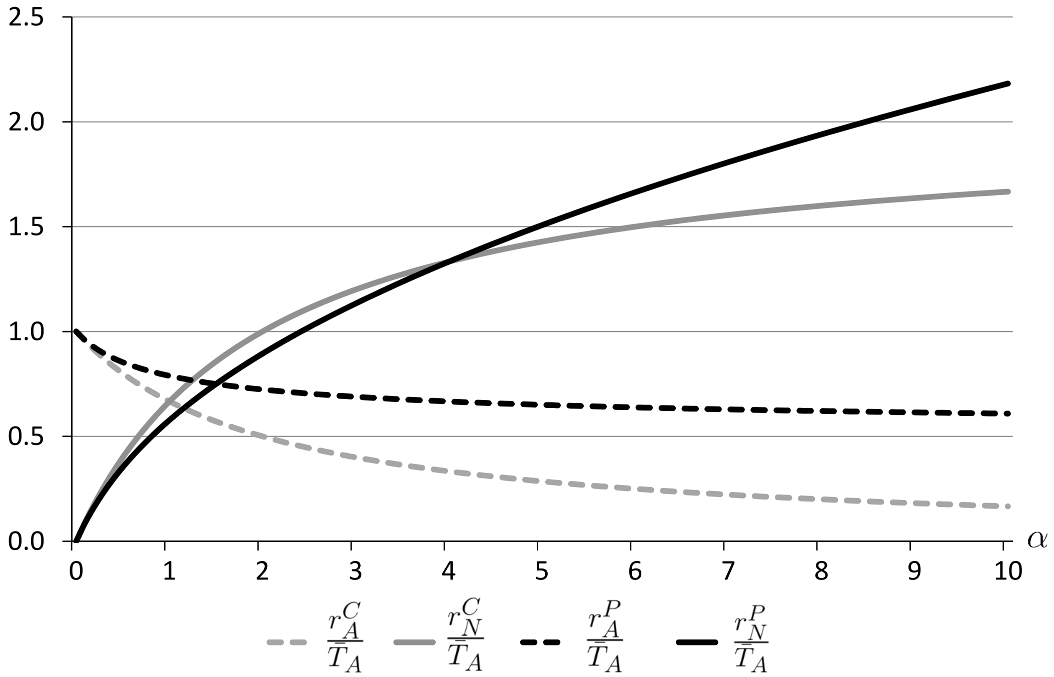


Figure 2.2: Emission reductions in the bottom-up approach with optimal no-lose target

According to Proposition 3, using the bottom-up approach and applying the optimal no-lose targets, the non-Annex I country's actual emission reductions in the case of market power are higher than in the case of a competitive market if the relative reduction potential of the non-Annex I country is sufficiently high, i.e. $\alpha > 4$ (see also Figure 2.2). The finding is interesting, because the country with market power is usually expected to reduce less emissions in order to offer fewer certificates and, in turn, the certificates-buying Annex I community has to reduce more. However, if the no-lose target is set optimally in relation to a given Annex I's target $\bar{T}_A$, this need not be the case if the non-Annex I country's emission reduction potential is high enough compared to the Annex I community. Here, the higher emission reductions are forced by a more ambitious optimal no-lose target in the market power case (Proposition 2). That is, market power has a positive effect on global emission reductions if a bottom-up target-setting is chosen as it allows higher global emission reductions than the competitive market.

In section 2.6 we will see that this result does not hold for overall abatement costs. That is, the higher global emission reductions in the market power case are achieved through higher costs due to market inefficiencies.

## 2.5 The no-lose target in a top-down environment

We now focus on the top-down approach in which the global reduction target is exogenous and denoted by $\bar{T}$. In contrast to the bottom-up approach, both the optimal no-lose target and the Annex I community's target are endogenously determined in the competitive market case and the market power case:

$$T_A^C + T_N^C = \bar{T} \tag{2.28}$$

$$T_A^P + T_N^P = \bar{T} \tag{2.29}$$

Applying Proposition 1 to (2.12) with (2.28) leads to

$$T_N^C = \frac{\alpha}{2(1+\alpha)}\bar{T} \tag{2.30}$$

in the competitive market case of the top-down approach and its application to (2.18) with (2.29) to

$$T_N^P = \frac{\sqrt{1+2\alpha}-1}{\sqrt{1+2\alpha}+1}\bar{T}. \tag{2.31}$$

in the market power case of the top-down approach. The Annex I community's target is then endogenously determined by $T_A^C = \bar{T} - T_N^C$ and $T_A^P = \bar{T} - T_N^P$, respectively.

The comparison of the two market forms with respect to the optimal no-lose targets shows that similar properties apply as in the bottom-up approach.

**Proposition 4.** *In the top-down approach with a fixed global target $\bar{T}$ and under the condition of an optimal no-lose target the following holds:*

*(i) The optimal no-lose target positively depends on $\alpha$ in the case of a competitive market as well as in the case of market power of the non-Annex I country.*

*(ii) The optimal no-lose target in the market power case is always higher than in the competitive market case, i.e. $T_N^P > T_N^C$ for every $\alpha > 0$, and the ratio $T_N^P/T_N^C$ increases with $\alpha$.*

*Proof.* The derivatives of the optimal no-lose targets (2.30) and (2.31) with respect to $\alpha$ are

$$\frac{dT_N^C}{d\alpha} = \frac{2}{4(1+\alpha)^2}\bar{T} > 0 \tag{2.32}$$

$$\frac{dT_N^P}{d\alpha} = \frac{2}{\sqrt{1+2\alpha}(\sqrt{1+2\alpha}+1)^2}\bar{T} > 0 \tag{2.33}$$

which proves (i).

For the first part of (ii) with (2.30) and (2.31) we have to prove

$$\frac{\sqrt{1+2\alpha}-1}{\sqrt{1+2\alpha}+1} > \frac{\alpha}{2(1+\alpha)}$$

for all $\alpha > 0$. This leads to

$$\begin{aligned} & (2+\alpha)\sqrt{1+2\alpha} > 2+3\alpha \\ \Leftrightarrow \quad & (2+\alpha)^2(1+2\alpha) > (2+3\alpha)^2 \end{aligned}$$

$$\begin{aligned}\Leftrightarrow \qquad 4+12\alpha+9\alpha^2+\alpha^3 &> 4+12\alpha+9\alpha^2\\ \Leftrightarrow \qquad 2\alpha^3 &> 0\end{aligned}$$

which is true because of $\alpha > 0$. For the second part of (ii) we have to show

$$\frac{d\left(\frac{T_N^P}{T_N^C}\right)}{d\alpha} = \frac{\frac{dT_N^P}{d\alpha}T_N^C - T_N^P\frac{dT_N^C}{d\alpha}}{(T_N^C)^2} > 0$$

which with (2.32) and (2.33) leads to

$$\begin{aligned}\frac{2\alpha}{2(1+\alpha)\sqrt{1+2\alpha}(\sqrt{1+2\alpha}+1)^2} &> \frac{2(\sqrt{1+2\alpha}-1)}{4(1+\alpha)^2(\sqrt{1+2\alpha}+1)}\\ \Leftrightarrow \qquad 8\alpha(1+\alpha) &> 4\sqrt{1+2\alpha}(\sqrt{1+2\alpha}-1)(\sqrt{1+2\alpha}+1)\\ \Leftrightarrow \qquad 1+\alpha &> \sqrt{1+2\alpha}\\ \Leftrightarrow \qquad (1+\alpha)^2 &> 1+2\alpha\\ \Leftrightarrow \qquad 1+2\alpha+\alpha^2 &> 1+2\alpha\\ \Leftrightarrow \qquad \alpha^2 &> 0\end{aligned}$$

which is true because of $\alpha > 0$ and, thus, the second part of (ii) is proved. □

Because of (2.28) and (2.29) the opposite of Proposition 2 holds for the endogenous target of the Annex I community: $T_A^C$ and $T_A^P$ negatively depend on $\alpha$, $T_A^P < T_A^C$ for every $\alpha > 0$ and the ratio $T_A^P/T_A^C$ decreases with $\alpha$ (see Figure 2.3).

The actual emission reductions of the non-Annex I country in the competitive market case (2.9) under the optimal no-lose target (2.30) in the top-down setting are given by

$$r_N^C = \frac{\alpha}{1+\alpha}\bar{T} \tag{2.34}$$

and in the market power case, the emission reductions, determined by (2.17) and (2.31), are given by

$$r_N^P = \frac{2\alpha}{1+2\alpha+\sqrt{1+2\alpha}}\bar{T}\,. \tag{2.35}$$

While the no-lose target has the same properties in the bottom-up and top-down approach, this does not hold for the actual emission reductions of the non-Annex I country.

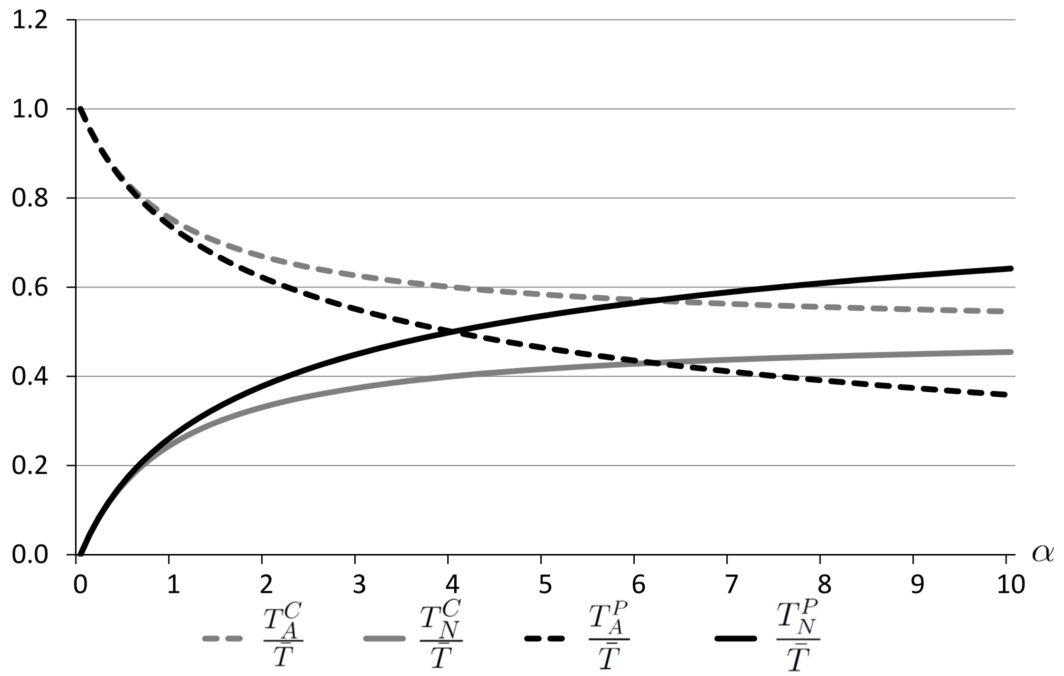


Figure 2.3: Optimal no-lose targets under a top-down target-setting approach

**Proposition 5.** *In the bottom-up target-setting approach with optimal no-lose target, the actual emission reductions of the non-Annex I country both in the competitive market case $r_N^C$ and in the market power case $r_N^P$ positively depend on $\alpha$ with $r_N^C > r_N^P$ for all $\alpha > 0$.*

*Proof.* The derivative of (2.34) with respect to $\alpha$ is

$$\frac{dr_N^C}{d\alpha} = \frac{1}{(1+\alpha)^2}\,\bar{T} > 0 \tag{2.36}$$

and the derivative of (2.35) is

$$\frac{dr_N^P}{d\alpha} = \frac{2+2\sqrt{1+2\alpha}-\frac{2\alpha}{\sqrt{1+2\alpha}}}{(1+2\alpha+\sqrt{1+2\alpha})^2}\,\bar{T}\,. \tag{2.37}$$

Derivative (2.37) is positive for $\alpha > 0$ if

$$\begin{aligned} & \sqrt{1+2\alpha}+1+2\alpha-\alpha > 0 \\ \Leftrightarrow \quad & 1+\alpha+\sqrt{1+2\alpha} > 0 \end{aligned}$$

which is true and, thus, with (2.36) proves the first part of the proposition. For the second part of the proposition, we compare (2.34) and (2.35). Hence,

$r_N^C > r_N^P$ is fulfilled if and only if

$$1 + 2\alpha + \sqrt{1+2\alpha} > 2 + 2\alpha$$
$$\Leftrightarrow \qquad \sqrt{1+2\alpha} > 1$$

which holds for $\alpha > 0$ and, thus, completes the proof. □

Although in the top-down setting the optimal no-lose target is always higher in the market power case than in a competitive market, for the non-Annex I country's emission reductions it is the other way round. Hence, the Annex I community's emission reductions in the case of market power are always higher than in a competitive market (see Figure 2.4). The reason for this is the fixed global target in the top-down setting, which prevents non-Annex I's emission reductions in the market power case to become higher than in the competitive market. Hence, although market power results in a higher contribution of the non-Annex I country to global emission reductions determined by the no-lose target it does not lower the actual emission reductions by the Annex I community but rather increases them.

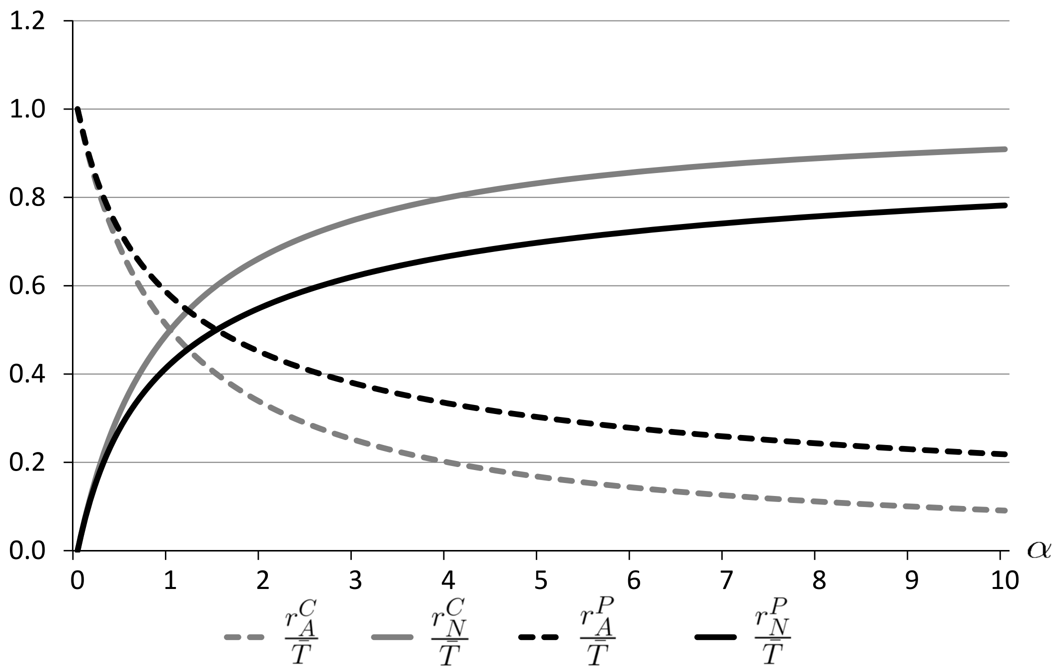


Figure 2.4: Emission reductions in the top-down approach with optimal no-lose target

## 2.6 Welfare effects

In the following we compare the before considered cases, particularly with respect to overall total costs $TC = TC_A + TC_N$, which occur from the total emission reductions of the Annex I community and the non-Annex I country. Our comparison includes the case without the non-Annex I country (labeled by 0), the case of a participating non-Annex I country as price taker in a competitive market (labeled by $C$), and the case of a participating non-Annex I country with market power (labeled by $P$). Here, we account for both target-setting approaches of bottom-up and top-down.

Since the non-Annex I country does not participate in the first case and due to the definition of the optimal no-lose target for the latter two cases (Definition 1), the Annex I community bears all costs from emission reductions in each case, i.e. $TC^0 = TC_A^0$, $TC^C = TC_A^C$, and $TC^P = TC_A^P$.

**Proposition 6.** *Under both target-settings, the bottom-up approach with a fixed Annex I community's target $\bar{T}_A$ and the top-down approach with a fixed global target $\bar{T}$, the ordering of the certificate market price is*

$$p^0 > p^P > p^C \tag{2.38}$$

*and of the total costs*

$$TC^0 > TC^P > TC^C \tag{2.39}$$

*for every $\alpha > 0$.*

*Proof.* In case of non-participation, the Annex I countries have to achieve their target with their own emission reductions, i.e. $r_A^0 = T_A$, and the certificate price is determined by the Annex I community's marginal abatement costs at their target (2.1), i.e. $p^0 = MC(r_A^0) = \alpha_A T_A$. In case of participation, the non-Annex I country bears no costs, i.e. $TC_N = 0$, and sells certificates to the Annex I countries, both in the competitive market case and in the market power case. Therefore, the Annex I community reduces less emissions than in the case of non-participation, i.e. $r_A < T_A$, and closes the gap to the target with certificates bought from the non-Annex I country. Since the Annex I countries act as price taker, the certificate price is equal to the Annex I community's marginal abatement costs (2.1), i.e. $p = MC(r_A) = \alpha_A r_A$. Hence, $p < p^0$ and $TC_A < TC_A^0$ and thus $TC < TC^0$.

For the comparison of the competitive market case with the market power case, we fist consider the top-down setting. It is well known that a given global target $\bar{T}$ is efficiently achieved (i.e. minimum total abatement costs) in a competitive market, while this is not the case for market power (Hahn, 1984). Hence, $TC^P < TC^C$. In the market power case, the non-Annex I country reduces less emissions than in the competitive market case (Proposition 5) and, thus, the Annex I community reduces more emissions, i.e. $r_A^P > r_A^C$. Since in both cases the market price is equal to the Annex I's marginal abatement costs, (2.7) and (2.15), and since $MC'(r_A) > 0$, i.e. the marginal abatement costs strictly increase in emission reductions, $p^P > p^C$ holds.

In the bottom-up setting, the global target in the case of market power is always higher than in the competitive market (Proposition 2), i.e. $T^P > T^C$ for every $\alpha > 0$. Assume that $T^P$ is achieved efficiently in a competitive market with market price $p^{PC}$ and total costs $TC^{PC}$. Since in a competitive market, the price is equal to the countries' marginal abatement costs, which strictly increase in their emission reductions, $p^{PC} > p^C$ and $TC^{PC} > TC^C$ hold. Then, according to the top-down argumentation before, $p^P > p^{PC}$ and $TC^P > TC^{PC}$ and, thus, $p^P > p^C$ and $TC^P > TC^C$. □

The two effects stated in Proposition 6 are well-known characteristics of emissions trading markets but nonetheless important: first, broader participation leads to lower prices and lower reduction costs. Second, market power leads to less efficient results than a competitive market, hence, for fixed targets costs and prices are higher in the market power case than they are in the competitive market. Particularly the first characteristic is interesting for the case of no-lose targets. Independent of the emission reduction contributions of the non-Annex I country, the participation of the non-Annex I country reduces the total costs of emission reductions which are covered by the Annex I community. Hence, the integration of the non-Annex I country is beneficial from a social perspective as well as for the Annex I community even if the no-lose target is little ambitious. [19]

[19] More specifically, the Annex I community's aggregated costs are decreasing by integrating the non-Annex I country. Looking at the individual countries of the Annex I community participating in the emissions trading market there are Annex I countries that are negatively affected by the participation of the non-Annex I country. Only those Annex I countries benefit from broader participation that are certificate buyers in the market. Annex I countries that can sell emission certificates are worse of as they have greater competition and, hence, have to sell less certificates at lower prices.

## 2.7 Case study

The following numerical example shall help to illustrate the implications and interpretations. The community of the Annex I countries includes all countries listed in Annex B of the Kyoto Protocol excluding the USA. A large non-Annex I country, namely China, is to be included in the emission reduction activities applying a no-lose target. The reduction target for the Annex I community is assumed to be 30% below 1990 levels by 2020.[20] This leads to necessary emission reductions of 1.9 $GtCO_2e$ in the Annex I countries in 2020 (see Table 2.1). Emission projections for 2020 are taken from calculations with the energy systems model POLES. The underlying scenario assumptions are taken from the World Energy Outlook 2010 (International Energy Agency, 2010). Marginal abatement costs are a linear approximation of marginal abatement cost curves from the POLES model. Slopes are given in Table 2.2. Including the USA and their high low-cost reduction potential lowers the slope of the Annex I countries from 38 to 21 k€/$(MtCO_2e)^2$.

| | 1990* | 2005* | 2020 |
|---|---|---|---|
| Emissions [$GtCO_2e$] | | | |
| AI incl. USA | 18.7 | 17.7 | 17.8 |
| AI excl. USA | 12.6 | 10.7 | 11.0 |
| China | 3.6 | 7.3 | 14.8 |
| Emission target [$GtCO_2e$] | | | |
| AI incl. USA | | | 13.1 |
| AI excl. USA | | | 8.8 |
| Reduction target [$GtCO_2e$] | | | |
| AI incl. USA | | | 4.7 |
| AI excl. USA | | | 2.2 |

* Historic emission data for 1990 and 2005 are taken from CAIT 8.0 .

Table 2.1: Emissions and emission reductions in 2020

Choosing a bottom-up approach for target-setting, the Annex I countries' reduction target is given exogenous. In our example, reductions are 4.7 and 2.2 $GtCO_2e$ including, respectively excluding the USA. Emission reductions from China are additional to the Annex I countries' emission reductions leading

[20] The IPCC indicates that a reduction of 25 to 40% below 1990 levels by 2020 from Annex I countries is necessary to keep global temperature increase below 2°C above pre-industrial levels (Metz et al., 2007).

to global emission reductions of 6.4 and 3.3 $GtCO_2e$ respectively in the case of a competitive market. If factoring in market power for China, the global emission reductions can be increased by 0.2 and 0.3 $GtCO_2e$ respectively. Hence, in both cases the emission reduction targets for China are significantly lower than emission reduction targets for the Annex I countries.

Optimal emission reductions lead to trading of emission certificates for 1.7 $GtCO_2e$ and 1.1 $GtCO_2e$ respectively from China to the Annex I countries in the case of a competitive market. In case of market power, the certificates traded between China and the Annex I countries are lower although the overall reduction target is higher. Comparing the numbers traded shows that China always sells less certificates in the case of market power than in the competitive market. This highlights the market-dominant position of China as a seller of certificates.

In contrast, in the case of the top-down approach, the global reduction target is exogenous and set to 4.7 and 2.2 $GtCO_2e$ respectively including and excluding the US. Splitting the reductions between the Annex I countries and China leads to emission reductions of 1.3 and 0.7 $GtCO_2e$ respectively for China in the case of a competitive market. Remaining reduction targets for the Annex I countries are 3.4 and 1.5 $GtCO_2e$. That means, in the case of participation of the USA China carries about 28% of the overall emission reduction burden. Excluding the USA the higher emission reduction costs in the remaining Annex I countries leads to China being able to carry about 32% of the overall emission reduction burden. The certificates traded between China and the Annex I countries are equivalent to 1.3 and 0.7 $GtCO_2e$ respectively in the case of a competitive market. In case of market power significantly less emission certificates are traded while the reduction target of China is again more ambitious than in the competitive market case. Interestingly, as in the case of Annex I excl. USA the reduction potential in China is more than twice as high than the reduction potential in the Annex I countries, optimal emission reductions in China in the case of market power are higher than optimal emission reductions in the Annex I countries although the reduction target is significantly lower.

| | Competitive market | | | Market power | | |
|---|---|---|---|---|---|---|
| | AI incl. USA | AI excl. USA | China | AI incl. USA | AI excl. USA | China |
| Slopes [1000€/($MtCO_2e$)$^2$] | 20.66 | 37.62 | 17.85 | 20.66 | 37.62 | 17.85 |
| Bottom-up approach | | | | | | |
| global target [$GtCO_2e$] | 6.4 | 3.3 | | 6.6 | 3.6 | |
| optimal target [$GtCO_2e$] | 4.7[1] | 2.2[1] | 1.7/ 1.1 | 4.7[1] | 2.2[1] | 1.9/ 1.4 |
| optimal reductions [$GtCO_2e$] | 3.0 | 1.1 | 3.4/ 2.3 | 3.6 | 1.6 | 3.0/ 2.0 |
| certificates traded [$GtCO_2e$] | 1.7 | 1.1 | -1.7/ -1.1 | 1.1 | 0.6 | -1.1/ -0.6 |
| Top-down approach | | | | | | |
| global target [$GtCO_2e$] | 4.7[1] | 2.2[1] | | 4.7[1] | 2.2[1] | |
| optimal target [$GtCO_2e$] | 3.4 | 1.5 | 1.3/ 0.7 | 3.3 | 1.3 | 1.4/ 0.9 |
| optimal reductions [$GtCO_2e$] | 2.2 | 0.7 | 2.5/ 1.5 | 2.6 | 1.0 | 2.1/ 1.2 |
| certificates traded [$GtCO_2e$] | 1.3 | 0.7 | -1.3/ -0.7 | 0.8 | 0.4 | -0.8/ -0.4 |

[1]exogenous

Table 2.2: Estimation of China's optimal no-lose reduction target

## 2.8 Conclusion

In this chapter, a two-stage decision process was introduced to analyze the potential of no-lose targets to act as a suitable instrument to integrate a non-Annex I country in international emission reduction efforts. The main goal was to estimate the contribution from a non-Annex I country to global emission reduction efforts applying a no-lose target while being incentive-compatible. We derived conditions for the no-lose target to incentivize participation of the non-Annex I country.

The analysis of the participation conditions shows for case of symmetric countries in a perfectly competitive market that the maximum (optimal) no-lose target is given by a burden-sharing between the non-Annex I country and the Annex I community of 1 to 3. That means, even in the case of similar reduction potentials high certificate transfers are necessary to induce the non-Annex I country to participate. Likewise, only a relatively small part of the global reduction burden can be carried by the non-Annex I country applying no-lose targets. Although the analyses show that for a high reduction potential of the non-Annex I country the burden-sharing is less badly balanced, the no-lose target always needs to be lower than the target of the Annex I community in the case of a competitive market.

In contrast, in the case of market power not only a more ambitious no-lose target is possible compared to a competitive market, the no-lose target may also exceed the aggregated target of the Annex I community. Furthermore, for bottom-up target-setting and applying the optimal no-lose target, the actual emission reductions of the non-Annex I country were found to be lower in the case of market power than in the competitive market if the abatement potential of the non-Annex I country is at least four times as high as the Annex I community's.

Using the participation conditions derived we argue that an optimal definition of a no-lose target fulfills the participation conditions with equality, thus leading to the highest possible contribution to emission reductions by the non-Annex I country and not allowing for any financial profits being gained via the carbon market. This characteristic remains unchanged in the case of market power when gains from the market-dominant position can be used to induce a higher contribution to emission reductions by the non-Annex I country. Therefore, no-lose targets may be politically more acceptable to integrate in particular large non-Annex I countries like China and India in an emissions trading market. On the one hand, the financial burden lays solely with the Annex I countries. On the other hand, preventing financial profits for large non-Annex I countries even in the case of market power, while at the same time resulting in own emission reduction contributions, could make such a target more acceptable for Annex I countries.

The above analyses are restricted to one non-Annex I country facing a no-lose target. While this allows some general statements on the effects of no-lose targets and their ability to contribute to global emission reductions one important factor is excluded from the analyses. If more than one non-Annex I country faces a no-lose target, they compete in supplying emission certificates in the emissions trading market. Hence, the participation decision affects the supply of emission certificates and, thus the market price. Via the revenue effect the market price in turn affects the participation decision of the non-Annex I countries. In the following chapter, the model will thus be expanded to include two non-Annex I countries facing no-lose targets.

# 3 Interaction of two non-Annex I countries

## 3.1 Introduction

In section 1.2, two effects were introduced that influence whether a no-lose target is profitable: the cost effect and the revenue effect. The cost effect is solely determined by the level of the no-lose target and the form of a country's abatement cost curve, i.e. whether a country's abatement potential is high and cheap or low and expensive. In contrast, the revenue effect depends on the level of the no-lose target, but also on the price for emission certificates in the emissions trading market. The target level determines the number of excess emission certificates a country can sell. This, and the price for emission certificates, determine a country's revenues (see the non-Annex I country's total costs given in (2.4)).

The various aspects of defining a profitable no-lose target for one non-Annex I country were analyzed in the last chapter. In the case of one non-Annex I country facing a no-lose target, the non-Annex I country can determine the market price for emission certificates and, hence, has all the information it needs to decide whether it is profitable to fulfill the no-lose target and participate in the emissions trading market. In the case where more than just one non-Annex I country is facing a no-lose target, determining the market price for emission certificates is more difficult. In that case, the market price is affected by each non-Annex I country's decision to participate in the emissions trading market or not.

In this chapter, we expand the analysis to the simplest case of interaction between non-Annex I countries, i.e. the case of two symmetric non-Annex I countries facing a no-lose target. Limiting the number of non-Annex I countries to two allows us to determine the main effects of interaction, while reducing the complexity of the model and the corresponding equations.

The modeling framework introduced in this chapter is an extension of the modeling framework applied in the last chapter. The non-Annex I countries' payoffs are again determined by their interaction with the Annex I community in an international emissions trading market. To model the link between the two non-Annex I countries' participation decision and the market price, a game-theoretical dimension, is added in the form of a participation game of the two non-Annex I countries. The game-theoretical extension reflects that the payoffs are affected by each non-Annex I country's decision to fulfill the no-lose target. The resulting payoffs are used to determine the Nash equilibria of the participation game.

Introducing a second non-Annex I country facing a no-lose target allows us to widen the analysis of no-lose targets with respect to the number of participants in the emissions trading market. While, in general, wider participation in the emissions trading system increases the economic efficiency of the trading system (see e.g. Boemare & Quirion, 2002), the framework will be applied to determine the impacts of broader participation in the special case of no-lose targets. In particular, we will analyze the effects of broader participation on the optimal no-lose targets introduced in the last chapter and on global emission reduction efforts.

Two cases are distinguished in the following analysis. We begin by applying the same fixed no-lose target in the case of one and two participating non-Annex I countries. This allows us to determine the effects from increased participation in the emissions trading market and the implications for the Annex I community. However, applying the same fixed no-lose target in the case of one and two participating non-Annex I countries does not take into account whether the no-lose target is profitable and, hence, induces participation by even one of the non-Annex I countries. In a second step, we therefore determine the "optimal no-lose targets" that take into account that no-lose targets have to be profitable to induce participation by one, respectively two non-Annex I countries. The impacts of the optimal no-lose targets on the emissions trading market and the Annex I community are analyzed. In addition, the optimal no-lose targets also allow an analysis of the environmental effectiveness of one, respectively two, participating non-Annex I countries.

As in chapter 2, two market forms are analyzed: a perfectly competitive market where all market participants are price takers and a market with market power on the part of the non-Annex I countries. The analyses are, however, restricted to the case of a bottom-up target-setting approach.

The chapter proceeds as follows: in section 3.2 the two-player participation game is introduced and the Nash equilibria based on the non-Annex I countries' payoffs for the two market forms are derived. In section 3.3, characteristics of the main decision parameter, the non-Annex I countries' payoffs, are determined. Results for fixed no-lose targets follow in section 3.4. The optimal no-lose targets are introduced and their implications for the international emissions trading market are presented in section 3.5. Section 3.6 concludes.

## 3.2 Modeling no-lose targets in a two-player game

The following chapter presents an extension to the modeling framework introduced in chapter 2.2 for two non-Annex I countries facing a no-lose target. The model and the subsequent analyses are restricted to two symmetric non-Annex I countries. The section proceeds as follows: in section 3.2.1, the general modeling framework for two non-Annex I countries facing no-lose targets is introduced. In section 3.2.2, the general framework is restricted to symmetric non-Annex I countries and the participation game is introduced, incorporating a game-theoretical component into the modeling framework. In sections 3.2.3 and 3.2.4, the non-Annex I countries' payoffs are determined by solving the previously introduced model. The resulting payoffs are then used to determine the Nash equilibria of the participation game, i.e. determine the constellations that are individually optimal strategies for both non-Annex I countries. Section 3.2.3 presents results for the competitive market case, while section 3.2.4 presents results for the case of market power on the side of the non-Annex I countries.

### 3.2.1 Modeling framework

Let us consider two players, labeled $N1$ and $N2$, representing two non-Annex I countries (instead of one). The two countries' emission reduction levels below a given baseline are denoted $r_i \geq 0, i \in \{N1, N2\}$, that is, a country's emissions cannot be higher than its baseline emission level. Reducing emissions below baseline causes costs.[21] The country's marginal abatement costs $MC_i(r_i) = \frac{dC_i}{dr_i}(r_i) = \alpha_i r_i$ are assumed to be linearly increasing with slope $\alpha_i > 0$. Hence, country $i$'s abatement costs (neglecting fixed costs) are of the form[22] $C_i(r_i) = \frac{\alpha_i}{2} r_i^2$.

Both non-Annex I countries face a no-lose reduction target given by $T_{N1}$ and $T_{N2}$. Independent of each other, each non-Annex I country has to decide on either complying with the no-lose target or not. If a country decides not to comply with the target, it does not reduce its emissions ($r_i = 0$) and, hence, its abatement costs are zero ($C_i(0) = 0$). If a country decides to comply with its target, it reduces its emissions ($r_i > 0$). Meeting the no-lose target induces abatement costs $C_i(T_i)$. As a reward for meeting the no-lose target, the non-Annex I country can, as before, participate in a restricted international emissions trading market.

In the restricted international emissions trading market the non-Annex I countries interact with the community of Annex I countries. The parameters and variables of the Annex I community are labeled by index A. Each country of the Annex I community is obliged to reach a national reduction target (with respect to baseline emissions) and is allowed to freely bargain emission certificates in the international emissions trading market.[23] The national reduction targets add up to the joint target $T_A$ of the Annex I community. Their joint emission reductions below baseline emissions are denoted by $r_A$. The marginal (aggregated) abatement cost curve $MC_A(r_A) = \frac{dC_A}{dr_A} = \alpha_A r_A$ is assumed to be linearly increasing. Hence, the (aggregated) abatement cost curve (neglecting fixed costs) is of the form $C_A = \frac{\alpha_A}{2} r_A^2$.

The restriction in the interaction between the non-Annex I countries and the community of Annex I countries is such that the non-Annex I countries can only act as certificate sellers in the international emissions trading market. Therefore, the non-Annex I country's marginal abatement costs at the no-lose reduction target need to be lower than the Annex I community's ag-

[21] As before, the abatement cost curves concentrate on net investment, operating and maintenance costs and do not consider positive effects like energy savings or other positive benefits. Hence, it is assumed that abatement costs are always positive.

[22] Note that all of our results qualitatively hold, even for weaker conditions for the abatement costs $MC_i > 0$ and $\frac{dMC_i}{dr_i} = MC' \geq 0$ and also if fixed costs are taken into consideration.

[23] This describes - in simple terms and excluding the CDM - the situation of the Kyoto Protocol where all countries facing reductions targets are allowed to participate in a common emissions trading market.

gregated abatement costs at their aggregated reduction target. Hence, a necessary condition for the non-Annex I country $i$ to become a net-seller of emission certificates is given by

$$\frac{T_i}{T_A} < \frac{\alpha_A}{\alpha_i} \text{ for } i = N1, N2\,. \tag{3.1}$$

In addition, to become a net-seller of certificates in the market, the non-Annex I country's emission reductions $r_i$ need to exceed the no-lose target $T_i$,

$$r_i - T_i \geq 0 \text{ for } i = N1, N2\,. \tag{3.2}$$

As a reward for meeting the no-lose target, the non-Annex I country $i$ gets emission certificates for the emission reductions above its target, i.e. $r_i - T_i$. These emission certificates can freely be sold in the international emissions trading market. The market price for emission certificates, given by $p$, is determined by the Annex I community's aggregate reduction target and the certificates the non-Annex I countries decide to sell, i.e. $p = p(r_A, r_{N1}, r_{N2})$.

As before, all countries facing reduction targets (i.e. the Annex I countries as well as the two non-Annex I countries facing a no-lose target) act in a cost-minimizing manner. Hence, country $k$'s optimization problem, $k \in \{A, N1, N2\}$, is given by

$$TC_k = C_k(r_k) - p(r_A, r_{N1}, r_{N2})(r_k - T_k) \rightarrow \min_{r_k}\,. \tag{3.3}$$

The target function of the non-Annex I country is denoted as its *incentive compatibility condition.*

The optimization problems have to be amended by a market clearing condition which ensures that global emission reductions equal the global emission target. Due to the no-lose character of the two non-Annex I countries' targets, the market clearing conditions depend on the decisions of the non-Annex I countries to comply or not to comply with their targets. If both non-Annex I countries decide to comply with their no-lose target, the market clearing condition

$$r_A + r_{N1} + r_{N2} = T_A + T_{N1} + T_{N2} \tag{3.4}$$

has to hold. In that case, the global emission target is given by the Annex I community's aggregated target plus both non-Annex I countries' targets. In case only one of the two non-Annex I countries, country i, decides to comply with its target, while the other non-Annex I country, country j, decides not to reduce its emissions (i.e. $r_j = 0$), the market clearing condition is given by

$$r_A + r_i = T_A + T_i \,. \tag{3.5}$$

If both non-Annex I countries decide not to comply with their no-lose targets (i.e. $r_{N1} = r_{N2} = 0$), the market clearing condition is given by

$$r_A = T_A \,. \tag{3.6}$$

Since the non-Annex I countries do not reduce their emissions compared to baseline emissions, they cannot act as certificate sellers on the international emissions trading market. Hence, the Annex I community has to fulfill its reduction target "domestically", i.e. without certificates from the non-Annex I countries.

As before, the interaction of the Annex I community and the non-Annex I countries in the international emissions trading market, according to (3.3), determine their individual optimal emission reductions $r^*_{N1}$, $r^*_{N2}$ and $r^*_A$ and the market price $p(r^*_A, r^*_{N1}, r^*_{N2})$.

In the next section, this framework will be complemented by the participation game of the two non-Annex I countries.

### 3.2.2 The participation game for two symmetric non-Annex I countries

For simplicity's sake, we assume for the following analyses that the two non-Annex I countries are symmetric, i.e. they have similar abatement costs and face similar no-lose reduction targets. The non-Annex I countries' parameters and variables are labeled $N$. In particular, $\alpha_N = \alpha_{N1} = \alpha_{N2}$ and $T_N = T_{N1} = T_{N2}$.

As a measure of the abatement potential relation between a non-Annex I country and the Annex I community, we, similar to chapter 2, define $\alpha$ as the ratio of the abatement potentials of the Annex I community and a non-Annex I country , i.e. $\alpha = \frac{\alpha_A}{\alpha_N}$. That is, the higher the non-Annex I country's abatement potential is, compared to the Annex I community's, the higher is the value of $\alpha$.

In order to analyze the participation decision of the two non-Annex I countries, we formulate the game as follows: two players, the non-Annex I countries $N1$ and $N2$, can decide to participate (p) or not to participate (n) as certificate sellers in the international emissions trading market. If a country decides to participate, it has to meet its no-lose target. Additional emission reductions can then be sold to the Annex I community. A non-Annex I country's payoff, the decision variable, is given by the negative of the total costs (3.3)

$$\Pi_i = -TC_i \, , i \in \{N1, N2\} \, . \tag{3.7}$$

For participation to be the optimal choice, the payoff $\Pi_i$ needs to be positive, i.e. the abatement costs $C_i(r_i^*)$ for reducing emissions by the optimal amount $r_i^*$ need to be smaller than the revenues a country can generate by selling emission certificates. Hence, similar to chapter 2

$$\Pi_i \geq 0 \tag{3.8}$$

is the *participation constraint* of the non-Annex I country. If a non-Annex I country chooses (n), i.e. does not participate in the international emissions trading market, its total costs $TC_i$ are zero and, hence, $\Pi_i = 0$.

In the case of one participating non-Annex I country $i$, the payoff $\Pi_N$ of the participating non-Annex I country is defined by the optimization problems of the Annex I community and the participating non-Annex I country $i$ applying the market clearing condition (3.5). Similarly, in the case of two participating non-Annex I countries, the non-Annex I countries' payoffs $\widetilde{\Pi}_N$ are defined by all countries' optimization problems and market clearing condition (3.4). The general form of the payoff matrix of the game is given in Figure 3.1.

| | | Player $N2$ | |
|---|---|---|---|
| | | p | n |
| Player $N1$ | p | $\widetilde{\Pi}_N$ <br> $\widetilde{\Pi}_N$ | 0 <br> $\Pi_N$ |
| | n | $\Pi_N$ <br> 0 | 0 <br> 0 |

Figure 3.1: Payoff matrix for two symmetric non-Annex I-countries

In the following, we will derive the payoffs $\Pi_N$ and $\widetilde{\Pi}_N$ for the case of one and two participating non-Annex I countries to derive the Nash equilibria of the game. In section 3.2.3 we solve the model, assuming that the market for emission certificates is competitive. Following the analysis in the case of a competitive market, we solve the model, assuming that the non-Annex I countries can act as oligopolists in the international emissions trading market in section 3.2.4.

### 3.2.3 Nash equilibria in a competitive market

Endogenously determined variables in case of a perfectly competitive market are labeled by $C$. Variables in case of two participating non-Annex I countries are in addition marked with a tilde.

We start by analyzing the case of two participating non-Annex I countries. To derive the non-Annex I countries' payoffs $\widetilde{\Pi}_N$, we solve the Annex I and non-Annex I countries' minimization problems given by equation (3.3). Market clearing condition (3.4) applies.[24]

The first order conditions yield a certificate market price equal to all countries' marginal abatement costs, i.e.

$$\widetilde{p}^C = \alpha_A \widetilde{r}_A^C = \alpha_N \widetilde{r}_{N1}^C = \alpha_N \widetilde{r}_{N2}^C \,. \tag{3.9}$$

By rearranging market clearing condition (3.4) to

$$\widetilde{r}_{N1}^C = \widetilde{r}_{N2}^C = \frac{T_A + 2T_N - r_A}{2} \,,$$

we derive the optimal emission reductions of the Annex I community as

$$\widetilde{r}_A^C = \frac{\alpha_N}{2\alpha_A + \alpha_N}(T_A + 2T_N) = \frac{1}{2\alpha + 1}\widetilde{T} \tag{3.10}$$

with $\widetilde{T} = T_A + 2T_N$ being the global reduction target in case of two participating non-Annex I countries as before. Applying (3.10) to (3.2.3) results in the optimal emission reductions of the non-Annex I countries being given by

$$\widetilde{r}_{N1}^C = \widetilde{r}_{N2}^C = \frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 2T_N) = \frac{\alpha}{2\alpha + 1}\widetilde{T} \,. \tag{3.11}$$

[24] A step-by-step derivation of the formula can be found in Appendix B.

From equation (3.9) it follows that the market price $\widetilde{p}^C$ in equilibrium is given by

$$\widetilde{p}^C = \frac{\alpha_A \alpha_N}{2\alpha_A + \alpha_N}(T_A + 2T_N) = \frac{\alpha_A}{2\alpha + 1}\widetilde{T}\,. \tag{3.12}$$

The above equations confirm that in a competitive market the price and optimal emission reductions are only determined by the total amount of emission reductions $\widetilde{T}$ and the slope of the countries' marginal abatement cost curves, but are independent of the individual countries' targets.

Having derived the equilibrium price and the optimal emission reductions, we can now determine the non-Annex I countries' payoff $\widetilde{\Pi}_N^C$ in a competitive market by combining (3.10), (3.11) and (3.12) with (3.7). This yields

$$\widetilde{\Pi}_N^C = \frac{\alpha_A}{2\alpha + 1}\left(\frac{\alpha}{2(2\alpha + 1)}\widetilde{T}^2 - \widetilde{T}T_N\right)\,. \tag{3.13}$$

Unlike optimal emission reductions and the market price for emission certificates, the non-Annex I countries' payoff depends not only on the global reduction target $\widetilde{T}$, but also on the non-Annex I countries' target and the slope of the Annex I community's marginal abatement cost curve. Hence, for the non-Annex I countries' payoff and, thus, the incentive to participate in the international emissions trading market, the no-lose target and the Annex I community's abatement potential have an important role in addition to the relative abatement potential $\alpha$ and the global reduction target.

For participation in the international emissions trading market to be profitable for both non-Annex I countries, the payoff $\widetilde{\Pi}_N^C$ needs to be positive. From equation (3.13) it follows that the participation constraint for two non-Annex I countries in a competitive market is fulfilled for

$$\frac{T_N}{T_A} \leq \frac{\alpha_A}{2(\alpha_A + \alpha_N)} = \frac{\alpha}{2(\alpha + 1)}\,. \tag{3.14}$$

We now turn to the case of only one participating non-Annex I country. Results in the case of one participating non-Annex I country are the same as the results derived in section 2.2.3 in the last chapter. They nevertheless are included here again for the sake of completeness. However, we refrain from presenting a detailed derivation of the formula.

To derive the participating non-Annex I country's payoff $\Pi_N^C$, we apply the same logic as before. In case of one participating non-Annex I country, market clearing condition (3.5) applies. Solving the minimization problems of one non-Annex I country and the Annex I community leads to

$$p^C = \alpha_A r_A^C = \alpha_N r_i^C \,. \tag{3.15}$$

Applying (3.5) to (3.15) yields

$$r_A^C = \frac{\alpha_N}{\alpha_A + \alpha_N}(T_A + T_N) = \frac{1}{\alpha + 1} T \tag{3.16}$$

as optimal emission reductions for the Annex I country with $T = T_A + T_N$ describing the global reduction target in the case of one participating non-Annex I country. The optimal emission reductions of the participating non-Annex I country are given by

$$r_i^C = \frac{\alpha_A}{\alpha_A + \alpha_N}(T_A + T_N) = \frac{\alpha}{\alpha + 1} T \tag{3.17}$$

and the market price in equilibrium is given by

$$p^C = \frac{\alpha_A \alpha_N}{\alpha_A + \alpha_N}(T_A + T_N) = \frac{\alpha_A}{\alpha + 1} T \,. \tag{3.18}$$

As in case of two participating non-Annex I countries, the equations show that the optimal emissions and the market price depend on the slope of the countries' marginal abatement cost curves and the global emission target $T$, but are independent of the no-lose target and the Annex I countries' targets.

Applying the equations (3.16), (3.17) and (3.18) to (3.7) yields the payoff $\Pi_N^C$ for one participating non-Annex I country in a competitive market as

$$\Pi_N^C = \frac{\alpha_A}{\alpha + 1}\left(\frac{\alpha}{2(\alpha + 1)} T^2 - T T_N\right) \,. \tag{3.19}$$

As before, the non-Annex I country's payoff not only depends on the ratio $\alpha$ and the global reduction target, but also on the slope of the Annex I community's marginal abatement cost curve and the no-lose target.

For the participation constraint to be fulfilled for one non-Annex I country, the following condition can be derived from (3.19)

$$\frac{T_N}{T_A} < \frac{\alpha_A}{\alpha_A + 2\alpha_N} = \frac{\alpha}{\alpha + 2} \,. \tag{3.20}$$

The resulting payoff matrix for the two non-Annex I countries is given in Figure 3.2.

To derive the Nash equilibria[25] of the participation game, we need to further specify the payoffs $\widetilde{\Pi}_N^C$ and $\Pi_N^C$. Comparing relations (3.13) and (3.19), it can be seen that the payoff in the case of two participating non-Annex I countries given by relation (3.13) is lower than the payoff in the case of one participating non-Annex I country given by relation (3.19).[26] Thus, a profitable no-lose target can be more ambitious in case of one participating non-Annex I country than in case of two participating non-Annex I countries.

With the derived payoffs, three cases can be distinguished:

(i) $\widetilde{\Pi}_N^C < 0, \Pi_N^C < 0$, i.e. the no-lose target is neither profitable in the case of two nor in the case of one participating non-Annex I countries;

(ii) $\widetilde{\Pi}_N^C > 0, \Pi_N^C > 0$, i.e. the no-lose target is profitable if one as well as two non-Annex I countries participate;

(iii) $\widetilde{\Pi}_N^C < 0, \Pi_N^C > 0$, i.e. the no-lose target is profitable if one non-Annex I country participates, but not profitable if both non-Annex I countries participate.

In the first case, the payoffs $\widetilde{\Pi}_N^C$ and $\Pi_N^C$ are negative. This yields non-participation as being the dominant strategy for the two non-Annex I countries. That is, a non-Annex I country can never profit from participating in the international emissions trading market independent of the other non-Annex I country's decision. Hence, the Nash equilibrium is given by (n,n). From the participation constraint for one non-Annex I country (3.14) follows that this case results if

$$\frac{T_N}{T_A} > \frac{\alpha}{\alpha + 2} \tag{3.21}$$

applies for the ratio of the Annex I community's target and the no-lose target. Resulting payoffs for the two non-Annex I countries are $(0, 0)$.

Similarly, in the second case, all payoffs are positive and, hence, participation is the dominant strategy for both non-Annex I countries, i.e. the best

[25]The Nash equilibrium is defined as a profile of strategies such that each player's strategy is an optimal response to the other players' strategies. For a more formal definition, see e.g. Fudenberg and Tirole (1996).

[26]The proof is provided in Appendix B.

strategy independent of the other non-Annex I country's decision. Thus, the resulting Nash equilibrium is given by (p,p). From (3.20) follows that the second case results if

$$\frac{T_N}{T_A} < \frac{\alpha}{2(\alpha+1)} \tag{3.22}$$

holds. Payoffs for the non-Annex I countries are $(\widetilde{\Pi}_N^C, \widetilde{\Pi}_N^C)$.

The third case is characterized by two asymmetric pure-strategy Nash equilibria[27] given by (p,n) and (n,p). Thus, participation of one non-Annex I country is only profitable if the other non-Annex I country decides to stay out of the market. Otherwise, demand for emission certificates is not high enough to cover the costs from the no-lose targets for both non-Annex I countries. Case 3 occurs for

$$\frac{\alpha}{\alpha+2} > \frac{T_N}{T_A} > \frac{\alpha}{2(\alpha+1)} \, . \tag{3.23}$$

The non-Annex I countries' payoffs are given by $(\Pi_N^C, 0)$ and $(0, \Pi_N^C)$ respectively.[28]

In contrast to the non-Annex I countries' payoffs, the conditions for one, respectively two, participating non-Annex I countries being the Nash equilibrium of the participation game are determined by $\alpha$ only, i.e. the abatement ratio of the non-Annex I countries and the Annex I community. Further, the relations (3.21) and (3.22) show that profitable no-lose targets, even if they are only profitable in the case of one participating non-Annex I country, cannot be more ambitious than the Annex I community's aggregated reduction target. In the case of two participating non-Annex I countries being the Nash equilibrium, reductions from the individual no-lose targets are even lower than 1/2 of the Annex I community's reduction target. Hence, total contributions from no-lose targets remain below the Annex I community's share.

[27] In addition, a mixed-strategy Nash equilibrium exists with participation being played with a probability of $\frac{\Pi_N^C}{\widetilde{\Pi}_N^C + \Pi_N^C}$. The mixed-strategy equilibrium will not be included in this analysis.

[28] The third case is identical to the hawk-dove game introduced by Smith and Price (1973). In contrast to coordination games like the battle of sexes, anti-coordination is the preferable situation for both players in this game.

### 3.2.4 Nash equilibria in a market with market power

In this section, we analyze the participation game introduced before assuming market power on the part of the non-Annex I countries instead of a competitive market. Market power is modeled in the form of a Cournot duopoly. That is, the non-Annex I countries take the price-taking behavior of the Annex I community into account when determining their payoffs. Non-Annex I countries compete in quantities (in this case of emission certificates) rather than in prices (Mas-Colell, Whinston, & Green, 1995). All endogenously determined variables are labeled by $P$. As before, parameters for two participating non-Annex I countries are marked with a tilde.

To derive the non-Annex I countries' payoffs $\Pi_N^P$ and $\widetilde{\Pi}_N^P$, we start by determining optimal emission reductions and market prices for emission certificates for one and two participating non-Annex I countries. The non-Annex I countries take the price-taking behavior of the Annex I community into account when deciding on their emission reductions and, hence, the number of emission certificates to be sold. From the market clearing conditions (3.4) and (3.5) it follows that the Annex I community's emission reductions are described by the functional relation $r_A = h(r_{N1}, r_{N2})$ with

$$\widetilde{h}(r_{N1}, r_{N2}) = T_A - (r_{N1} - T_N) - (r_{N2} - T_N) = \widetilde{T} - r_{N1} - r_{N2} \qquad (3.24)$$

in case of two participating non-Annex I countries and

$$h(r_i) = T_A - (r_i - T_N) = T - r_i \qquad (3.25)$$

in case of one participating non-Annex I country $i$.

We start by analyzing the case of two participating non-Annex I countries. A detailed derivation of the formula is provided in Appendix B.

The solution to the Annex I community's optimization problem (3.3) assuming price-taking behavior and applying (3.24) yields

$$\widetilde{p}^P = \alpha_A \widetilde{r}_A^P = \alpha_A(T_A - (\widetilde{r}_{N1}^P - T_N) - (\widetilde{r}_{N2}^P - T_N)) \,. \qquad (3.26)$$

To solve the optimization problem of the non-Annex I country $N1$, we apply (3.26) to (3.3). Equating the first derivative to zero results in

$$\widetilde{r}_{N1}^{P} = \frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 3T_N - \widetilde{r}_{N2}^{P}) = \frac{\alpha}{2\alpha + 1}(T_A + 3T_N - \widetilde{r}_{N2}^{P})\,. \tag{3.27}$$

Due to symmetry between the two non-Annex I countries, optimal emission reductions of $N2$ are given by

$$\widetilde{r}_{N2}^{P} = \frac{\alpha}{2\alpha + 1}(T_A + 3T_N - \widetilde{r}_{N1}^{P})\,. \tag{3.28}$$

Applying (3.27) to (3.28) results in optimal emission reductions of the non-Annex I countries of

$$\widetilde{r}_{N1}^{P} = \widetilde{r}_{N2}^{P} = \frac{\alpha_A}{3\alpha_A + \alpha_N}(T_A + 3T_N) = \frac{\alpha}{3\alpha + 1}(\widetilde{T} + T_N)\,. \tag{3.29}$$

Applying (3.29) to (3.24) yields optimal emission reductions of the Annex I community of

$$\begin{aligned}\widetilde{r}_{A}^{P} &= \frac{\alpha_N}{3\alpha_A + \alpha_N}(T_A + 2T_N) + \frac{\alpha_A}{3\alpha_A + \alpha_N}T_A \\ &= \frac{1}{3\alpha + 1}\widetilde{T} + \frac{\alpha}{3\alpha + 1}T_A\,.\end{aligned} \tag{3.30}$$

Applying (3.30) to (3.26) yields a market price of

$$\begin{aligned}\widetilde{p}^{P} &= \frac{\alpha_A\alpha_N}{3\alpha_A + \alpha_N}(T_A + 2T_N) + \frac{\alpha_A^2}{3\alpha_A + \alpha_N}T_A \\ &= \frac{\alpha_A}{3\alpha + 1}\widetilde{T} + \frac{\alpha\alpha_A}{3\alpha + 1}T_A\,.\end{aligned} \tag{3.31}$$

Note that in contrast to the case of a competitive market, where optimal emission reductions only depend on the global reduction target, the non-Annex I countries' no-lose target has an additional impact on the countries' optimal emission reductions in case of market power and, hence, also on the market price for emission certificates.

Applying (3.29), (3.30) and (3.31) to (3.7) yields a non-Annex I country's payoff in case of two participating non-Annex I countries of

$$\begin{aligned}\widetilde{\Pi}_N^P = \frac{\alpha_A}{(3\alpha_A + \alpha_N)^2} \Bigg( & \left( \left( \alpha_A^2 + \frac{1}{2}\alpha_A\alpha_N \right) T_A^2 - \left(2\alpha_A\alpha_N + \alpha_N^2\right) T_A T_N \right. \\ & \left. - \left( \frac{9}{2}\alpha_A\alpha_N + 2\alpha_N^2 \right) T_N^2 \right) . \end{aligned} \tag{3.32}$$

For the participation constraint in case of two non-Annex I countries in the market power case to be fulfilled, the following condition has to hold

$$\frac{T_N}{T_A} < \frac{\alpha_A}{\alpha_N + (3\alpha_A + \alpha_N)\sqrt{\frac{\alpha_N}{2\alpha_A + \alpha_N}}} = \frac{\alpha\sqrt{2\alpha + 1}}{3\alpha + 1 + \sqrt{2\alpha + 1}} . \tag{3.33}$$

We now turn to the case of one participating non-Annex I country. Again, the results in case of one participating non-Annex I country are the same as the results derived in section 2.2.4 of the last chapter, but are included here again for the sake of completeness.

In the case of one participating non-Annex I country, the participating non-Annex I country can act as monopolist in the international emissions trading market, i.e. it is the only non-Annex I country supplying emission certificates to the market. Applying (3.25) and solving the Annex I community's minimization problem (3.3) results in

$$p^P = \alpha_A r_A^P = \alpha_A \left( T_A - \left( r_i^P - T_N \right) \right) . \tag{3.34}$$

Applying (3.34) to (3.3) and solving the non-Annex I country's optimization problem yields optimal emission reductions of

$$r_i^P = \frac{\alpha_A}{2\alpha_A + \alpha_N} \left( T_A + 2T_N \right) = \frac{\alpha}{2\alpha + 1} \left( T + T_N \right) . \tag{3.35}$$

Applying (3.35) to market clearing condition (3.5) yields optimal emission reductions of the Annex I community of

$$\begin{aligned} r_A^P &= \frac{\alpha_N}{2\alpha_A + \alpha_N}(T_A + T_N) + \frac{\alpha_A}{2\alpha_A + \alpha_N} T_A \\ &= \frac{1}{2\alpha + 1} T + \frac{\alpha}{2\alpha + 1} T_A . \end{aligned} \tag{3.36}$$

Hence, the market price is given by

$$\begin{aligned} p^P &= \frac{\alpha_A \alpha_N}{2\alpha_A + \alpha_N}(T_A + T_N) + \frac{\alpha_A^2}{2\alpha_A + \alpha_N} T_A \\ &= \frac{\alpha_A}{2\alpha + 1} T + \frac{\alpha \alpha_A}{2\alpha + 1} T_A \,. \end{aligned} \tag{3.37}$$

Applying (3.35), (3.36) and (3.37) to (3.7) yields a payoff for one participating non-Annex I country of

$$\Pi_N^P = \frac{\alpha_A}{2\alpha_A + \alpha_N} \left( \frac{1}{2} \alpha_A T_A^2 - \alpha_N T_A T_N - \alpha_N T_N^2 \right) . \tag{3.38}$$

For the participation constraint in case of one non-Annex I country with market power to be fulfilled, the following relation has to hold

$$\frac{T_N}{T_A} < \frac{\alpha_A}{\alpha_N + \sqrt{2\alpha_A \alpha_N + \alpha_N^2}} = \frac{\alpha}{1 + \sqrt{2\alpha + 1}} \,. \tag{3.39}$$

Having derived the payoffs $\widetilde{\Pi}_N^P$ and $\Pi_N^P$, we can specify the payoff matrix in case of market power (see Figure 3.3).

To determine the Nash equilibria in case of market power, we compare the non-Annex I countries' payoffs $\widetilde{\Pi}_N^P$ and $\Pi_N^P$. The comparison shows that, similar to the competitive market case, payoffs for one participating non-Annex I country are higher than payoffs for two participating non-Annex I countries, i.e. $\Pi_N^P > \widetilde{\Pi}_N^P$ holds.[29] Hence, similar to the competitive market case, three cases can arise:

(i) $\widetilde{\Pi}_N^P < 0, \Pi_N^P < 0$, i.e. the no-lose target is neither profitable in case of two nor in case of one participating non-Annex I country;

(ii) $\widetilde{\Pi}_N^P > 0, \Pi_N^P > 0$, i.e. the no-lose target is profitable if one as well as two non-Annex I countries participate;

(iii) $\widetilde{\Pi}_N^P < 0, \Pi_N^P > 0$, i.e. the no-lose target is profitable if one non-Annex I country participates, but is not profitable if both non-Annex I countries participate

In the first case, non-participation is the dominant strategy for both non-Annex I countries. Hence, the Nash equilibrium is given by (n,n) and payoffs

[29] The proof is given in Appendix B.

are $(0,0)$. From the participation constraint for two non-Annex I countries it follows that under market power conditions the first case occurs for

$$\frac{T_N}{T_A} > \frac{\alpha\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}}\,. \tag{3.40}$$

In the second case, all payoffs are positive and, hence, participation is the dominant strategy for both non-Annex I countries. That is, participation is profitable, independent of the other non-Annex I country's decision. The Nash equilibrium is given by (p,p) with payoffs $(\widetilde{\Pi}_N^P, \widetilde{\Pi}_N^P)$. From the participation constraint follows that the second case results if

$$\frac{T_N}{T_A} < \frac{\alpha}{1+\sqrt{2\alpha+1}} \tag{3.41}$$

holds.

The third case again yields two asymmetric pure-strategy Nash equilibria[30] with (p,n) and (n,p). That is, participation is only profitable for a non-Annex I country if the other non-Annex I country decides not to participate. The payoffs are given by $(\Pi_N^P, 0)$ and $(0, \Pi_N^P)$. This case occurs if the following condition applies for the target ratio $\frac{T_N}{T_A}$

$$\frac{\alpha}{1+\sqrt{2\alpha+1}} > \frac{T_N}{T_A} > \frac{\alpha\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}}\,. \tag{3.42}$$

As in the competitive market case, the conditions for one, respectively two, participating non-Annex I countries being the Nash equilibria of the participation game are solely determined by $\alpha$. In contrast to the conditions in the competitive market, the reductions from the no-lose target are, however, not limited. In particular, the contribution from no-lose targets to global emission reductions can, thus, be higher than 50% of the global emission reduction effort and, hence, larger than the contribution from the Annex I community. The same result was found to be true for one participating non-Annex I country in chapter 2. As it is an important result, it is mentioned again here.

In the following sections, we will derive implications of applying no-lose targets to two non-Annex I countries on global emission reductions and impacts

[30] Here as well, a mixed-strategy Nash equilibrium exists where participation is played with a probability of $\frac{\Pi_N^P}{\widetilde{\Pi}_N^P + \Pi_N^P}$. The mixed-strategy equilibrium will not be included in this analysis.

on the international emissions trading market based on the formula derived above. We will begin by applying the same fixed no-lose targets for the case of one and two participating non-Annex I countries and analyze the impacts on the emissions trading market in section 3.4. That part of the analysis provides general insights on the effects of increased participation by non-Annex I countries. However, the analysis of fixed no-lose targets does not take into account if the no-lose target is profitable for one or two non-Annex I countries at all. Hence, we determine and analyze the impacts of the "optimal no-lose targets" in section 3.5 which take into account the Nash equilibria of the participation game analyzed above. Before turning to the analysis of the impacts of no-lose targets, a short analysis of the main decision parameter of the non-Annex I countries, the payoffs, is provided in the following section.

| | | Player 2: p | Player 2: n |
|---|---|---|---|
| Player 1 | p | $\frac{\alpha_A\alpha_N}{(2\alpha_A+\alpha_N)^2}\left(T_A+2T_N\right)\left(\frac{1}{2}\alpha_A T_A-\left(\alpha_A+\alpha_N\right)T_N\right)$<br>$\frac{\alpha_A\alpha_N}{(2\alpha_A+\alpha_N)^2}\left(T_A+2T_N\right)\left(\frac{1}{2}\alpha_A T_A-\left(\alpha_A+\alpha_N\right)T_N\right)$ | $0$<br>$\frac{\alpha_A\alpha_N}{(\alpha_A+\alpha_N)^2}\left(T_A+T_N\right)\left(\frac{1}{2}\alpha_A T_A-\left(\frac{1}{2}\alpha_A+\alpha_N\right)T_N\right)$ |
| | n | $\frac{\alpha_A\alpha_N}{(\alpha_A+\alpha_N)^2}\left(T_A+T_N\right)\left(\frac{1}{2}\alpha_A T_A-\left(\frac{1}{2}\alpha_A+\alpha_N\right)T_N\right)$<br>$0$ | $0$<br>$0$ |

Figure 3.2: Payoffs $\widetilde{\Pi}_N^C$ and $\Pi_N^C$ for two non-Annex I countries in a competitive market game

| | | Player 2: p | Player 2: n |
|---|---|---|---|
| Player 1 | p | $\frac{\alpha_A}{(3\alpha_A+\alpha_N)^2}\left(\left(\frac{1}{2}\alpha_A\alpha_N+\alpha_A^2\right)T_A^2\right.$ $\left.-\left(\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2\right)T_AT_N-\left(2\alpha_A\alpha_N+\alpha_N^2\right)T_N^2\right)$<br>$\frac{\alpha_A}{(3\alpha_A+\alpha_N)^2}\left(\left(\frac{1}{2}\alpha_A\alpha_N+\alpha_A^2\right)T_A^2\right.$ $\left.-\left(\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2\right)T_AT_N-\left(2\alpha_A\alpha_N+\alpha_N^2\right)T_N^2\right)$ | $0$<br>$\frac{\alpha_A}{2\alpha_A+\alpha_N}\left(\frac{1}{2}\alpha_A T_A^2-\alpha_N T_A T_N-\alpha_N T_N^2\right)$ |
| | n | $\frac{\alpha_A}{2\alpha_A+\alpha_N}\left(\frac{1}{2}\alpha_A T_A^2-\alpha_N T_A T_N-\alpha_N T_N^2\right)$<br>$0$ | $0$<br>$0$ |

Figure 3.3: Payoffs $\widetilde{\Pi}_N^P$ and $\Pi_N^P$ for two non-Annex I countries in a game with market power

## 3.3 Characteristics of non-Annex I countries' payoffs

In the modeling framework introduced in the previous chapter, the main factor determining whether a no-lose target is profitable are the non-Annex I countries' payoffs, which were derived in the last section. As the formula in the last section showed, while the participation constraints are determined by the countries' reduction potential ratio $\alpha$ only, the non-Annex I countries' payoffs are determined by the countries' slope of the marginal abatement cost curves $\alpha_A$ and $\alpha_N$ as well as the targets $T_A$ and $T_N$. We will use this section to derive the main characteristics of the non-Annex I countries' payoff functions, i.e. the monotonicity with respect to $\alpha_A$, $\alpha_N$, $T_A$ and $T_N$. The analysis will show that differences exist in the payoff functions depending on the market form.

The following proposition indicates the payoff's dynamics with respect to $\alpha_A$ and $\alpha_N$.

**Proposition 7.** *For the non-Annex I country's payoffs in case of no-lose targets, the following holds:*

*(i) The non-Annex I countries' payoffs increase with $\alpha_A$ independent of the number of participating non-Annex I countries and independent of the market form.*

*(ii) In a competitive market, the non-Annex I countries' payoffs increase with $\alpha_N$ for $\frac{T_N}{T_A} < \frac{2\alpha_A - \alpha_N}{4\alpha_A + 6\alpha_N}$ in the case of two participating non-Annex I countries, and for $\frac{T_N}{T_A} < \frac{\alpha_A - \alpha_N}{\alpha_A + 3\alpha_N}$ in the case of one participating non-Annex I country.*

*In the case of market power, the non-Annex I countries' payoffs decrease with $\alpha_N$ independent of the number of participating non-Annex I countries.*

The proof is presented in Appendix B. One insight from Proposition 7 is that the dynamics of the payoff functions are independent of the number of participating non-Annex I countries. Hence, the results can be generalized for a larger number of symmetric non-Annex I countries facing no-lose targets.

Further, as part (i) of the proposition states, the non-Annex I countries' payoffs in case of no-lose targets are positively correlated with the slope of the

Annex I community's marginal abatement cost curve. Hence, higher abatement costs, i.e. lower reduction potential, in the Annex I community results in higher payoffs for the non-Annex I countries. This is immediately apparent as higher marginal abatement costs in the Annex I community allow the participating non-Annex I country/ countries to sell more emission certificates and, hence, the revenues from emissions trading increase. This applies independently of the market form.

In contrast, the impact of $\alpha_N$ can be ambiguous (part (ii) of the proposition) in the case of a competitive market. The impact is determined by the relationship of the target levels and the slopes of the marginal abatement cost curves. In particular, $\alpha$ needs to be larger than $1/2$ and 1, respectively in case of two and one participating non-Annex I countries for a positive correlation. That is, only then does an increasing $\alpha_N$ result in an increase in the non-Annex I countries' payoff. Further, the non-Annex I country's share on global emission reduction efforts cannot be too large compared to $\alpha$. More precisely, let an individual non-Annex I country's share in global emission reductions be given by $1/k$ and the Annex I community's share be given by $(k-2)/k$ and $(k-1)/k$ in the case of two and one participating non-Annex I countries. For the correlation to be positive, the following needs to hold:

$$\alpha < \frac{-(k+4)}{8-2k}$$

in case of two participating non-Annex I countries and

$$\alpha < \frac{-(k+2)}{2-k}$$

in case of one participating non-Annex I country. Hence, for larger values of $k$, i.e. a smaller share of the individual non-Annex I country in global emission reduction efforts, $\alpha$ can be smaller, i.e. the Annex I community's reduction potential compared to the non-Annex I country's reduction potential can be larger.

The impact of $\alpha_N$ in case of market power is again unambiguous, as is the case for $\alpha_A$. Hence, here higher marginal abatement costs, i.e. larger values for $\alpha_N$, result in lower payoffs as the costs increase.

Figures 3.4 and 3.5 give an example of the NAI countries' payoff functions. The values for the target levels and the slopes of the marginal abatement cost

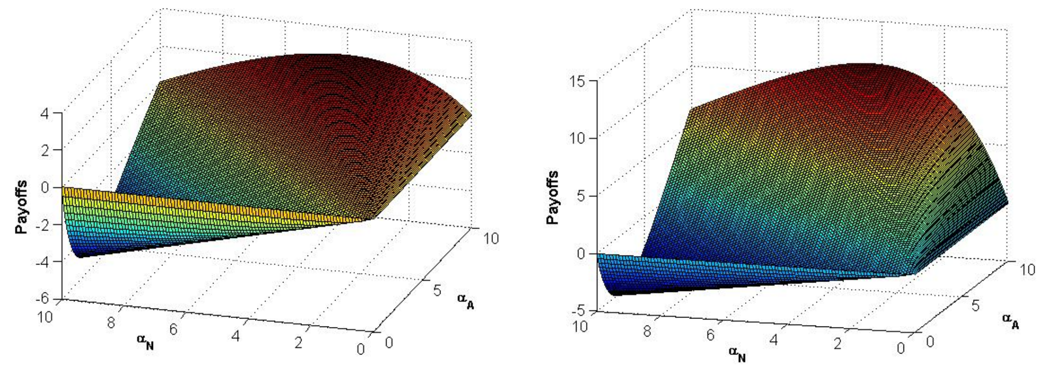


Figure 3.4: Non-Annex I country's payoff for two (left), respectively one (right) participating non-Annex I countries in a competitive market for $T_A = 4$ and $T_N = 1$

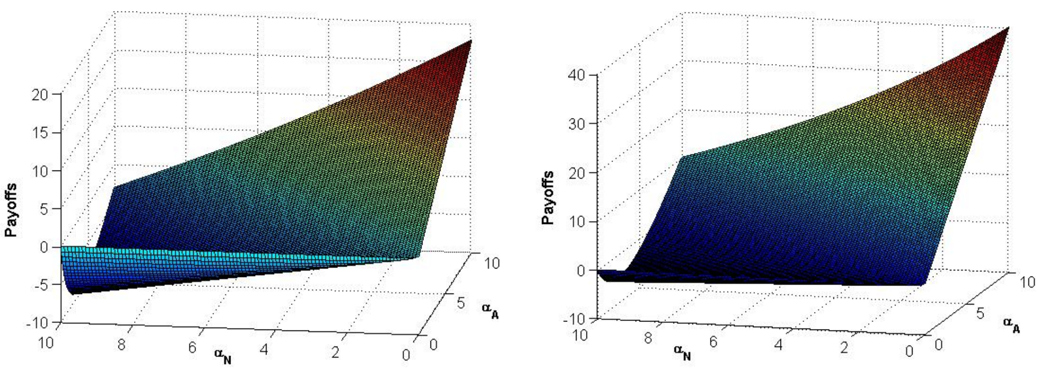


Figure 3.5: Non-Annex I country's payoff for two (left), respectively one (right) participating non-Annex I countries in a market power case for $T_A = 4$ and $T_N$=1

curves are chosen for illustrative purposes and are not meant to represent realistic values. Figure 3.4 shows the payoff function in the case of a competitive market. The impact of the ambiguous effect of $\alpha_N$ can clearly be seen in the shape of the function in the right picture. In contrast, the payoff function in the case of market power increases with $\alpha_A$ and decreases with $\alpha_N$ as can be seen in Figure 3.5.

The shape of the payoff function in the case of the competitive market has an important implication. It indicates that, under certain circumstances in the competitive market, the non-Annex I country is not interested in bringing down its marginal abatement costs as that would lower its payoffs. Bringing down the marginal abatement costs could lower the price for emission certificates and, hence, lead to a decrease in the country's payoffs, as it has to act as a price-taker in the market. This further implies that measures like R&D cooperation are not necessarily in the best interests of the non-Annex I country as would normally be assumed. This effect can, however, be prevented if the no-lose target is stringent enough.

In contrast to $\alpha_A$ and $\alpha_N$, the influence of the targets $T_A$ and $T_N$ on the non-Annex I country's payoff is always unambiguous.

**Proposition 8.** *For the non-Annex I country's payoffs applying no-lose targets, the following holds:*

*(i) The non-Annex I country's payoff increases with an increasing Annex I community's target.*

*(ii) The non-Annex I country's payoff decreases with an increasing non-Annex I country's no-lose target.*

The proof is also provided in Appendix B. The effects of the target levels are independent of the number of participating non-Annex I countries as well as of the market form. The AI community's target has an impact on the price for emission certificates, while not changing the non-Annex I country's abatement costs. Higher target levels increase the demand for emission certificates from Annex I countries, thus leading to an increase in the price for emission certificates. The higher price increases the non-Annex I country's revenue from selling certificates, hence leading to increases in the payoffs. In contrast, a higher no-lose target level increases the non-Annex I country's abatement costs and reduces the supply of emission certificates. The proposition states that these effects in sum cannot be compensated by higher prices for certificates, hence resulting in lower payoffs.

## 3.4 Effects of increased participation

As indicated above, the remainder of this chapter will be used to derive the implications of no-lose targets for the international emissions trading market and for global emission reduction efforts. For the analyses in this section, we apply the same fixed reduction targets $T_N$ and $T_A$ in the case of one and two participating non-Annex I countries. Global emission reductions would be $\widetilde{T} = T_A + 2T_N$ in the case of two participating non-Annex I countries and

$T = T_A + T_N$ in the case of one participating non-Annex I country. However, the no-lose targets are not necessarily profitable for one or two non-Annex I countries, hence it is not guaranteed that these global emission reductions are realized. Analyses of the optimal no-lose targets which take into account the Nash equilibria of the participation game will follow in section 3.5.

As in the case of fixed reduction targets it is not guaranteed that the no-lose targets are profitable and, hence, will result in one or two of the non-Annex I countries contributing to global emission reduction efforts, we do not need to analyze the effects on global emission reductions. Instead, we immediately turn to the analysis of the impacts on the emissions trading market. Comparing optimal emission reductions and market prices in the case of one and two participating non-Annex I countries yields the following results.

**Proposition 9.** *Let $T_A$ and $T_N$ be the exogenously fixed emission reduction targets for the AI community and the NAI countries. Independent of the market form, the following holds:*

*(i) Optimal emission reductions of the Annex I community negatively depend on $\alpha$ and the Annex I community's optimal emission reductions are lower for two participating non-Annex I countries than for one participating non-Annex I country, i.e. $\widetilde{r}_A^C < r_A^C$ and $\widetilde{r}_A^P < r_A^P$.*

*(ii) Optimal emission reductions of the participating non-Annex I country positively depend on $\alpha$ and the non-Annex I country's optimal emission reductions are lower for two participating non-Annex I countries than for one participating non-Annex I country, i.e. $\widetilde{r}_i^C < r_i^C$ and $\widetilde{r}_i^P < r_i^P$.*

*(iii) The market price for emission certificates positively depends on $\alpha_A$ and $\alpha_N$ and is lower for two participating non-Annex I countries than for one participating non-Annex I country, i.e. $\widetilde{p}^C < p^C$ and $\widetilde{p}^P < p^P$.*

*Proof.* The first derivatives with respect to $\alpha$ are given by

$$\begin{aligned}
\frac{d\widetilde{r}_A^C}{d\alpha} &= -\frac{2}{(2\alpha+1)^2}\widetilde{T} < 0 \\
\frac{dr_A^C}{d\alpha} &= -\frac{1}{(\alpha+1)^2}T < 0 \\
\frac{d\widetilde{r}_A^P}{d\alpha} &= -\frac{2}{(3\alpha+1)^2}T_A - \frac{6}{(3\alpha+1)^2}T_N < 0
\end{aligned}$$

$$\frac{dr_A^P}{d\alpha} = -\frac{1}{(2\alpha+1)^2}T_A - \frac{2}{(2\alpha+1)^2}T_N < 0$$

and

$$\begin{aligned}
\frac{d\widetilde{r}_i^C}{d\alpha} &= \frac{1}{(2\alpha+1)^2}\widetilde{T} > 0 \\
\frac{dr_i^C}{d\alpha} &= \frac{1}{(\alpha+1)^2}T > 0 \\
\frac{d\widetilde{r}_i^P}{d\alpha} &= \frac{1}{(3\alpha+1)^2}(\widetilde{T} + T_N) > 0 \\
\frac{dr_i^P}{d\alpha} &= \frac{1}{(2\alpha+1)^2}(T + T_N) > 0\,.
\end{aligned}$$

Thus, the first parts of (i) and (ii) are proved.

For the second part of (i) in a competitive market it is

$$\begin{aligned}
& & \widetilde{r}_A^C &< r_A^C \\
&\Leftrightarrow & \frac{1}{2\alpha+1}(T_A + 2T_N) &< \frac{1}{\alpha+1}(T_A + T_N) \\
&\Leftrightarrow & (\alpha + 1 - 2\alpha - 1)T_A &< (2\alpha + 1 - 2\alpha - 2)T_N \\
&\Leftrightarrow & \frac{T_N}{T_A} &< \alpha\,.
\end{aligned}$$

This is always fulfilled if the targets applied are no-lose targets (condition (3.1)).

For the market power case it is

$$\begin{aligned}
& & \widetilde{r}_A^P &< r_A^P \\
&\Leftrightarrow & \frac{1}{3\alpha+1}(T_A + 2T_N) + \frac{\alpha}{3\alpha+1}T_A &< \frac{1}{2\alpha+1}(T_A + T_N) + \frac{\alpha}{2\alpha+1}T_A \\
&\Leftrightarrow & (\alpha+1)T_N &< (\alpha+1)\alpha T_A \\
&\Leftrightarrow & \frac{T_N}{T_A} &< \alpha\,.
\end{aligned}$$

Again, this is fulfilled if (3.1) holds.

For the second part of (ii) in a competitive market it is

$$\begin{aligned} & \widetilde{r}_i^C < r_i^C \\ \Leftrightarrow \quad & \frac{\alpha}{2\alpha+1}(T_A + 2T_N) < \frac{\alpha}{\alpha+1}(T_A + T_N) \\ \Leftrightarrow \quad & (\alpha + 1 - 2\alpha - 1)T_A < (2\alpha + 1 - 2\alpha - 2)T_N \\ \Leftrightarrow \quad & \frac{T_N}{T_A} < \alpha \,. \end{aligned}$$

This is always fulfilled when applying no-lose targets (condition (3.1)).

In case of market power it is

$$\begin{aligned} & \widetilde{r}_i^P < r_i^P \\ \Leftrightarrow \quad & \frac{\alpha}{3\alpha+1}(T_A + 3T_N) < \frac{\alpha}{2\alpha+1}(T_A + 2T_N) \\ \Leftrightarrow \quad & (6\alpha + 3 - 6\alpha - 2)T_N < (3\alpha + 1 - 2\alpha - 1)T_A \\ \Leftrightarrow \quad & \frac{T_N}{T_A} < \alpha \,. \end{aligned}$$

This follows from (3.1). Hence, the second part of (ii) is proved.

For the first part of (iii), from $p = \alpha_A r_A$ follows:

$$\frac{dp}{d\alpha_A} = r_A + \alpha_A \frac{dr_A}{d\alpha_A}$$

and

$$\frac{dp}{d\alpha_N} = \alpha_A \frac{dr_A}{d\alpha_N} \,.$$

From $\frac{dr_A}{d\alpha_N} = \frac{dr_A}{d\alpha}\frac{d\alpha}{d\alpha_N}$ and $\frac{d\alpha}{d\alpha_N} = -\frac{\alpha_A}{\alpha_N^2}$ follows

$$\frac{dp}{d\alpha_N} > 0$$

for the derivatives with respect to $\alpha_N$.

The following holds for the first derivative of $\alpha$ with respect to $\alpha_A$:

$$\frac{d\alpha}{d\alpha_A} = \frac{1}{\alpha_N} \,.$$

For the first derivative of the market price $p$ with respect to $\alpha_A$ it follows from the above derivatives and the derivatives $\frac{dr_A}{d\alpha}$ that

$$\begin{aligned}
\frac{d\widetilde{p}^C}{d\alpha_A} &= \frac{1}{(2\alpha+1)^2}\widetilde{T} > 0\,,\\
\frac{dp^C}{d\alpha_A} &= \frac{1}{(\alpha+1)^2}T > 0\,,\\
\frac{d\widetilde{p}^P}{d\alpha_A} &= \frac{3\alpha^2+2\alpha+1}{(3\alpha+1)^2}T_A + \frac{2}{(3\alpha+1)^2}T_N > 0\,,\\
\frac{dp^P}{d\alpha_A} &= \frac{2\alpha^2+2\alpha+1}{(2\alpha+1)^2}T_A + \frac{1}{(2\alpha+1)^2}T_N > 0\,.
\end{aligned}$$

The second part of (iii) follows in both cases from (i) with $p = \alpha_A r_A$. □

As global emission reductions resulting in the case of one and two participating non-Annex I countries differ in the above proposition, comparing results with regards to emission reductions and prices is difficult. Nonetheless, two effects can be found. First, although participation by two non-Annex I countries results in higher global emission reductions, the market price for emission certificates in the case of two participating non-Annex I countries is lower than in the case of only one participating non-Annex I country. This result is reasonable, as the non-Annex I countries act as sellers of emission certificates in the international emissions trading market. Hence, increased participation from non-Annex I countries increases the supply of emission certificates in the market and, thus, lowers the price.

Second, the lower price for emission certificates affects both the Annex I community's and the non-Annex I countries' optimal emission reductions. In the case of the non-Annex I countries' optimal emission reductions, the lower price leads to a decrease in the individual countries' optimal emission reductions. In contrast, non-Annex I countries' total emission reductions increase, thereby allowing the Annex I community to reduce less emissions at home and buy more certificates in the international emissions trading market. That means, if one of the non-Annex I countries drops out of the emissions trading market, the remaining non-Annex I country can increase its emission reductions. Hence, the number of emission certificates it can sell to the Annex I community increases. However, the increase is not high enough to compensate for the supply of emission certificates from the second non-Annex I country.

Hence, from the point of view of a non-Annex I country, participation of another non-Annex I country has two negative effects: it reduces the number of certificates it can sell and, at the same time, lowers the price for emission certificates. Both factors negatively affect the non-Annex I country's payoff. In contrast, for the Annex I community, participation of two non-Annex I countries is favorable: it decreases the price for emission certificates and, at the same time, increases the supply of emission certificates in the market. This allows the Annex I community to reduce their domestic emission reduction efforts and buy cheaper emission certificates instead. These effects hold, independent of the market form.

The following proposition compares the impacts of no-lose targets on the emissions trading market in the case of market power with the impacts on a competitive market. Again, the same exogenously fixed reduction targets $T_A$ and $T_N$ are applied. The comparison shows the inefficiencies resulting from market power.

**Proposition 10.** *Let $T_A$ and $T_N$ be exogenously fixed emission reduction targets for the Annex I community and the non-Annex I countries. In the case of one, respectively two, participating non-Annex I countries, the following holds:*

*(i) The Annex I community's optimal emission reductions are higher in the case of market power than in the competitive market, i.e. $\widetilde{r}_A^P > \widetilde{r}_A^C$ and $r_A^P > r_A^C$.*

*(ii) The non-Annex I countries' optimal emission reductions are lower in the case of market power than in the competitive market, i.e. $\widetilde{r}_i^P < \widetilde{r}_i^C$ and $r_i^P < r_i^C$.*

*(iii) The market price for emission certificates is higher in the case of market power than in the competitive market, i.e. $\widetilde{p}^P > \widetilde{p}^C$ and $p^P > p^C$.*

*Proof.* For the Annex I community's emission reductions in the case of two participating non-Annex I countries, the following applies

$$\begin{aligned}\widetilde{r}_A^P - \widetilde{r}_A^C =& \frac{1}{3\alpha+1}\widetilde{T} - \frac{\alpha}{2\alpha+1}T_A - \frac{1}{2\alpha+1}\widetilde{T}\\ =& \frac{2\alpha}{(2\alpha+1)(3\alpha+1)}\left(\alpha T_A - T_N\right) .\end{aligned}$$

For this to be greater than zero, the term in brackets needs to be greater than zero, hence

$$\alpha T_A - T_N > 0 \Leftrightarrow \frac{T_N}{T_A} < \alpha .$$

This follows from (3.1).

For the Annex I community's emission reductions in the case of one participating non-Annex I country, the following applies

$$\begin{aligned} r_A^P - r_A^C =& \frac{1}{2\alpha+1}T + \frac{\alpha}{2\alpha+1}T_A - \frac{1}{\alpha+1}T \\ =& \frac{\alpha}{(2\alpha+1)(\alpha+1)}(\alpha T_A - T_N) \end{aligned}$$

The rest follows as above.

To show part (ii) of the proposition for two participating non-Annex I countries, the following applies:

$$\begin{aligned} \widetilde{r}_i^C - \widetilde{r}_i^P =& \frac{\alpha}{2\alpha+1}\widetilde{T} - \frac{\alpha}{3\alpha+1}(\widetilde{T} + T_N) \\ =& \frac{\alpha}{(2\alpha+1)(3\alpha+1)}\left(\alpha T_A - T_N\right) . \end{aligned}$$

For this to be greater than zero, the term in brackets needs to be greater than zero which follows from (3.1).

Similarly, in the case of two participating non-Annex I countries the following inequality needs to hold

$$\begin{aligned} r_i^C - r_i^P =& \frac{\alpha}{\alpha+1}T - \frac{\alpha}{2\alpha+1}(T + T_N) \\ =& \frac{\alpha}{(2\alpha+1)(\alpha+1)}(\alpha T_A - T_N) . \end{aligned}$$

The rest follows as above.

Part (iii) of the proposition follows from the inequalities for the Annex I community and $p = \alpha_A r_A$. □

The results of Proposition (10) are well-known results for market power (see e.g. Hahn, 1984). In general, market power has the following effects on an emissions trading market: for a given target, the non-Annex I country/countries with market power realize less emission reductions than in the competitive market. Hence, the supply of emission certificates in the market is reduced. This results in higher prices for emission certificates, on the one hand, leading to higher domestic emission reductions by the Annex I community, on the other hand.

The higher market prices in case of market power compared to the competitive market also indicate that the emissions trading market in the case of market power does not allow reaching a given global reduction target cost efficiently. Although in general market power has a negative effect on the economic efficiency of an emissions trading market, we will show in the next section that market power can be used to increase the non-Annex I countries' no-lose targets. Thus, the negative effect on the economic efficiency can in parts be offset by an increase in the environmental effectiveness of the no-lose targets.

## 3.5 Optimal no-lose targets and their impact

### 3.5.1 The optimal no-lose target

In the last section, we analyzed the implications of increased participation by non-Annex I countries applying fixed no-lose targets. The fixed no-lose targets did not take into account Nash equilibria of the participation game determined in the last section. Hence, the no-lose targets analyzed so far were not necessarily profitable. In this section, we will restrict the analyses to profitable no-lose targets. Similar to the analyses in chapter 2, we define "optimal no-lose targets" which account for the Nash equilibria of the participation game and, hence, are profitable for one or two non-Annex I countries.

**Definition 2.** *A no-lose target is called* optimal *if it meets the following two requirements:*

*(i) The no-lose target is as ambitious as possible.*

*(ii) The sum of the non-Annex I country's costs and revenues from emission reduction and trading are zero.*

It is easy to see that the optimal no-lose target for one and two participating non-Annex I countries is given by the limits of the participation constraints.

**Proposition 11.** *The optimal no-lose targets in a competitive market are given by*

$$\widetilde{T}_N^C = \frac{\alpha}{2(\alpha+1)} T_A$$

*in the case of two participating non-Annex I countries and by*

$$T_N^C = \frac{\alpha}{\alpha + 2} T_A$$

*in the case of one participating non-Annex I country.*

*Similarly, in case of market power the optimal no-lose targets are given by*

$$\widetilde{T}_N^P = \frac{\alpha\sqrt{2\alpha + 1}}{3\alpha + 1 + \sqrt{2\alpha + 1}} T_A$$

*in case of two participating non-Annex I countries and by*

$$T_N^P = \frac{\alpha}{1 + \sqrt{2\alpha + 1}} T_A$$

*in case of one participating non-Annex I country.*

*Proof.* The limits of the participation constraints are the highest no-lose target that one, respectively two, non-Annex I countries are willing to accept with the conditions for a Nash equilibrium still being intact. Hence requirement (i) is met. Since the optimal no-lose target is determined by the participation constraint which is determined by the non-Annex I country's payoff, requirement (ii) is fulfilled. □

Hence, in the case of two non-Annex I countries facing no-lose targets, the optimal no-lose targets are characterized by three properties. First, they ensure that participation by one, respectively two, non-Annex I countries is a Nash equilibrium of the participation game introduced in section 3.2. This characteristic arises from the induced interaction between non-Annex I countries and was, hence, left out in chapter 3. The other two characteristics are identical to the characteristics of the optimal no-lose targets discussed in chapter 3: second, the optimal no-lose targets ensure that the non-Annex I countries' contribution to emission reductions is as large as possible. Third, the optimal no-lose targets do not allow the participating non-Annex I countries to generate positive payoffs from trading in the international emissions trading market. Hence, they prevent that large financial profits can be generated by the non-Annex I countries.

We discussed before that the third characteristic is a good reason to make no-lose targets more acceptable for Annex I countries, which have to carry the total costs of the emission reductions through the emissions trading market, although non-Annex I countries provide part of the reductions themselves. For the following analyses, the characteristics one and two are, however, more important. They ensure that the no-lose targets are profitable and that they are chosen in a way to maximize the non-Annex I countries' contribution to global emission reductions for one and two non-Annex I countries.

A comparison of the payoffs in section 3.2 showed that, for a given no-lose target, the payoff in the case of one participating non-Annex I country is always higher than the payoff in case of two participating non-Annex I countries. From this follows immediately that the participation constraint for one non-Annex I country is stricter than the participation constraint for two non-Annex I countries. Hence, the optimal no-lose target in the case of one participating non-Annex I country is more ambitious than the optimal no-lose target in the case of two participating non-Annex I countries.

The following proposition provides a comparison of the optimal no-lose targets in the case of market power and a competitive market.

**Proposition 12.** *For one or two participating non-Annex I countries, the following holds:*

*(i) The optimal no-lose target in the case of market power is more ambitious than the optimal no-lose target in the case of a competitive market, i.e.* $\widetilde{T}_N^P > \widetilde{T}_N^C$ *and* $T_N^P > T_N^C$*.*

*(ii) The target ratios* $\widetilde{T}_N^P / \widetilde{T}_N^C$ *and* $T_N^P / T_N^C$ *increase with* $\alpha$*.*

*Proof.* For the first part of the proposition, we need to compare the optimal no-lose targets in the case of market power and in a competitive market. In the case of two participating non-Annex I countries, a comparison of the optimal no-lose targets yields

$$\begin{aligned}
& \widetilde{T}_N^P > \widetilde{T}_N^C \\
\Leftrightarrow \quad & \frac{\alpha\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}} T_A > \frac{\alpha}{2(\alpha+1)} T_A \\
\Leftrightarrow \quad & \frac{2\alpha+1}{3\alpha+1} > \sqrt{\frac{1}{2\alpha+1}} \\
\Leftrightarrow \quad & \alpha^2(8\alpha+3) > 0
\end{aligned}$$

which is always fulfilled for positive $\alpha$.

In the case of only one participating non-Annex I country, the comparison yields

$$\begin{aligned} & T_N^P > T_N^C \\ \Leftrightarrow \quad & \frac{\alpha}{1+\sqrt{2\alpha+1}} T_A > \frac{\alpha}{\alpha+2} T_A \\ \Leftrightarrow \quad & \alpha + 1 > \sqrt{2\alpha+1} \\ \Leftrightarrow \quad & \alpha^2 > 0 \end{aligned}$$

which is always fulfilled.

For the second part of the proposition, we need to derive the first derivatives of the target ratios. For two participating non-Annex I countries, it is given by

$$\begin{aligned} \frac{d\left(\frac{\widetilde{T}_N^P}{\widetilde{T}_N^C}\right)}{d\alpha} &= \frac{d\left(\frac{2(\alpha+1)\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}}\right)}{d\alpha} \\ &= \frac{\left(2\sqrt{2\alpha+1} + \frac{2(\alpha+1)}{\sqrt{2\alpha+1}}\right)\left(\sqrt{2\alpha+1}+3\alpha+1\right) - 2(\alpha+1)\sqrt{2\alpha+1}\left(\frac{1}{\sqrt{2\alpha+1}}+3\right)}{(3\alpha+1+\sqrt{2\alpha+1})^2} \\ &= \frac{(4\alpha+2)\sqrt{2\alpha+1}+6\alpha^2-2}{\sqrt{2\alpha+1}(3\alpha+1+\sqrt{2\alpha+1})^2} . \end{aligned}$$

For the first derivative to be greater than zero, the nominator needs to be greater than zero. This follows from $\alpha > 0$ and $(4\alpha+2)\sqrt{2\alpha+1} > 2$.

For one participating non-Annex I country, the first derivative is given by

$$\begin{aligned} \frac{d\left(\frac{T_N^P}{T_N^C}\right)}{d\alpha} &= \frac{d\left(\frac{\alpha+2}{1+\sqrt{2\alpha+1}}\right)}{d\alpha} \\ &= \frac{1+\sqrt{2\alpha+1} - \frac{(\alpha+2)}{\sqrt{2\alpha+1}}}{(1+\sqrt{2\alpha+1})^2} \\ &= \frac{\sqrt{2\alpha+1}+2\alpha+1-\alpha-2}{\sqrt{2\alpha+1}(1+\sqrt{2\alpha+1})^2} . \end{aligned}$$

The first derivative is positive for

$$\sqrt{2\alpha+1} + \alpha - 1 > 0$$

which is true because of $\alpha > 0$. $\square$

The comparison shows that, in the case of market power, the no-lose target can be more ambitious than in the competitive market and still induce participation by one, respectively two countries. The higher prices that have to be paid by the Annex I community due to market power and that would result in higher payoffs for the non-Annex I countries can be used to increase the non-Annex I country's target and, thus, the global emission reduction target. A similar effect was found in the modeling results for one non-Annex I country in the last chapter. The above proposition shows that the result prevails in the duopoly market where two non-Annex I countries participate, although the market power is reduced compared to the monopoly case with only one participating non-Annex I country.

Part (ii) of the proposition determines for which market form the optimal no-lose targets are more affected by $\alpha$, hence, for which market form the differences in the countries' reduction potential has the greater impact on the optimal no-lose target.In the case of one as well as in case of two participating non-Annex I countries, the target in the case of market power is more affected than the target in the competitive market case. Hence, the target ratio increases with $\alpha$ in both cases.

### 3.5.2 Implications for global emission reduction targets

The analyses in the last section provided two properties of the optimal no-lose targets. First, the optimal no-lose target in the case of market power is more ambitious than the optimal no-lose target in the case of a competitive market. Second, the optimal no-lose target in the case of one participating non-Annex I country is more ambitious than the optimal no-lose target in the case of two participating non-Annex I countries. A follow-up question is whether the more ambitious no-lose target in the case of only one participating non-Annex I country can compensate the emission reduction efforts from the second non-Annex I country. As Proposition 13 shows, this is not the case for two symmetric non-Annex I countries.

**Proposition 13.** *For total non-Annex I emission reduction targets resulting from optimal no-lose targets, the following holds:*

*(i) The total non-Annex I emission reduction target is higher for two participating non-Annex I countries than for only one participating non-Annex I country, i.e.* $2\widetilde{T}_N^C > T_N^C$ *and* $2\widetilde{T}_N^P > T_N^P$*, independent of the market form.*

(ii) *The target ratio between the optimal no-lose targets with two and one participating non-Annex I countries* $\widetilde{T}_N^C/T_N^C$ *and* $\widetilde{T}_N^P/T_N^P$ *decreases with* $\alpha$ *independent of the market form.*

(iii) *For large* $\alpha$ *and in a competitive market, the difference between the total non-Annex I countries' reduction target in the case of two and one participating non-Annex I countries approaches zero.*

*For large* $\alpha$ *and in the case of market power, the difference between the total non-Annex I countries' reduction target in the case of two and one participating non-Annex I countries approaches* $\infty$*.*

*Proof.* To show part (i) of the proposition, we need to compare the global emission reduction targets. For a competitive market, the following relation

$$\begin{aligned} & 2\widetilde{T}_N^C > T_N^C \\ \Leftrightarrow \quad & \frac{2\alpha}{2(\alpha+1)}T_A > \frac{\alpha}{\alpha+2}T_A \\ \Leftrightarrow \quad & 2\alpha+4 > 2\alpha+2 \end{aligned}$$

holds for all $\alpha$.

In case of market power, the relation is given by

$$\begin{aligned} & 2\widetilde{T}_N^P > T_N^P \\ \Leftrightarrow \quad & \frac{2\alpha\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}}T_A > \frac{\alpha}{1+\sqrt{2\alpha+1}}T_A \\ \Leftrightarrow \quad & \alpha+1+\sqrt{2\alpha+1} > 0 \end{aligned}$$

This holds for all positive $\alpha$.

To show part (ii) of the proposition, we need to calculate the first derivatives of the target ratios. In the competitive market, it is given by

$$\begin{aligned} \frac{d\left(\frac{\widetilde{T}_N^C}{T_N^C}\right)}{d\alpha} &= \frac{d\left(\frac{\alpha+2}{2(\alpha+1)}\right)}{d\alpha} \\ &= \frac{2(\alpha+1)-2(\alpha+2)}{4(\alpha+1)^2} \\ &= -\frac{1}{2(\alpha+1)^2}, \end{aligned}$$

which is smaller than zero for all $\alpha$.

Similarly, the first derivative for the market power case is given by

$$\begin{aligned}
\frac{d\left(\frac{\tilde{T}_N^P}{T_N^P}\right)}{d\alpha} &= \frac{d\left(\frac{2\alpha+1+\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}}\right)}{d\alpha} \\
&= \frac{\left(2+\frac{1}{\sqrt{2\alpha+1}}\right)\left(3\alpha+1+\sqrt{2\alpha+1}\right)-\left(2\alpha+1+\sqrt{2\alpha+1}\right)\left(3+\frac{1}{\sqrt{2\alpha+1}}\right)}{(3\alpha+1+\sqrt{2\alpha+1})^2} \\
&= \frac{-\alpha-1-\sqrt{2\alpha+1}}{\sqrt{2\alpha+1}(3\alpha+1+\sqrt{2\alpha+1})^2}
\end{aligned}$$

which is smaller than zero for all $\alpha > 0$.

For part (iii) we need to derive the limit of the difference in the non-Annex I countries' total reduction targets for $\alpha \to \infty$:

$$\begin{aligned}
\lim_{\alpha\to\infty} \frac{\alpha}{(\alpha+1)(\alpha+2)} T_A &= 0 \\
\lim_{\alpha\to\infty} \frac{\alpha\left(\alpha+1+\sqrt{2\alpha+1}\right)}{3\alpha+2+3\alpha\sqrt{2\alpha+1}+2\sqrt{2\alpha+1}} T_A &= \infty\,.
\end{aligned}$$

□

Proposition 13 states that for symmetric non-Annex I countries the global emission reduction target which results when applying the optimal no-lose target for two non-Annex I countries is higher than the global emission reduction target which results when applying the optimal no-lose target for one non-Annex I country. The increase in the optimal no-lose target due to the fact that it has to be profitable for only one participating non-Annex I country, thus does not compensate for the contributions from the second non-Annex I country. Hence, to reach the maximal global emission reduction target applying no-lose targets, both symmetric non-Annex I countries need to be integrated into the international emissions trading market. This result holds not only for a competitive market, but also in the case of market power.

For both market forms, the difference between the optimal no-lose targets for one and two non-Annex I countries increases with increasing differences in the reduction potential between the Annex I community and a non-Annex I country, i.e. an increasing $\alpha$. In the competitive market, the non-Annex I countries' total emission reduction target converges for one and two participating non-Annex I countries for large $\alpha$. That is, for large differences in the abatement costs of Annex I and non-Annex I countries, it becomes less relevant for the global emission reduction target whether the optimal no-lose target for one or two non-Annex I countries is applied. In contrast, in the case of market power, the difference in non-Annex I countries' total emission reduction targets between one and two non-Annex I countries increases. This implies that in the case of market power even for large $\alpha$, it is important to include both non-Annex I countries to increase the environmental effectiveness of the no-lose targets.

The share of an individual non-Annex I country's contribution to global emission reduction efforts is determined by $\alpha$. In the competitive market case, it is given by

$$\frac{\widetilde{T}_N^C}{T_A} = \begin{cases} \frac{1}{2} & \text{for } \alpha \to \infty \\ \frac{1}{4} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} \tag{3.43}$$

for two participating non-Annex I countries and by

$$\frac{T_N^C}{T_A} = \begin{cases} 1 & \text{for } \alpha \to \infty \\ \frac{1}{3} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} \tag{3.44}$$

for one participating non-Annex I country.

If symmetry exists between the Annex I community and the non-Annex I countries, i.e. $\alpha = 1$, the optimal no-lose target is $\frac{1}{4}$ of the Annex I community's reduction target in the case of two participating non-Annex I countries and significantly higher with $\frac{1}{3}$ of the Annex I community's reduction target in the case of one participating non-Annex I country. That is, total non-Annex I countries' emission reductions are $\frac{1}{2}T_A$ in the case of two participating non-Annex I countries versus $\frac{1}{3}T_A$ in the case of one participating non-Annex I country. For large $\alpha$ the difference in the total non-Annex I countries' reduction target between one and two participating non-Annex I countries is negligible.

In the case of market power, the share in case of one and two participating non-Annex I countries is given by

$$\frac{\widetilde{T}_N^P}{T_A} = \begin{cases} \infty & \text{for } \alpha \to \infty \\ \frac{\sqrt{3}}{4+\sqrt{3}} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} . \tag{3.45}$$

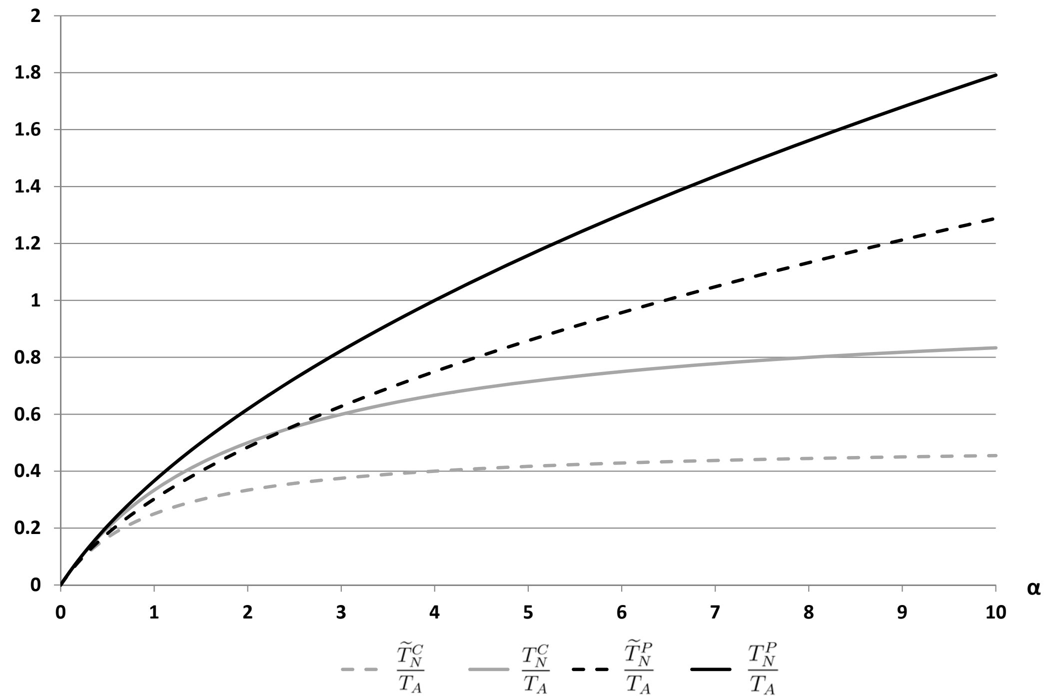


Figure 3.6: Optimal no-lose targets for one and two participating non-Annex I countries

for two participating non-Annex I countries and

$$\frac{T_N^P}{T_A} = \begin{cases} \infty & \text{for } \alpha \to \infty \\ \frac{1}{1+\sqrt{3}} & \text{for } \alpha = 1 \\ 0 & \text{for } \alpha \to 0 \end{cases} . \tag{3.46}$$

for one participating non-Annex I country.

In contrast to the competitive market, the optimal no-lose targets in the case of market power assuming symmetry between Annex I and non-Annex I are higher. Further, the limit for large values for $\alpha$ shows that the optimal no-lose target in the case of market power can increase indefinitely, compared to the Annex I community's reduction target (see also Figure 3.6). This in particular shows that the non-Annex I country's share in global emission reduction efforts is not limited to 50% as in the case of a competitive market.

Before turning to the impact of the optimal no-lose targets on the emissions trading market, we will close this section with a comparison of the level of ambition of the optimal no-lose targets.

**Proposition 14.** *Let $T_A$ be an exogenously given Annex I community's reduction target. For $\alpha > \frac{1+\sqrt{5}}{2}$ the optimal no-lose target for two non-Annex I countries in the market power case does not even induce participation by one non-Annex I country in the competitive market.*

*Proof.*

$$\begin{aligned} & \frac{\widetilde{T}_N^P}{T_A} = \frac{\alpha\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}} > \frac{T_N^C}{T_A} = \frac{\alpha}{\alpha+2} \\ \Leftrightarrow \quad & \sqrt{2\alpha+1}(\alpha+1) > 3\alpha+1 \\ \Leftrightarrow \quad & 2\alpha(\alpha^2-2\alpha-1) > 0 \\ \Leftrightarrow \quad & \alpha > \frac{1+\sqrt{5}}{2} \end{aligned}$$

□

Hence, in particular for high reduction potential in the non-Annex I countries compared to the Annex I community, i.e. $\alpha > \frac{1+\sqrt{5}}{2}$, the differences in the reduction targets and the participation incentives vary greatly for market power and a competitive market (see also Figure 3.6). Hence, large differences in the marginal abatement costs in favor of the non-Annex I countries allow significantly higher global emission reductions in the case of market power than in the case of a competitive market.

### 3.5.3 Implications for the emissions trading market

Finally, we will analyze the impacts of the optimal no-lose targets on the international emissions trading market. In contrast to Proposition 9, where the impacts of fixed no-lose targets on the emissions trading market were analyzed, applying the optimal no-lose targets takes into account that the no-lose targets should be profitable to induce fulfilling of the target. A comparison of the optimal no-lose targets in the previous section showed that, when applying the optimal no-lose targets, the fact remains that global emission reduction targets differ in the case of one and two participating countries. Hence, the comparison of the results with respect to costs and prices is limited. The following proposition can be taken as a generalization of Proposition 9 for optimal no-lose targets.

**Proposition 15.** *Applying the optimal no-lose targets in the case of one, respectively two, non-Annex I countries, independent of the market form, the following holds:*

*(i) The Annex I community's optimal emission reductions in the case of two participating non-Annex I countries are always lower than in the case of one participating non-Annex I country, i.e.* $\widetilde{r}_A^C(\widetilde{T}_N^C) < r_A^C(T_N^C)$ *and* $\widetilde{r}_A^P(\widetilde{T}_N^P) < r_A^P(T_N^P)$.

*(ii) The non-Annex I country's optimal emission reductions in the case of two participating non-Annex I countries are always lower than in the case of one participating non-Annex I country, i.e.* $\widetilde{r}_i^C(\widetilde{T}_N^C) < r_i^C(T_N^C)$ *and* $\widetilde{r}_i^P(\widetilde{T}_N^P) < r_i^P(T_N^P)$.

*(iii) The market price for emission certificates in the case of two participating non-Annex I countries is always lower than in the case of one participating non-Annex I country, i.e.* $\widetilde{p}^C(\widetilde{T}_N^C) < p^C(T_N^C)$ *and* $\widetilde{p}^P(\widetilde{T}_N^P) < p^P(T_N^P)$.

*Proof.* In the case of a competitive market, the following equation applies for the Annex I community's optimal emission reductions:

$$\begin{aligned}\widetilde{r}_A^C(\widetilde{T}_N^C) - r_A^C(T_N^C) &= \frac{1}{2\alpha+1}(T_A + 2\widetilde{T}_N^C) - \frac{1}{\alpha+1}(T_A + T_N^C) \\ &= \frac{2\alpha+1}{(2\alpha+1)(\alpha+1)}T_A - \frac{2\alpha+2}{(\alpha+1)(\alpha+2)}T_A \\ &= \frac{-\alpha}{(\alpha+1)(\alpha+2)}T_A < 0\,.\end{aligned}$$

In the case of market power, the Annex I community's optimal emission reductions are given by

$$\begin{aligned}\widetilde{r}_A^P(\widetilde{T}_N^P) - r_A^P(T_N^P) =& \frac{1}{3\alpha+1}(T_A + 2\widetilde{T}_N^P) + \frac{\alpha}{3\alpha+1}T_A - \frac{1}{2\alpha}(T_A + T_N^P) + \frac{\alpha}{2\alpha+1}T_A \\ =& \left(\frac{3\alpha^2+4\alpha+1+(3\alpha+1)\sqrt{2\alpha+1}}{(3\alpha+1)(3\alpha+1+\sqrt{2\alpha+1})} - \frac{2\alpha+1+(1+\alpha)\sqrt{2\alpha+1}}{(2\alpha+1)(1+\sqrt{2\alpha+1})}\right)T_A \\ =& -\frac{6\alpha^3+5\alpha^2+\alpha+\sqrt{2\alpha+1}(3\alpha^3+4\alpha^2+\alpha)}{(2\alpha+1)(3\alpha+1)(1+\sqrt{2\alpha+1})(3\alpha+1+\sqrt{2\alpha+1})}T_A\,.\end{aligned}$$

For $\alpha > 0$ this is smaller than zero.

The non-Annex I country's optimal emission reductions in a competitive market are given by

$$\begin{aligned}\widetilde{r}_i^C(\widetilde{T}_N^C) - r_i^C(T_N^C) &= \frac{\alpha}{2\alpha+1}(T_A + 2\widetilde{T}_N^C) - \frac{\alpha}{\alpha+1}(T_A + T_N^C) \\ &= \frac{-3\alpha^3 - 2\alpha^2}{(2\alpha+1)(\alpha+1)(\alpha+2)} T_A < 0\,.\end{aligned}$$

In the case of market power, the non-Annex I country's optimal emission reductions are given by

$$\begin{aligned}\widetilde{r}_i^P(\widetilde{T}_N^P) - r_i^P(T_N^P) =& \frac{\alpha}{3\alpha+1}(T_A + 3\widetilde{T}_N^P) - \frac{\alpha}{2\alpha+1}(T_A + 2T_N^P) \\ =& \alpha\left(\frac{1+\sqrt{2\alpha+1}}{3\alpha+1+\sqrt{2\alpha+1}} - \frac{2\alpha+1+\sqrt{2\alpha+1}}{(2\alpha+1)(1+\sqrt{2\alpha+1})}\right) T_A \\ =& -\frac{\alpha^2(2\alpha-1-\sqrt{2\alpha+1})}{(2\alpha+1)(1+\sqrt{2\alpha+1})(3\alpha+1+\sqrt{2\alpha+1})} T_A\,.\end{aligned}$$

For $\alpha > 0$ this is smaller than zero.

Part (iii) of the proposition follows from (i) and $p = \alpha_A r_A$. □

Hence, the results found in Proposition 9 prevail when applying optimal no-lose targets instead of fixed no-lose targets. Due to the property of the optimal no-lose target being profitable, this allows us to draw a more general conclusion. The results imply that integration of two non-Annex I countries applying optimal no-lose targets is beneficial for two reasons: it allows higher global emission reduction targets and, at the same time, lowers the price for emission certificates in the emissions trading market and leads to a decrease in the Annex I community's domestic emission reductions. Hence, it increases the environmental effectiveness, while also resulting in a higher efficiency in the international emissions trading market.

## 3.6 Conclusions

In this chapter, a two-player framework was presented to analyze the situation of two symmetric non-Annex I countries facing the decision to fulfill a no-lose target and participate in the international emissions trading market. The two countries' decision is directly linked, via the market price which affects the revenue effect. To model this link, the modeling framework introduced in chapter 2 was extended and a game-theoretical component was added.

The analyses show that three cases with differing Nash equilibria exist, two of which result in the participation of at least one non-Annex I country. The subsequent analyses of the impacts on the emissions trading market provided three main insights. First, to maximize the global emission reduction target, the optimal no-lose targets in the case of two non-Annex I countries need to be implemented, although the optimal no-lose target in the case of one participating non-Annex I country is higher than the optimal no-lose target in the case of two participating non-Annex I countries. Second, applying optimal no-lose targets, the market price for emission certificates is lower in the case of two participating non-Annex I countries than in the case of one. This results in lower domestic reductions in the Annex I community as well as the non-Annex I countries. Hence, participation of both non-Annex I countries does not only result in environmental benefits, but also in economic efficiency. Third, similar to the case of one non-Annex I country in chapter 2, the analyses of two non-Annex I countries facing a no-lose target show that market power can result in significantly higher optimal no-lose targets than a competitive market. This is in particular the case when large differences exist between the marginal abatement costs in the Annex I community and the non-Annex I countries. The effect that participation of two non-Annex I countries results in higher global emission reduction targets is intensified if market power exists on the part of the non-Annex I countries.

Another important point, in particular from a political point of view, was found in the analysis of the non-Annex I countries' payoff functions. It showed that, for particularly lenient no-lose targets and a large reduction potential in the non-Annex I country, compared to the Annex I community, in a competitive market a non-Annex I country is not necessarily interested in bringing down its marginal abatement costs. In contrast, under certain circumstances, lower marginal abatement costs in the non-Annex I country would lower the country's payoffs. This finding is particularly important, if no-lose targets are to be complemented with other policies like e.g. R&D cooperation which directly focuses on reducing a country's marginal abatement costs. Hence, this finding indicates that further research in that area is necessary.

While the model introduced can be seen as a starting point for analyses of no-lose targets in emissions trading markets, it presents a highly stylized version of an emissions trading market. We restricted the analysis to two symmetric countries. Asymmetry of non-Annex I countries with respect to abatement costs can have major impacts on the emissions trading market, as well as on the profitability of a no-lose target and, hence, the decision of a non-Annex I country to fulfill the target. Extending the asymmetry to the level of the no-lose targets further allows us to model the effects of individual no-lose targets. Also, extending the model to allow analyses of more than two non-Annex I countries, while significantly increasing the complexity of the participation game, would provide further valuable insights into the impacts of no-lose targets on global emission reductions and the emissions trading market under more realistic assumptions. In order to overcome these obstacles in the theoretical analyses, the following chapter provides a quantitative analysis of no-lose targets including 137 heterogeneous countries, 18 of which face no-lose targets and, hence, the decision to participate in the international emissions trading market.

# 4 Can no-lose targets contribute to the 2°C target?[31]

## 4.1 Introduction

The last two chapters focused on the economic analysis of no-lose targets. In particular, two aspects were addressed: the the potential of no-lose targets to result in a non-Annex I country's contribution to emission reduction efforts (chapter 2) and the effects of competition of more than one non-Annex I country facing a no-lose target (chapter 3). For the economic analysis, two theoretical frameworks were presented that model the application of no-lose targets in a highly stylized setting. Particularly, three aspects were simplified. First,in the theoretical framework, the number of non-Annex I countries facing no-lose targets was limited to one and two, respectively to reduce the complexity of the model. In contrast, in reality a much higher number of non-Annex I countries qualifies for an application of no-lose targets. Second, the analyses in chapter 3 were limited to symmetric non-Annex I countries while in reality countries are heterogeneous. Third, the form of the marginal abatement cost curves was assumed to be linear to reduce the complexity of the derivatives and formula.

We will use this chapter to complement the economic analysis with a quantitative analysis of the application of no-lose targets. Although quantitative analyses also face a large number of assumptions and restrictions, the analysis shall help to provide a first more realistic estimation of contributions from non-Annex I countries to global emission reductions applying no-lose targets.

Empirical analyses of no-lose target systems are rare and mainly relate to sectoral no-lose targets. J. Schmidt et al. (2008) analyze sectoral no-lose targets

[31] This is a preprint of an article submitted for consideration in Climate Policy

for the cement, the iron and steel and the electricity sector but do not consider participation in emissions trading as incentive mechanism. Amatayakul et al. (2008) analyze the potential for emission reductions applying no-lose targets in the electricity sector in seven developing countries. They estimate that a reduction of about 10% below baseline could be achieved generating about 410 to 540 million certificates per year between 2012 and 2020. However, they do not model the demand for emission certificates nor the market price for certificates. den Elzen et al. (2010) allow developing countries to participate, among others, in international emissions trading via no-lose targets prior to accepting an agreement involving binding reduction targets. They model emission reductions of 10% below baseline in 2020 being realized through no-lose targets. However, they do not check if fulfilling the no-lose target is profitable.

The only study taking into account that the reduction target for a non-Annex I country should be profitable is R. C. Schmidt and Marschinski (2010). In this study, however, analyses are limited to one non-Annex I country (China). Applying marginal abatement cost curves they estimate that China can contribute up to 1.1 $GtCO_2e$ to global emission reductions if participating in an emissions trading market with the USA and the EU. The analyses are based on the assumption that China maximizes its revenues from emissions trading.

In this chapter, we quantitatively analyze the non-Annex I countries' potential to contribute to global emission reductions applying no-lose targets. In particular, we attempt to assess if no-lose targets can help in keeping mean temperature increase below 2°C. As before, we consider the economic incentives that need to be fulfilled for a no-lose target to be profitable and hence the non-Annex I country to meet the target and participate in the international emissions trading market. We further focus on analyzing given no-lose targets rather than modeling the negotiation process and endogenously deriving no-lose targets as a result of the negotiation process. Hence, we move away from the target-setting approach (bottom-up or top-down) and the optimal no-lose targets analyzed in the subsequent chapters.

Methodologically, we rely on marginal abatement cost curves derived from policy simulations with the global partial equilibrium model POLES to analytically solve the participation decision of several non-Annex I countries facing no-lose targets while taking into account cost and revenue effects. The algorithm implemented allows us to determine participation incentive-compatible constellations of no-lose targets for non-Annex I countries, associated emission reductions and their effects on global emissions.

We use the commonly accepted and politically discussed burden-sharing proposal by the IPCC as starting point for the analyses (Metz et al., 2007). According to den Elzen and Hoehne (2010a)[32] the increase in global GHG emissions must not exceed 1990 levels by more than 10% to 30% by 2020 in order to limit mean temperature increase to 2°C above pre-industrial levels. Annex I countries must decrease their GHG emissions by 25% to 40% below 1990 levels by 2020 (Metz et al., 2007) while emissions from non-Annex I countries need to stay 15% to 30% below baseline in 2020 (den Elzen & Hoehne, 2010a). We analyze the IPCC burden-sharing scenario assuming uniform reduction targets for non-Annex I countries. That is, all non-Annex I countries facing a no-lose target face the same reduction target (measured as percentage below baseline emissions). In a second step we explore options for increasing participation from non-Annex I countries like applying less ambitious uniform no-lose targets or individualizing no-lose targets for large developing countries like China, India and Brazil. Finally, we show how uniform no-lose targets may effectively contribute to achieving the 2°C target once the burden-sharing arrangements between Annex I and non-Annex I countries is altered appropriately.

In contrast to the subsequent chapters, we restrict the quantitative analysis to the case of a competitive market and do not analyze the effects of strategically acting non-Annex I countries.

The chapter is organized as follows. Section 4.2 describes the modeling approach including data and the algorithm derived to calculate no-lose targets. Section 4.3 presents the results of the scenarios derived from the IPCC burden-sharing approach. Section 4.4 includes the findings for the alternative reduction scenarios. Finally, section 4.5 discusses the main findings and offers guidance for no-lose targets policy design.

## 4.2 Methodology

This section presents the methodology developed to analyze the effects of no-lose targets. Section 4.2.1 introduces the markets modeled and the flow of traded certificates. In section 4.2.2 the countries' optimization problems to-

[32]The analysis provides background information on the derivation of the IPCC analyses

gether with the solution algorithm are introduced. Sections 4.2.3 and 4.2.4 describe the data and the assignment of countries to the different markets.

### 4.2.1 Trading markets

For the subsequent analyses, we distinguish three groups of countries:

**(i)** Annex I countries, which all commit to binding targets for 2020 (AI),

**(ii)** non-Annex I countries, which are eligible to participate in a no-lose target scheme (NAI_NLT) and

**(iii)** the remaining non-Annex I countries, which do not face any emission targets (NAI_REST).

Two different markets are modeled: an international emissions trading market (IETM) and an offsetting market (OM)[33]. Countries within the IETM can freely trade emission certificates among each other, but may be required to meet a minimum share of their individual targeted emission reductions domestically ("domestic quota"). Countries within the OM can sell offsetting credits to the countries within the IETM but can neither trade among each other nor buy emission certificates from the countries within the IETM. Similarly, countries within the IETM face an "offsetting limit", which is the maximum share of the individual targeted emission reductions that can be met via offsetting credits.

The countries within the three different country groups are assigned to the two markets as follows (see also Figure 4.1). AI countries are allowed to participate in the international emissions trading market and are subject to domestic quotas and offsetting limits. NAI_NLT countries can participate in the international emissions trading market if they decide to fulfill their no-lose targets. Unlike AI countries, NAI_NLT countries can only sell certificates and are not allowed to buy offsetting credits. Hence, a NAI_NLT country has to fulfill 100% of its no-lose reduction commitment domestically if it wants to sell cerfiticates.[34] NAI_REST countries are assigned to the offsetting market and can sell offsetting credits to the AI countries, but not to NAI_NLT countries.

[33]In essence, the offsetting market represents the Clean Development Mechanism (CDM).

[34]It is assumed that non-Annex I countries cannot choose whether they want to be in the NAI_REST group or the NAI_NLT group. Hence, a NAI_NLT country is not allowed to become a member of the offsetting market and sell its emission reductions as offsetting credits instead.

These rules can lead to differences in the prices for emission certificates and offsetting credits. Because of arbitrage, however, the price of the emission certificates traded among AI countries and of the emission certificates sold by NAI_NLT countries must be identical.

We assume the levels of the domestic quota and the offsetting limit to be the same for all AI countries. We set the default value for the domestic quota at 10% and for the offsetting limit at 20% (for the remaining 90% of emission reductions). Hence, AI countries must meet at least 72% of the emission reductions by domestic action or via certificate trading in the international emissions trading market. We further assume that only a fraction of the total emission reduction potential of a NAI_REST country can be used for offsetting purposes at the prevailing certificate price. Following Castro (2010), we set this share at 20%.[35]

The post-Kyoto negotiations involve discussions about additional mechanisms to help finance abatement activities in NAI countries. To avoid double funding, we assume that countries with no-lose targets will not be eligible for such financing mechanisms.

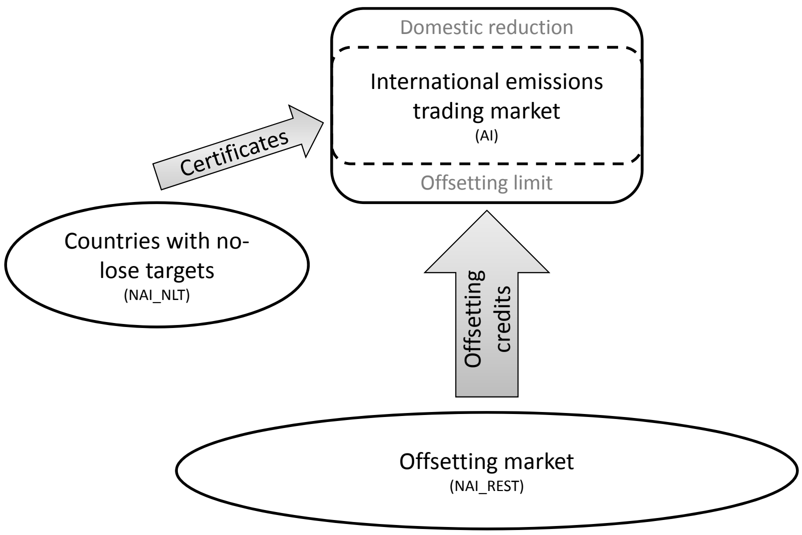


Figure 4.1: Types of markets and the flow of traded certificates

[35]For six developing countries, Castro (2010) estimates that between 1% and 31% of their emission reduction potential is captured via CDM projects. The figure for China for the year 2020 is, for example, 21%.

### 4.2.2 The modeling of no-lose targets

#### Formal model

In this section, we formalize the objectives of the three country groups. The assumptions are similar to the modeling framework applied in chapters 2 and 3. In particular, we assume that a NAI_NLT country $i$ with a no-lose target $T_i$ faces the following optimization problem:

$$TC_i = C_i(r_i) - p^C(r_i - T_i) \rightarrow \min_{r_i} \tag{4.1}$$

$$s.t. \quad TC_i = C_i(r_i) - p^C(r_i - T_i) \leq 0\,, \tag{4.2}$$

where $p^C$ is the market price for emission certificates, $r_i$ stands for the realized emission reductions in country $i$ compared to baseline and $C_i(r_i)$ are the associated abatement costs. A country's no-lose target $T_i$ is given as emission reductions below baseline and is exogenously given as the outcome of climate negotiations.[36] Hence, country $i$ is assumed to minimize its total costs $TC_i$, i.e. abatement costs (for the entire emission reductions) minus revenues from selling emission certificates (the difference between actual and targeted reductions). Condition (4.2) reflects that a rational country will participate in the international emissions trading market and hence fulfill its no-lose target if revenues from selling certificates are not lower than abatement costs (*participation constraint*). Hence, the no-lose target must be profitable. Otherwise, a country's emissions are assumed to take on baseline levels (i.e. $r_i = 0$). Figure 4.2 illustrates condition (4.2) for a NAI_NLT country facing a no-lose target of $T_j$. For a certificate price of $p$, the revenues from selling certificates $(r_j^* - T_j)$ minus abatement costs for the associated emission reductions (beyond $T_j$) is given by the area $B + B'$. The country will participate in the no-lose target if these profits from certificate trading $B + B'$ exceed the abatement costs associated with the no-lose target $T_j$ (area $A$). The area $B + B' - A$ may also be termed the country's payoff. For a lower certificate price $p'$, the costs of the no-lose target are still $A$, but they are now lower than the profits from certificate trading ($B'$). Hence, if the certificate price is at $p'$ the country will not participate in the no-lose target. In this case, the country's payoff is zero as the country will not reduce any emissions (i.e. $r_j^* = 0$) and, hence,

[36] We do not model the negotiation process, but rather explore whether a given no-lose target will be realized.

$B + B' - A = 0$.

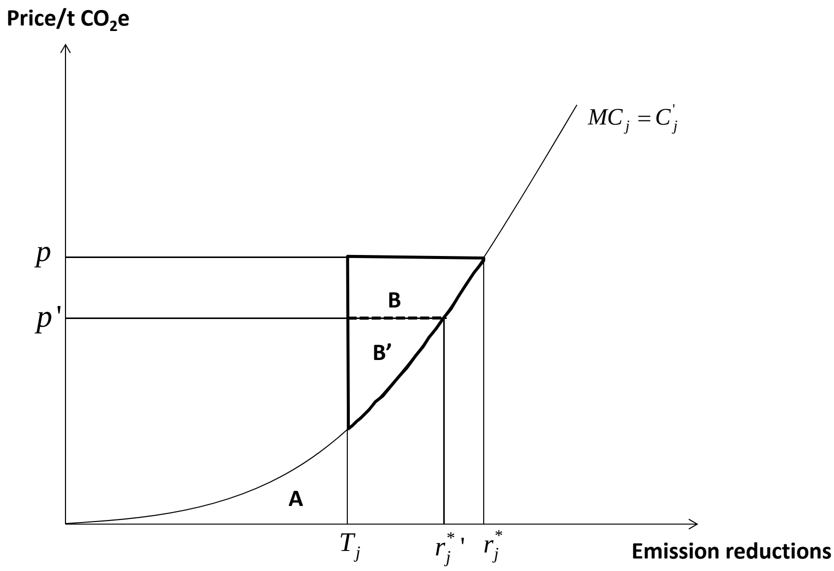


Figure 4.2: Abatement costs and revenues from trading for a no-lose target country

The optimization problem for an AI country $j$ is given by

$$TC_j = C_j(r_j) - p^C(r_j - T_j) \rightarrow \min_{r_j} . \tag{4.3}$$

Thus, AI countries are also assumed to minimize their compliance costs, i.e. the sum of abatement costs $C_j$ and the costs/revenues from emissions trading. Finally, the optimization problem for a NAI_REST country $k$ is given by

$$TC_k = 0.2(C_k(r_k) - q^c r_k) \rightarrow \min_{r_k} \tag{4.4}$$

where $q^C$ is the market price for offsetting credits. As NAI_REST countries only sell offsetting credits but do not face an emission reduction target their total costs are given by the profits from selling offsetting credits.

In addition, the following market clearing condition must hold:

$$\sum_{j \in AI} r_j + \sum_{i \in NAI\_NLT} r_i + \sum_{k \in NAI\_REST} r_k = \sum_{j \in AI} T_j + \sum_{\substack{i \in NAI\_NLT, \\ T_i \text{ profitable}}} T_i \, . \tag{4.5}$$

Equation (4.5) requires that the sum of emission reductions in all countries equals the sum of all targeted emission reductions which are met. The latter include all reduction targets from AI countries plus the no-lose targets of those NAI_NLT, where the participation constraint is satisfied.

Finally, the following sets of inequalities need to hold:
for all $j \in AI$:

$$r_j \leqq DQ_j T_j \tag{4.6}$$

and

$$OL_j(1 - DQ_j)T_j \geq T_j - r_j - \sum_{i \in NAI\_NLT} EC_{i,j} - \sum_{\substack{l \in AI \\ l \neq j}} EC_{l,j}\,. \tag{4.7}$$

The inequalities (4.6) ensure that in each AI country domestic emission reductions are equal or higher than the required domestic quota $DQ$. The second set of inequalities (4.7) ensures that in each AI country the offsetting limit $OL$ is fulfilled. $\sum_{i \in NAI\_NLT} EC_{i,j}$ describes the number of emission certificates AI country $j$ buys from the participating NAI_NLT countries and $\sum_{\substack{l \in AI \\ l \neq j}} EC_{l,j}$ the sum of emission certificates AI country $j$ buys from other AI countries. We further assume the markets for emission certificates and offsetting credits to be perfectly competitive, so that all countries act as price takers.

### Solution algorithm

Next, we briefly outline the logic of the solution algorithm for the multi-country optimization problem, where several NAI_NLT countries face a no-lose target and decide of whether to participate in the international emissions trading market. The aim of the algorithm is to identify an equilibrium solution IETM* of AI and NAI_NLT countries participating in the international emissions trading market. This equilibrium solution IETM* is characterized by two conditions. First, for all NAI_NLT countries in IETM* the participation condition (4.2) is fulfilled, i.e. participation is profitable ("internal stability"). Second, if any NAI country outside of IETM* joined IETM*, participation in IETM* would no longer be profitable for at least one NAI country in IETM* ("external stability"[37]).

[37] Note that our definition of external stability differs from the game-theoretical criterion of external stability applied to describe stability of coalitions. For an application to climate policy see for example Brèchet et al. (2010)

Our algorithm employs a recursive function to identify the countries with profitable no-lose targets and consists of four steps (see Appendix C.1 for a more formal description). In step 1, all AI and all NAI_NLT countries are assumed to participate in the IETM. In step 2, the prices for certificates $p^C$ and offsetting credits $q^C$ as well as the numbers of emission certificates and offsetting credits traded are determined by solving the optimization problem for all countries within the IETM and for the NAI_REST countries. The results are then used to calculate total costs for the NAI_NLT countries within the IETM. Step 3 checks if the no-lose targets are profitable for the NAI_NLT countries participating in the IETM. If the no-lose target of at least one NAI_NLT country within the IETM is found to be unprofitable, the NAI_NLT country with the highest loss, i.e. the largest negative payoff is eliminated from the IETM.[38] We then return to step 2 for the resulting new IETM and calculate prices and costs for all country groups. In this way, the countries for which no-lose targets are not profitable, are excluded from the market step-by-step until an IETM is found where the no-lose targets of all NAI_NLT countries within the IETM are profitable (internal stability). Finally, in step 4, our algorithm checks whether the IETM found in step 3 satisfies external stability. To do so, excluded NAI_NLT countries are individually added to the IETM, beginning with the largest (in terms of emissions) remaining eligible NAI. For the resulting new IETM we return to step 2 to calculate prices and costs and check if the IETM is internally stable. If one of the new IETMs is found to be internally stable, it is the new IETM$^*$ and we restart step 4. If external stability holds for all these constellations, the IETM from step 4 is IETM$^*$.

### 4.2.3 Marginal abatement cost curves and data

Our analyses refer to reduction targets for the year 2020. Calculations are based on marginal abatement cost curves for the year 2020 calculated with the global energy system model POLES[39]. To generate the marginal abatement cost curves, the POLES model was calibrated to the World Energy Outlook 2010, New Policies Scenario (International Energy Agency, 2010). To derive

[38] Of course, using a different selection criterion like loss per capita or loss per unit of GDP would lead to different outcomes.

[39] For a description and applications of the POLES model see for example, Criqui (2001) or Russ and Criqui (2007). POLES is a partial equilibrium model, hence the marginal abatement cost curves do not include macro-economic effects.

marginal abatement cost curves for the year 2020 the model was solved in one-year-steps from 2008 to 2020 with a linearly increasing price for GHG emissions. This implies that emission reduction targets become stricter over time, while the Kyoto Period (2008-2012) is not explicitly modeled.

The POLES model generates marginal abatement cost curves for 58 countries and regions. To further disaggregate the regional level for the analyses most recent historic emissions data from UNFCCC inventories (United Nations, 2012) and the International Energy Agency (International Energy Agency, 2011) were used. Combining historic data and the growth and abatement rates from the POLES scenario marginal abatement cost curves for 137 countries for the year 2020 were derived.

The marginal abatement cost curves are calculated at the country level and include abatement potentials for all six Kyoto GHGs but exclude emissions and abatement potentials from land-use, land-use change and forestry (LULUCF) and deforestation (REDD)[40]. World total emissions also include emissions from international bunker fuels. Following the World Energy Outlook 2010, we assume a growth rate of 90% between 1990 and 2020 for bunker fuels (International Energy Agency, 2010). Emission reduction targets and measures for bunker fuels are not included. Historic and baseline GHG emissions by country groups are displayed in Table 4.1.

| Country group | 1990 | 2005 | 2020 |
|---|---|---|---|
| | *[Gt $CO_2e$]* | *[Gt $CO_2e$]* | *[Gt $CO_2e$]* |
| AI | 18.4 | 18.5 | 18.3 |
| NAI_NLT | 8.8 | 15.8 | 28.4 |
| NAI_REST | 3.5 | 5.0 | 6.7 |

Table 4.1: Historic and baseline GHG emissions from 1990 - 2020 by country groups

### 4.2.4 Country groups

For the subsequent analyses we define the three country groups introduced above as follows:

[40]Including emissions and emission reduction potential from LULUCF and REDD could change quantitative as well as qualitative results in particular for non-Annex I countries like Brazil or Indonesia.

**AI:** All 39 countries listed in Annex B of the Kyoto Protocol (including the USA) and Turkey. An aggregate Annex I target for 2020 is defined and all AI countries are assumed to commit to the same percentage reduction in 2020 compared to 1990 levels, i.e. uniform reduction targets are applied to all AI countries. For a few countries this assumption results in emission targets which are above baseline emissions in some scenarios ("hot air").[41]

**NAI_NLT:** To reduce computation time not all NAI countries are considered eligible for no-lose targets. Instead, the group of NAI_NLT countries only includes countries whose total baseline GHG emissions in 2020 exceed 300 $MtCO_2e$. These 18 countries cover more than 80% of NAI countries' projected GHG emissions in 2020.[42]

**NAI_REST:** The remaining 79 NAI countries.

## 4.3 "IPCC" scenarios

### 4.3.1 "IPCC" scenario definition

The first set of policy scenarios is based on the burden-sharing proposed in the 4$^{th}$ IPCC assessment report (Metz et al., 2007).[43] Accordingly, emission reductions in the range of 25% to 40% below 1990 levels for Annex I countries and a "substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-Planned Asia" for non-Annex I countries for the year 2020 are necessary to stay on a path to the 2 °C target. den Elzen and Hoehne (2010a) quantify the quantifying the emission reductions from non-Annex I countries as 15% to 30% below baseline in 2020. Further, global emissions in 2020 should not exceed 1990 levels by more than 10% to 30%.

Based on these emission ranges compatible with the 2 °C target, we define the subsequent three "IPCC" scenarios applying uniform reduction targets for AI and NAI_NLT countries:

[41] These countries are typically countries from the former Soviet Union like Russia, Belarus and the Ukraine as well as Eastern European States.

[42] The countries included in NAI_NLT are Argentina (ARG), Brazil (BRA), China (CHN), Egypt (EGY), Indonesia (IDN), India (IND), Iran (IRN), Kazakhstan (KAZ), Republic of Korea (KOR), Malaysia (MYS), Mexico (MEX), Nigeria (NGA), Pakistan (PAK), Saudi Arabia (SAU), Thailand (THA), Taiwan (TWN), Vietnam (VNM) and South Africa (ZAF).

[43] For a detailed overview of different burden-sharing approaches see den Elzen et al. (1999), Kartha, Kjellen, Baer, and Athanasiou (2009) and den Elzen and Hoehne (2010b).

**IPCC_amb:** a global target of 10% above 1990 levels and an Annex I target of 40% below 1990 levels,

**IPCC_med:** global emission target of 30% above and an Annex I target of 25% below 1990 levels and

**IPCC_low:** a global emission target of 30% above and an Annex I target of 40% below 1990 levels.

The IPCC_amb scenario combines the more ambitious end of the global reduction range (10% global emission growth) with the more ambitious target for Annex I countries. The IPCC_low scenario combines the less ambitious end of the global reduction range (30% global emission growth) with the lower reduction target for Annex I countries. Hence, the two scenario represent the more ambitious and the less ambitious end of the reduction range for global emission reduction efforts as well as for the Annex I countries' reduction efforts. The IPCC_med scenario combines the less ambitious global reduction target with the higher reduction target for Annex I countries. Hence, for this scenario no-lose targets are expected to be particularly profitable. In sum, the analyzed scenarios represent the upper and the lower end of the global emission reduction range for 2020 compatible with a 2 °C target.

Following the approach by den Elzen and Hoehne (2010a), the non-Annex I countries' aggregate emission target is derived from the global emission target by subtracting the Annex I countries' emission target. To calculate the NAI_NLT countries' emission targets we further subtracted baseline emissions for the NAI_REST countries applying our modeling baseline. The resulting emission targets were then translated into emission reduction targets below baseline in 2020.

Compared to our modeling baseline the reduction targets for NAI_NLT countries correspond to emission reductions of 43%, 30% and 20% below baseline in IPCC_amb, IPCC_med and IPCC_low, respectively (see Table 4.2).

### 4.3.2 Results for "IPCC" scenarios

Results for the "IPCC" scenarios in the equilibrium solution IETM* appear in Table 4.3. Table 4.4 presents the findings for prices of certificates and offsetting credits (in 2005€/$tCO_2e$ given in columns one and two) and for changes in total compliance costs ($TC$) and in AI countries' total compliance costs $TC_{AI}$

| Scenario | global | | AI | NAI_NLT |
|---|---|---|---|---|
| | *to 1990 [%]* | *to baseline [Gt $CO_2e$]* | *to 1990 [%]* | *to baseline [%]* |
| IPCC_amb | 10 | -19.1 | -40 | -43 |
| IPCC_med | 30 | -12.6 | -25 | -30 |
| IPCC_low | 30 | -12.6 | -40 | -20 |

Table 4.2: Global and regional emission reduction targets for 2020 in the "IPCC" scenarios

compared to a scenario without a no-lose target scheme. Changes in global total costs $TC$ (are an indicator for the associated efficiency gains. Changes in AI countries' aggregated total costs $TC_{AI}$ are given in column four. The last column in Table 4.4 shows the payoffs as a share of the abatement costs associated with meeting the no-lose targets. In terms of Figure 4.2, the payoff ratio corresponds to the ratio of area $(B + B' - A)$ to area $A$.

Results in Table 4.4 indicate that the offsetting limit is not binding for any of the "IPCC" scenarios considered since arbitrage leads to identical prices for emission certificates and offsetting credits. Prices are highest in IPCC_amb, but since no-lose targets are also ambitious participation is not profitable for any NAI_NLT country in IPCC_amb. As a consequence, the 10% global emission growth target will be missed.

For different reasons, prices are substantially lower in the two other "IPCC" scenarios, both of which aim for the 30% global emission growth target. In IPCC_med, targets for AI countries are more lenient than in IPCC_amb and the high amounts of "hot air", which are traded within IETM*, also dampen the price for certificates. As a result, none of the NAI_NLT countries finds it profitable to participate in the IETM even though their no-lose targets are less ambitious than in the IPCC_amb scenario. Thus, IPCC_med misses the envisaged 30% global emission growth target.

In contrast, in scenario IPCC_low, where AI countries' targets are rather ambitious and no-lose targets are rather weak, eleven NAI_NLT countries find it profitable to participate in the IETM. Realized emission reductions from NAI_NLT countries add up to 1.8 $GtCO_2e$, resulting in global emission reductions of 8.8 $GtCO_2e$. Also, IPCC_low allows for substantial efficiency gains compared to a scenario without NAI_NLT countries' participation. Notably, global compliance costs decrease by 19% and compliance costs for AI countries decrease by 14% compared to a scenario without a NLT scheme. In particular, those AI countries, which face relatively stringent targets, benefit from purchasing large numbers of certificates from NAI_NLT countries (about 1.5 $GtCO_2e$ accounting for about 20% of the AI countries' aggregated emission reduction target). NAI_NLT countries are also better off: NAI_NLT countries' aggregate revenues from selling certificates are 41% higher than would be needed to make participation by these countries profitable. The uniform no-lose targets applied also result in substantial differences in the participating NAI_NLT countries' payoffs. For example, for Nigeria payoffs are than 10 times larger than needed to meet its participation constraint. They are "only" 30% higher for Malaysia, Taiwan, Thailand and Vietnam.

Although scenario IPCC_low induces participation by non-Annex I countries and, hence, increases global emission reductions, only 31% of the envisaged emission reductions for NAI_NLT countries are realized and the 30% global emission growth target is missed. It should be noted though that emissions in IPCC_low are lower than in IPCC_amb.

Besides the levels of the NLT, the profitability of the no-lose targets also depends on the domestic quota, the offsetting limit and the amount of hot air. While a high domestic quota and a high offsetting limit reduce the demand for certificates from the IETM, "hot air" certificates are a low-cost alternative to certificates from NAI_NLT countries. A sensitivity analysis for the IPCC_low scenario shows that varying the domestic quota and the offsetting limit within reasonable limits does not affect the profitability of the no-lose targets. Similarly, limiting "hot air" by applying a more sophisticated burden-sharing among Annex I countries or prohibiting Annex I countries from selling "hot air" also does not lead to changes in the profitability of no-lose targets for NAI_NLT countries in the analyzed scenarios either. An overview on the results of the sensitivity analyses is provided in Appendix C.2.

In sum, only scenario IPCC_low induces several NAI_NLT countries (including India but not China) to participate in no-lose targets, but still fails to achieve the envisaged global emission targets.[44] According to our quantitative analysis, reduction ranges of 25% to 40% below 1990 levels for Annex I countries in combination with no-lose targets of 15% to 30% below baseline will not lead to global emission levels considered compatible with the 2 °C target.

[44]For completeness we also analyzed a scenario targeting at a global emission target of 10% above 1990 levels and applying a reduction target of 25% below 1990 levels for Annex I countries. Similar to the IPCC_amb scenario, no NAI_NLT countries were found to participate in NLT.

The results also imply that either Annex I countries' targets are too lenient or that NAI_NLT countries' no-lose targets are too stringent.

## 4.4 Alternative scenarios

In this section we explore three alternative ways to the "IPCC" scenarios to increase participation by NAI_NLT countries. First, we continue to apply uniform targets for NAI_NLT countries but lower the ambition of the no-lose targets compared to the "IPCC" scenarios. Hence, by design, in these "lenient no-lose target" scenarios (LT) the global emission target of 30% will be missed. More lenient no-lose targets may result in lower global emissions than more ambitious targets, as was the case in IPCC_low. Varying the target levels offers more general insights on the properties of no-lose targets and also allows identifying the level of NLT where global emissions are lowest. Then we consider two types of alternative scenarios which are compatible with the 2 °C target. First, we allow the reduction targets to differ across three large NAI_NLT countries Brazil, India and China (BIC). Second, in the BuS scenarios we alter the burden-sharing of emission reductions compared to the IPCC scenarios, such that no-lose targets for NAI_NLT countries become more lenient while targets for AI countries become more ambitious. Details on the alternative scenarios implemented can be found in Table 4.5.

| Scenario | No. of part. NAI_NLT | Envisaged reductions by NAI_NLT | Realized reductions by NAI_NLT | | Certificates sold by NAI_NLT | Realized global reductions | "Hot Air" |
|---|---|---|---|---|---|---|---|
| | | [$MtCO_2e$] | [$MtCO_2e$] | [%] | [$MtCO_2e$] | [$MtCO_2e$] | [$MtCO_2e$] |
| IPCC_amb | 0 | 11 454 | - | 0 | - | 7 097 | 80 |
| IPCC_med | 0 | 8 357 | - | 0 | - | 4 287 | 219 |
| IPCC_low | 11* | 5 653 | 1 749 | 31 | 1 530 | 8 846 | 80 |

*IND, IDN, KAZ, MYS, NGA, PAK, KOR, ZAF, TWN, THA, VNM

Table 4.3: Participation and emission reductions by NAI_NLT in 2020 in "IPCC" scenarios

| Scenario | Price IETM | Price OM | Global compliance costs | AI compliance costs | Payoff ratio |
|---|---|---|---|---|---|
| | [€/$tCO_2e$] | [€/$tCO_2e$] | [%] | [%] | [%] |
| IPCC_amb | 152.73 | 152.73 | 0 | 0 | 0 |
| IPCC_med | 63.78 | 63.78 | 0 | 0 | 0 |
| IPCC_low | 101.81 | 101.81 | -19 | -14 | 41 |

Table 4.4: Prices and compliance costs in 2020 in "IPCC" scenarios

| Scenario | global | AI | NAI_NLT |
|---|---|---|---|
| | *to 1990 [%]* | *to 1990 [%]* | *to baseline [%]* |
| LT scenarios | > 30 | -40 | -2 to -22 |
| BIC_10 | > 30 | -40 | Brazil: -12, India: -16, China: -15, Other: -10 |
| BuS_10_FP | 10 | -84 | -13 |
| BuS_30_FP | 30 | -56 | -9 |
| BuS_10 | 10 | -72 | -31 |
| BuS_30 | 30 | -46 | -21 |

Table 4.5: Global and regional emission reduction targets for 2020 in the alternative scenarios

### 4.4.1 Results for scenarios with lenient no-lose targets

When no-lose targets become more lenient, there are two countervailing effects on global emissions. On the one hand, lower no-lose targets imply lower emission reduction contributions by an individual NAI_NLT country. On the other hand, more countries will participate in no-lose targets. Thus, neither a high ratio of realized to envisaged emission reductions nor a large number of participating NAI_NLT countries necessarily imply global emission reductions.

The LT (lenient targets) scenarios are based on the IPCC_low scenario. The uniform NLT is then gradually increased from 20% to 0%, while the 40% reduction target for AI countries is kept constant. Results of this sensitivity analysis are displayed in Figure 4.3 and Figure 4.4.

As the NLT becomes more ambitious, the gab between the envisaged and the realized NAI_NLT emission reductions by NAI_NLT countries widens in Figure 4.3. Up to a uniform reduction rate of 6% below baseline, all NAI_NLT will participate. Further, the maximum emission reductions from NAI_NLT are achieved for a reduction rate of 18%. In this case seven out of 18 eligible NAI_NLT countries reduce emissions by 3.8 $GtCO_2e$ compared to baseline; but this is still shy of meeting envisaged global emission reductions. For higher uniform reduction rates, the payoff for China becomes negative (as indicated by the large drop in realized emission reductions in Figure 4.3). For tighter no-lose targets the certificate price in Figure 4.4 continues to rise, and the revenue effect induces participation by some smaller NAI_NLT countries, but they cannot make up for China's dropping out of the IETM*.

It is worth noting that the realized emission reductions from NAI_NLT countries in the scenarios with no-lose targets between 7% and 18% are larger than in the IPCC_low scenario, because many more NAI_NLT countries participate. This illustrates that more lenient NLT may actually result in lower global emissions, lower global compliance costs and lower compliance costs for Annex I countries than under IPCC_low.

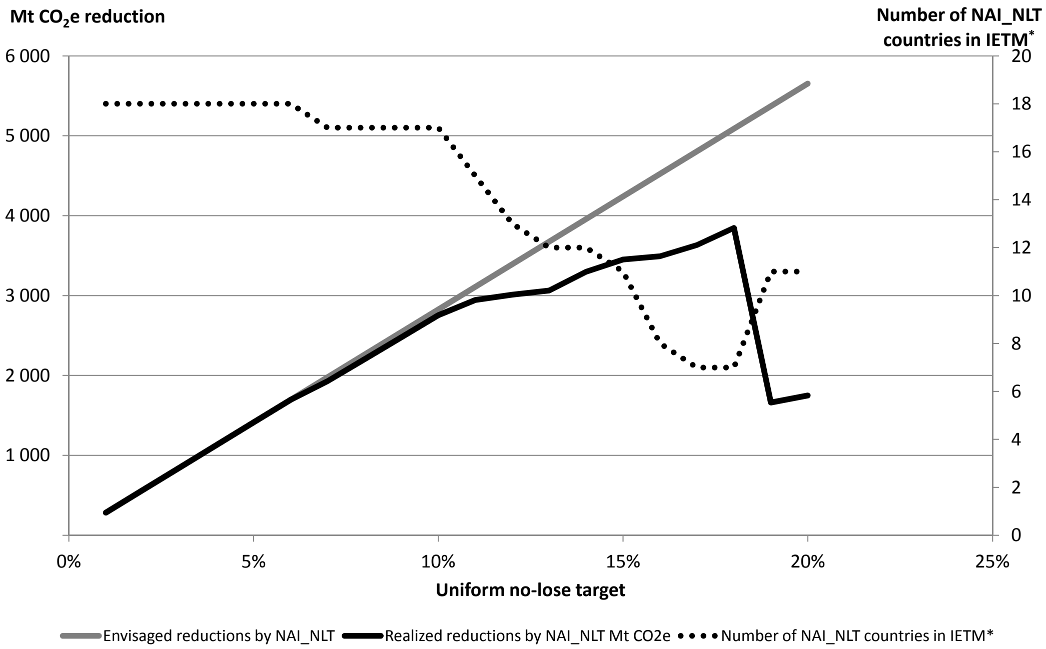


Figure 4.3: Participation and emission reductions from NAI_NLT countries under a 40% reduction scenario for AI countries in 2020 - Sensitivity analysis for no-lose targets levels

### 4.4.2 Results for scenarios with individual no-lose targets for large emitters

Section 4.4.1 illustrates the importance of considering the participation incentives of large emitters when deciding on the level of reduction rates for NAI_NLT countries. Further, the results of IPCC_low in section 4.3.2 showed that in case of uniform reduction targets low cost countries can realize high payoffs from profitable no-lose targets. In this section, we deviate from the assumption that all NAI_NLT countries face a uniform reduction target. Instead, we allow individual no-lose targets for the largest emitters among the NAI_NLT countries, i.e. Brazil, India and China (BIC). Individual targets may better account for heterogeneity across NAI_NLT countries, e.g. with respect to abatement costs. Hence, individual no-lose targets may lead to lower payoffs for some NAI_NLT countries, higher global emission reductions than uniform targets, and lower total costs at the global level and for AI countries. For NAI_NLT countries other than BIC we assume a uniform reduction target of 10% below baseline while AI countries face a uniform 40% reduction target

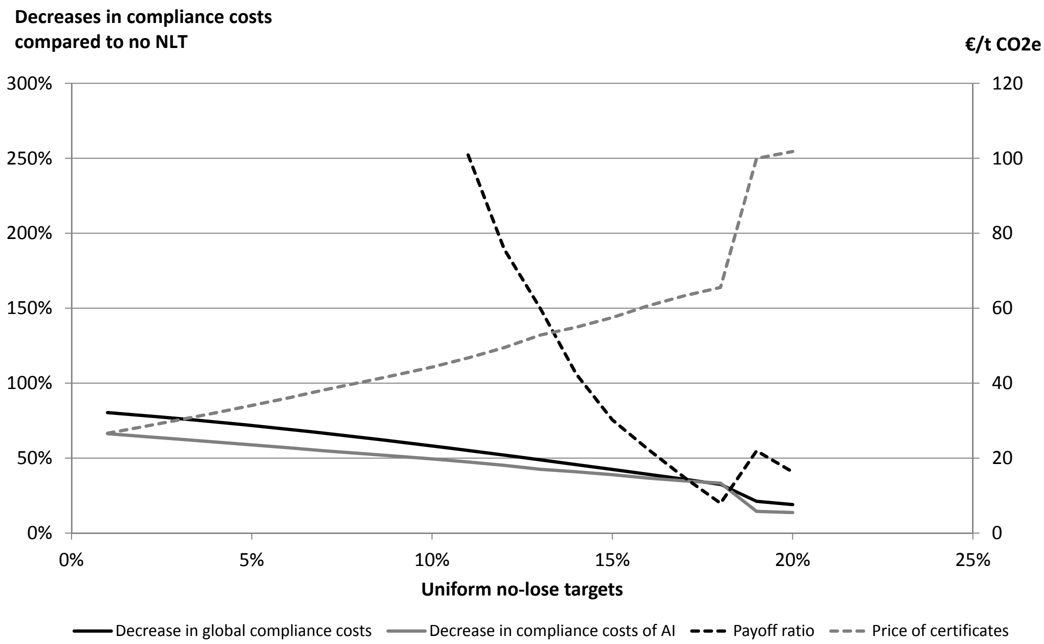


Figure 4.4: Prices and changes in costs compared to IPCC_low in 2020 - Sensitivity analysis for no-lose targets levels

as before (BIC scenario).

Our solution algorithm now starts with a uniform no-lose reduction target of 10% for BIC and for all other NAI_NLT countries. In this starting scenario, no-lose targets turn out to be profitable for all NAI_NLT countries but Mexico. The reduction rates are then individualized and increased for BIC beginning with China followed by India and Brazil until participation in the international emissions trading market is no longer profitable for at least one of the BIC countries. We refer to the three reduction targets, where the participation constraints for all three BIC countries becomes binding, as the "threshold reduction targets". Since tighter reduction targets for BIC result in a lower supply of certificates from these countries certificate prices increase as no-lose targets for BIC become tighter. Because other NAI_NLT countries benefit via the revenue, they continue to participate in the international emissions trading market.

For IETM*, we find threshold reduction targets for Brazil, India and China of 12%, 16% and 15%.[45] More detailed results on the scenario as well as the

[45]If lower uniform targets than 10% are chosen for NAI_NLT countries other than BIC, the country-specific targets for BIC will be lower and global emissions will be higher because

starting scenario are provided in Table C.2 in Appendix C.3. Compared to the starting scenario with uniform NLT of 10% for all NAI_NLT countries, the BIC scenarios leads to higher emission reductions of about 1 $GtCO_2e$ and to lower compliance costs for AI countries. In general, the additional effects of individualizing reduction targets for some countries compared to the starting scenario is smaller, the closer the uniform targets in the starting scenario are to the "threshold reduction targets". Compared to the IPCC_low scenario, in the BIC scenario global compliance costs are 20% lower, compliance costs of AI countries are 25% lower, while global emission reductions are 22.5% higher.

In sum, individualizing the no-lose targets for the largest emitters leads to lower global emissions than the "IPCC" scenarios and to similar emissions as the "best" LT scenarios are able to achieve. However, the envisage global emission growth targets of 30% and 10% will be missed by about 1.8 $GtCO_2e$ or 8.3 $GtCO_2e$, respectively.

### 4.4.3 Results for alternative burden-sharing scenarios

Since none of the scenarios considered so far resulted in participation by all eligible NAI_NLT countries, the envisaged global emission growth targets of 10% and 30% were missed. Emission levels for NAI_NLT countries were too high either because no-lose targets were too ambitious as in the "IPCC" scenarios or because reduction targets were too lenient as in the LT and BIC scenarios, so that even high ratios of realized versus envisaged reductions were not sufficient to meet global emission targets. In this section, we explore the effects of shifting the burden of emission reductions between Annex I and non-Annex I countries, while requiring that the global emission growth targets of 10% or 30% are met. All alternative burden-sharing scenarios (BuS scenarios) assume that AI and NAI_NLT countries are subject to uniform reduction targets.

We distinguish two kinds of alternative burden-sharing scenarios. In the "full participation" BuS_10_FP and BuS_30_FP scenarios, we calculate the no-lose target level at which all NAI_NLT countries participate in the no-lose target scheme.[46] In comparison, for the BuS_10 and BuS_30 scenarios, we

of the revenue effect. Lower targets for other NAI_NLT countries imply higher supply and lower prices of certificates, and hence lower country-specific threshold reduction targets for BIC. For example, a uniform target of 5% for other NAI_NLT countries results in threshold reduction targets for Brazil, India and China of 11%, 14% and 13%, respectively.

[46] This scenario corresponds to an international emissions trading scenario, where – just like the AI countries – all NAI_NLT countries have to meet binding emission targets. Im-

no longer require all eligible non-Annex I countries to participate in no-lose targets, but continue to enforce the global emission growth rates of 10% and 30%, respectively.

Our findings for the BuS_FP scenarios suggest that a global emission growth target of 10% can be reached if AI countries reduce emissions by 84% compared to 1990 levels and if uniform no-lose targets are set at 13%. For the 30% global emission growth target, Annex I countries face a reduction rate of 56% and the no-lose target is 9%. In both scenarios, NLT emission reductions in NAI_NLT countries (reductions up to $T_j$ in Figure 4.2) account for about 20% of global emission reductions. An additional 45% of global emission reductions is realized in the NAI_NLT countries but paid for via certificate trading by AI countries (reductions between $T_j$ and $r_j^*$ in Figure 4.2). In this case, about 2/3 of global emission reductions are realized in NAI_NLT countries. The prices for emission certificates and offsetting credits are 68€/t$CO_2$e and 144€/t$CO_2$e for the 30% and the 10% global emission growth targets, respectively (see Table 4.6).

In comparison, the BuS_10 and BuS_30 scenarios imply more lenient reduction targets for AI countries, but stricter NLT for NAI_NLT and considerably less NAI_NLT countries which participate in the NLT scheme. For the 10% global emission growth target in 2020, Annex I countries need to reduce emissions by 72% below 1990 levels and the NLT for the five NAI_NLT countries is 31%. For the global emission growth target of 30%, the reduction rate for AI countries is 46% and the NLT for the seven NAI_NLT countries is 21%. NAI_NLT countries' own contribution to global emission reductions (reductions up to $T_j$ in Figure 4.2) increases to about 45% for the 10% global emission growth target and even 47% for the 30% global emission growth target. In addition, 25% (for the 10% global emission growth target) and 19% (for the 30% global emission growth target) of global emission reductions are realized in NAI_NLT countries but paid for by AI countries (reductions between $T_j$ and $r_j^*$ in Figure 4.2). Similar to the BuS_FP scenarios, in the BuS_30 scenario (Bus_10 scenario) emission reductions in NAI_NLT countries account for about 2/3 (70%) of global reductions. The prices for emission certificates and offsetting credits are somewhat higher than in the BuS_FP scenarios (see Table 4.6).

plementing the equivalent outcome (in terms of global emissions) via binding targets for all countries, however, would not recognize the participation constraints of NAI_NLT countries.

Table 4.7 compares the main findings of the alternative burden-sharing scenarios to the "IPCC" scenario with the lowest global emissions, i.e. the IPCC_low scenario. Interestingly, BuS_30_FP not only leads – by design – to lower global emissions (by 43%), but also to lower global costs (by 2%), suggesting that this setting is not only more environmentally effective but also globally more cost-efficient. In this case, NAI_NLT countries enjoy large payoffs because of the uniform NLT scheme, while AI countries face higher compliance costs because of more ambitious reduction targets in BuS_30_FP compared to IPCC_low. From the perspective of AI countries both these aspects may render BuS_30_FP politically unacceptable. For all other BuS scenarios the higher global emission reductions also result in higher global compliance cost, in particular for the 10% global emission growth target.

The findings further suggest that for the 10% and the 30% global emissions growth targets "full participation" results in lowest total compliance costs, but compliance costs for AI countries are significantly higher than in the BuS scenarios. This finding illustrates again that, in case of uniform reduction targets, the more (high cost) non-Annex I countries are to participate in no-lose targets, the higher are the additional costs Annex I countries have to bear. From this perspective, Annex I countries should favor no-lose targets that induce participation by large, low-cost non-Annex I countries, rather than by all eligible non-Annex I countries.

| Scenario | Price IETM | Price OM | No. of part. NAI_NLT | Envisaged reductions by NAI_NLT | Realized reductions by NAI_NLT | | Certificates sold by NAI_NLT |
|---|---|---|---|---|---|---|---|
| | [€/$tCO_2e$] | [€/$tCO_2e$] | | [$MtCO_2e$] | [$MtCO_2e$] | [%] | [$MtCO_2e$] |
| BuS_10_FP | 143.67 | 143.67 | 18 | 3 675 | 3 675 | 100 | 8 628 |
| BuS_30_FP | 67.81 | 67.81 | 18 | 2 544 | 2 544 | 100 | 5 648 |
| BuS_10 | 152.73 | 151.19 | 5* | 8 616 | 6 193 | 72 | 3 623 |
| BuS_30 | 85.65 | 85.65 | 7** | 5 936 | 4 487 | 76 | 3 162 |

* CHN, IND, KOR, NIG, PAK

** CHN, IDN, IND, KAZ, KOR, NIG, PAK

Table 4.6: Alternative burden-sharing scenarios for a 2 °C stabilization scenario

| Scenario | Global emission reductions* | Global compliance costs | AI compliance costs |
|---|---|---|---|
| | [%] | [%] | [%] |
| BuS_10_FP | 170 | 141 | 258 |
| BuS_30_FP | 43 | -2 | 31 |
| BuS_10 | 172 | 220 | 201 |
| BuS_30 | 44 | 24 | 15 |

* Differences in global emission reductions between BuS_10_FP and BuS_10 and BuS_30_FP and BuS_30 are due to rounding errors.

Table 4.7: Global emission reductions and costs in the alternative burden-sharing scenarios compared to the IPCC_low scenario

## 4.5 Conclusions

The model-based quantitative analyses presented in this chapter for the year 2020 illustrate that properly designed no-lose targets may benefit eligible non-Annex I countries, contribute to global emission reductions, and reduce compliance costs for Annex I countries. In this respect, climate policy faces the challenge of identifying burden-sharing arrangements which are acceptable to Annex I and non-Annex I countries and to determine no-lose targets which induce participation by a sufficient number of non-Annex I countries to meet the global climate target without causing undesirable distributional effects such as excessive payoffs (rents) for some non-Annex I countries at the expense of Annex I countries.

More specifically, the findings provide guidance for policy making. In particular, our findings suggest that implementing no-lose targets for non-Annex I countries under the burden-sharing as discussed in the latest IPCC assessment report (Metz et al., 2007) will not lead to global emission levels considered compatible with the 2 °C target, because participation in no-lose targets is profitable for a few non-Annex I countries, at best. More lenient no-lose targets than those implemented in our "IPCC" scenarios may actually result in lower global emissions, lower global compliance costs and lower compliance costs for Annex I countries than more ambitious no-lose targets. Likewise, individualizing no-lose target levels for large emitters may increase participation by non-Annex I countries, lower global emissions and reduce payoffs for non-Annex I countries. While both options may offer a politically less challenging, yet environmentally and economically effective way for non-Annex I countries to contribute to global emission reductions, resulting global emission levels are not consistent with the 2 °C target.

Our findings also show that no-lose targets may help achieving the 2 °C target in a more environmentally effective and cost-efficient way, if the burden sharing is adjusted appropriately, that is binding emission targets for Annex I countries become more stringent while no-lose targets for non-Annex I countries become more lenient compared to the "IPC" scenarios. In this case, requiring full participation by all non-Annex I countries in no-lose target scheme results in the lowest total compliance costs, but meeting the participation constraint of the high-cost non-Annex I countries may involve high compliance costs for Annex I countries and large payoffs for low-cost non-Annex I countries. Alternatively, requiring participation in no-lose targets by the largest five to seven emitters only to reach the 2 °C target, involves no-lose targets of 21% and 31% below baseline in 2020 for the 10% and 30% global emissions growth scenarios, respectively, and, hence, in the range considered in the "IPCC" scenarios. The required emission reductions for Annex I countries of 72% (for the 10% global emissions growth scenario) and 64% (for the 30% global emissions growth scenario) by 2020 compared to 1990 levels are much more ambitious than envisaged in the "IPCC" scenarios, though. Also, in this alternative burden-sharing scenario non-Annex I countries realize about 2/3 of required global emission reductions in 2020. While the reduction targets found in our alternative burden-sharing scenarios are less balanced than the burden-sharing suggested by the IPCC, they are in line with other burden-sharing scenarios suggested in the academic literature (Winkler, Vorster, & Marquard, 2009) or in the policy arena such as the Carbon Space approach (Kanitkar et al., 2010), the Brazilian Proposal (United Nations, 1997), or the Greenhouse Development Rights approach (Baer, Athanasiou, Kartha, & Kemp-Benedict, 2008). From a political, economical or technical perspective, however, these alternative burden-sharing proposals are likely to be even more difficult to implement than an IPCC-type burden-sharing.

# 5 Conclusions and outlook

The global emission reductions necessary to limit the increase in mean global temperature to 2°C above pre-industrial levels require contributions from all large emitters. In order to extend the range of countries contributing to global emission reductions beyond the Annex I community, new instruments need to be found and introduced. One possible instrument, no-lose targets, was analyzed in this thesis. No-lose targets provide non-Annex I countries with an incentive to contribute to global emission reductions by allowing them to sell excess emission certificates, which are generated by reducing emissions beyond the target, in the international emissions trading market. The aim of this thesis was to determine whether no-lose targets are a suitable instrument to commit non-Annex I countries to global emission reduction efforts and to deepen the economic understanding of the instrument by providing economic analyses that have been missing from the literature so far.

This thesis presented two theoretical frameworks to analyze no-lose targets from an economic perspective. First, the simplest constellation, that of one non-Annex I country facing a no-lose target and interacting with the Annex I community in the international emissions trading market was analyzed. A two-stage model was introduced to analyze the participation decision of the non-Annex I country, based on the revenues from selling excess emission certificates in the emissions trading market and the abatement costs for meeting the no-lose target. In a second step, this framework was extended to model two non-Annex I countries facing a no-lose target. A game-theoretical component was added to the framework to analyze the impacts that the decision of one non-Annex I country has on the decision of the other non-Annex I country. The analyses focused on two symmetric non-Annex I countries.

As a complement to the highly stylized economic analyses, a quantitative analysis applying marginal abatement cost curves from a global partial equilibrium model was carried out. In particular, the quantitative analysis allowed us to include a larger number of non-Annex I countries facing no-lose targets (18) and to take the heterogeneity of non-Annex I countries into account when analyzing the potential of no-lose targets to contribute to reaching the 2°C target.

Subsequently, a short summary of the main results is provided, followed by a critical reflection of the methods applied and an outlook to further research.

## 5.1 Conclusions

Analyses in this thesis focused on three different aspects of no-lose targets. First, a quantification of the contribution from no-lose targets to global emission reductions, applying the theoretical frameworks, shows that, in the case of symmetry between the Annex I community and the non-Annex I country, the burden-sharing is 3 to 1 in a competitive market. That is, the Annex I community has to accept at least 3/4 of the global emission reduction effort for the non-Annex I country's no-lose target to be profitable. At the same time, large numbers of certificate transfers from the non-Annex I country to the Annex I community via the international emissions trading market are necessary to create profitability. Skipping the symmetry assumption between the Annex I community and the non-Annex I country, and assuming that the non-Annex I country's potential to reduce emissions is larger than the Annex I community's, increases the non-Annex I country's share in global emission reduction efforts. Yet, in a competitive market, the non-Annex I countries' share in global reduction efforts always has to remain below 50% for the no-lose target to be profitable, independent of the number of non-Annex I countries facing a no-lose target.

The quantitative analysis results in emission reductions of 46% and 72% below 1990 levels for Annex I countries and 21% and 31% below baseline for non-Annex I countries by 2020, when applying no-lose targets and targeting at global emission targets of 30% and 10% above 1990 levels as suggested to keep mean temperature increase below 2°C above pre-industrial levels. These target levels are found to be significantly more ambitious for Annex I countries than the reduction range of 25% to 40% below 1990 levels proposed in the IPCC 4$^{th}$ assessment report. The reduction range for non-Annex I countries is found to be at the lower target level of the corresponding reduction range for non-Annex I countries.

Hence, the analyses show that no-lose targets can result in contributions from non-Annex I countries to global emission reductions, but that the decidedly larger share of the reduction efforts is still the responsibility of the Annex I community, due to the profitability condition.

Second, the theoretical analysis of the interaction of two symmetric non-Annex I countries facing no-lose targets shows the optimal no-lose targets to be lower in the case of two participating non-Annex I countries than in the case of just one. Global emission reductions, however, are found to be higher for two participating non-Annex I countries. Hence, higher participation does not only result in a higher efficiency in the emissions trading market, but also in higher environmental benefits, due to higher global emission reductions. For large differences in abatement costs between the Annex I community and the non-Annex I countries, this effect lessens in a competitive market.

Results from the quantitative analysis counteract these findings, in particular when applying uniform reduction targets for all non-Annex I countries. In that case, the heterogeneity of the non-Annex I countries and the uniform reduction rate result in high profits for some of the non-Annex I countries. The large profits indicate a large supply of emission certificates in the emissions trading market, which lowers the price for those certificates. Hence, the high profits for some non-Annex I countries prevent higher emission reduction contributions from the non-Annex I countries in general. Instead, the best environmental effects are seen for uniform no-lose reduction targets that induce participation by all major emitting non-Annex I countries (in particular China and India). Hence, the higher economic efficiency does not automatically result in a better outcome for the environment. Individualized targets can reduce this effect, however, as determining the individual optimal no-lose target in reality and for a large number of non-Annex I countries may prove very difficult. Hence, the quantitative results allow the conclusion that smaller negotiating groups that contain the largest emitters may be a good alternative to the UNFCCC in the search for finding an environmentally effective agreement.

The third aspect particularly analyzed are the effects of market power on the no-lose target. The theoretical analyses show that market power on the part of the non-Annex I country/countries facing a no-lose target allows the non-Annex I country's/countries' share in global emission reduction efforts to increase. In particular, the share of non-Annex I countries in global emission reduction efforts can exceed the 50% limit identified in the competitive market. Increasing the no-lose target is possible, as strategically acting non-Annex I countries can generate higher prices and hence larger revenues from emissions trading.

As a result of adapting the no-lose target level accordingly, the non-Annex I country/countries cannot use their market power to generate profits, as is usually the case. Instead, the strategic behavior of the non-Annex I country can be used to increase the global reduction target (bottom-up target-setting approach) or the non-Annex I country's contributions to global emission reductions (top-down approach). Hence, Annex I countries do not necessarily need to regard market power on the side of the non-Annex I country/countries as a problem, due to the positive effects on emission reductions. The analyses show, however, that market power still results in welfare losses and, hence, increases the costs for the Annex I community.

In addition, the analyses of market power show a noteworthy effect of the optimal no-lose target on the non-Annex I country's optimal emission reductions in the case of a bottom-up target-setting approach, where the Annex I community's aggregated emission reduction target remains constant. If differences between the Annex I community's and the non-Annex I country's abatement costs become large enough, the optimal emission reductions of the non-Annex I country, in the case of market power, are lower than in the case of a perfectly competitive market applying the respective optimal no-lose target. This finding is surprising, as usually a non-Annex I country with market power would reduce less emissions than in the competitive market, to increase the price. However, the higher target level of the optimal no-lose target in case of market power forces the non-Annex I country to make higher emission reductions than in the case of a competitive market. This finding is limited to the bottom-up target-setting approach. In contrast, in the case of a top-down approach, the decrease of the Annex I community's reduction target in the wake of an increasing non-Annex I country's no-lose target prevents such an effect.

## 5.2 Critical reflection and outlook

The analyses presented in this thesis can be seen as a starting point to exploring the economic understanding of no-lose targets. In particular, the theoretical frameworks presented in chapters 2 and 3 which are suitable for determining the main economic effects of no-lose targets are, however, highly stylized and supplementary quantitative analyses show that not all results are maintained when a more realistic framework is applied. A possible extension of the theoretical frameworks is introducing heterogeneous non-Annex I countries to account for heterogeneity of countries in reality. It would further allow analyses of different market power concepts, like the effects of market power of one non-Annex I country on smaller non-Annex I countries (Stackelberg leadership model). Similarly, the standard game-theoretical framework of modeling the participation decision of two non-Annex I countries chosen in this thesis could be extended to include uncertainty (Bayesian games). While allowing us to model the link between the decisions of non-Annex I countries facing no-lose targets, this would further allow us to account for the fact that one non-Annex I country does not necessarily have full information on the exact decision parameters of the other non-Annex I countries facing no-lose targets when making the decision.

Finally, for these analyses no-lose reduction targets were taken as given. In reality, the target level of no-lose targets would be the outcome of international negotiations. Hence, further research is necessary to analyze the strategic aspects of the target-setting procedure as a part of the negotiation process. In particular, the optimal no-lose targets introduced in this thesis present a socially optimal outcome of burden-sharing negotiations. Hence, they do not necessarily present the individually optimal outcome in terms of welfare from the point of view of a non-Annex I country. Further, the quantitative analysis in this thesis highlighted the important role of China (and India). Analyses of the negotiation process should take this into account (e.g. by modeling a right of veto for these countries), as it can be assumed – and the analyses in this thesis stressed this point – that no effective international agreement will be found that does not include at least these two non-Annex I countries.

While the complementary quantitative analysis helps to overcome the abstract character of the economic analyses, a number of shortcomings still apply. The analysis mainly focused on uniform no-lose reduction targets while in reality country-specific targets are much more likely. Introducing individualized no-lose targets as done for China, India and Brazil in this thesis appears promising. This approach could be extended to other non-Annex I countries to increase the contribution of global emission reduction efforts and limit the profits from emissions trading, although the effects should be smaller for smaller non-Annex I countries. Also, different selection criteria to identify the non-Annex I countries facing a profitable no-lose target could be implemented, in order to check the robustness of the results obtained in this analysis.

The marginal abatement cost curves applied were derived from a partial global equilibrium model. In general, to get more reliable modeling results, similar analyses could be performed with a wider range of models and the modeling results be compared. That approach reduces the model-induced effects and allows us to determine the economic effects of the analyzed instrument in more general terms. In particular, similar analyses could be conducted, applying a general equilibrium model to account for the welfare effects of no-lose targets which can be positive, although the no-lose target restricted to abatement costs and revenues from selling emission certificates is not profitable.

The present thesis focused on economic and environmental analyses of no-lose targets. While economic understanding of market-based instruments is important, economic barriers are not the only factor that can prevent non-Annex I countries from meeting their no-lose targets and hence contributing to global emission reductions. A very important factor in international negotiations on climate change are political barriers. Therefore, a more integrated approach is necessary to identifying the potential of no-lose targets. Apart from further analyses in both disciplines on no-lose targets, it includes bringing together work from the political science perspective (see e.g. Thompson, 2006) and the economic perspective to identify whether no-lose targets are an economically efficient and politically acceptable instrument that can lead non-Annex I countries to contribute to global emission reduction efforts.

Also, no-lose targets are only one possible instrument discussed to include non-Annex I countries in global emission reduction efforts. Similar analyses of the other instruments are necessary to adequately assess no-lose targets in the context of international emission reduction efforts. This would allow us to identify the instrument most suited to integrating non-Annex I countries from an economic, a political as well as an environmental perspective. The analysis of the non-Annex I country's payoff function in this thesis implied that, under certain circumstances, a no-lose target could counteract policies targeting at a reduction of a non-Annex I country's marginal abatement costs like R&D cooperation. Hence, it is necessary to analyze the interaction of different instruments to determine whether combining different instruments might help to reach the goal of keeping the global temperature increase below 2°C, or even counteract this.

# A Emissions by country

| Country | GHG emissions [$MtCO_2e$] | | | |
|---|---|---|---|---|
| | 1990* | 2005* | 2010** | 2020*** |
| Australia | 410 | 572 | 366 | 591 |
| Austria | 76 | 94 | 63 | 93 |
| Belarus | 154 | 85 | 59 | 126 |
| Belgium | 151 | 167 | 112[1] | 140 |
| Bulgaria | 113 | 68 | 41 | 71 |
| Canada | 588 | 746 | 518 | 825 |
| Croatia | 32 | 31 | na | 40 |
| Czech Republic | 187 | 143 | 109 | 151 |
| Denmark | 73 | 69 | 44 | 59 |
| Estonia | 43 | 21 | na | 22 |
| EU 27 | 5 547 | 5 332 | na | 4 990 |
| Finland | 72 | 71 | 63 | 72 |
| France | 555 | 575 | 363 | 533 |
| Germany | 1 214 | 1 005 | 763 | 883 |
| Greece | 113 | 139 | 91 | 138 |
| Hungary | 101 | 84 | 50 | 75 |
| Iceland | 3 | 4 | na | 4 |
| Ireland | 54 | 72 | 41 | 79 |
| Italy | 515 | 582 | 408 | 530 |
| Japan | 1 217 | 1 390 | 1 138 | 1 274 |
| Latvia | 27 | 12 | na | 13 |
| Lithuania | 47 | 20 | 14 | 27 |
| Luxembourg | 12 | 14 | na | 14 |
| Malta | 3 | 5 | na | 3 |
| Netherlands | 252 | 288 | 181 | 217 |

| Country | GHG emissions [$MtCO_2e$] | | | |
|---|---|---|---|---|
| | 1990* | 2005* | 2010** | 2020*** |
| New Zealand | 62 | 80 | 29 | 80 |
| Norway | 48 | 55 | 51 | 57 |
| Poland | 440 | 374 | 310 | 429 |
| Portugal | 63 | 86 | 56 | 79 |
| Romania | 241 | 132 | 78 | 163 |
| Russian Federation | 2 963 | 1 955 | 1 689 | 2 493 |
| Slovakia | 71 | 50 | 32 | 62 |
| Slovenia | 17 | 20 | na | 22 |
| Spain | 295 | 471 | 275 | 443 |
| Sweden | 73 | 75 | 48 | 64 |
| Switzerland | 55 | 57 | 39 | 50 |
| Turkey | 261 | 397 | 295 | 495 |
| Ukraine | 948 | 495 | 280 | 476 |
| United Kingdom | 734 | 684 | 493 | 598 |
| United States of America | 6 108 | 7 051 | 5 492 | 6 835 |
| Total | 18 391 | 18 549 | 13 591 | 18 326 |

* Data from CAIT 8.0

** Data from CDIAC (Boden & Blasing, 2011), $CO_2$ only

*** Projections from POLES based on historic data from IEA (2011)

[1] Belgium & Luxembourg

na: not available

Table A.1: Annex I countries' historic and projected emissions

| Country | GHG emissions [$MtCO_2e$] | | | |
|---|---|---|---|---|
| | 1990* | 2005* | 2010** | 2020*** |
| Argentina | 245 | 333 | 190 | 413 |
| Brazil | 695 | 1 025 | 420 | 1 533 |
| China | 3 599 | 7 273 | 8 241 | 14 810 |
| Egypt | 131 | 234 | 233 | 359 |
| India | 1 114 | 1 876 | 2 070 | 3 609 |
| Indonesia | 334 | 580 | 477 | 997 |
| Iran | 254 | 573 | 575 | 998 |
| Kazakhstan | 315 | 203 | 240 | 390 |
| Malaysia | 103 | 236 | 200 | 388 |
| Mexico | 437 | 642 | 466 | 723 |
| Nigeria | 183 | 296 | na | 417 |
| Pakistan | 146 | 244 | 167 | 471 |
| Republic of Korea | 314 | 608 | 563 | 671 |
| Saudi Arabia | 215 | 388 | 494 | 686 |
| South Africa | 341 | 433 | 452 | 457 |
| Thailand | 193 | 366 | 299 | 540 |
| Taiwan | 141 | 298 | 265 | 444 |
| Vietnam | 79 | 180 | 160 | 361 |
| Others | 3 525 | 5 016 | 4 408 | 6 655 |
| Total | 12 364 | 20 804 | 19 920 | 34 922 |

* Data from CAIT

** Data from CDIAC (Boden & Blasing, 2011), $CO_2$ only

*** Projections from POLES based on historic data from IEA (2011)

na: not available

Table A.2: Non-Annex I countries' historic and projected emissions

# B Derivation of formula and proofs to chapter 3

## B.1 Derivation of optimality conditions

**Two participating non-Annex I countries in a competitive market**

From the first order condition of the optimization problem (3.3) follows

$$\widetilde{r}_A^C = \frac{\alpha_N}{\alpha_A}\widetilde{r}_i^C\,.$$

Applying market clearing condition (3.4) yields optimal emission reductions of the Annex I community of

$$\begin{aligned} && \widetilde{r}_A^C &= \frac{\alpha_N}{2\alpha_A}(T_A + 2T_N - \widetilde{r}_A^C) \\ \Leftrightarrow && \widetilde{r}_A^C(1 + \frac{\alpha_N}{2\alpha_A}) &= \frac{\alpha_N}{2\alpha_A}(T_A + 2T_N) \\ \Leftrightarrow && \widetilde{r}_A^C &= \frac{2\alpha_A\alpha_N}{2\alpha_A(2\alpha_A + \alpha_N)}(T_A + 2T_N) \\ && &= \frac{\alpha_N}{2\alpha_A + \alpha_N}(T_A + 2T_N)\,. \end{aligned}$$

From market clearing condition (3.4) follows for the optimal emission reductions of the non-Annex I country

$$\begin{aligned} \widetilde{r}_i^C &= \frac{1}{2}(T_A + 2T_N - \widetilde{r}_A^C) \\ &= \frac{1}{2}\left(T_A + 2T_N - \frac{\alpha_N}{2\alpha_A + \alpha_N}(T_A + 2T_N)\right) \\ &= \frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 2T_N) \end{aligned}$$

for the optimal emission reductions of the non-Annex I countries. For market price $\widetilde{p}^C$ follows

$$\widetilde{p}^C = \alpha_N \widetilde{r}_i^C = \frac{\alpha_A \alpha_N}{2\alpha_A + \alpha_N}(T_A + 2T_N)\,.$$

Hence, the payoff $\widetilde{\Pi}_N^C$ of the non-Annex I countries is given by

$$\begin{aligned}
\widetilde{\Pi}_N^C &= \widetilde{p}^C(\widetilde{r}_i^C - T_N) - C_N(\widetilde{r}_i^C) \\
&= \frac{\alpha\alpha_N}{2\alpha+1}\widetilde{T}\left(\frac{\alpha}{2\alpha+1}\widetilde{T} - T_N\right) - \frac{1}{2}\frac{\alpha^2\alpha_N}{(2\alpha+1)^2}\widetilde{T}^2 \\
&= \frac{\alpha^2\alpha_N}{(2\alpha+1)^2}\widetilde{T}^2 - \frac{\alpha^2\alpha_N}{2(2\alpha+1)^2}\widetilde{T}^2 - \frac{\alpha\alpha_N}{2\alpha+1}\widetilde{T}T_N \\
&= \frac{\alpha\alpha_N}{2\alpha+1}\left(\frac{\alpha}{2(2\alpha+1)}\widetilde{T}^2 - \widetilde{T}T_N\right)\,.
\end{aligned}$$

For the payoff to be positive we need to show that

$$\begin{aligned}
& & \frac{\alpha}{2(2\alpha+1)}\widetilde{T} - T_N &> 0 \\
&\Leftrightarrow & \alpha T_A - 2(\alpha+1)T_N &> 0 \\
&\Leftrightarrow & \frac{T_N}{T_A} &< \frac{\alpha}{2(\alpha+1)}\,.
\end{aligned}$$

### One participating non-Annex I country in a competitive market

In case of one participating non-Annex I country $i$ optimal emission reductions are derived applying market clearing condition (3.5). From solving the Annex I communities optimization problem we get

$$\begin{aligned}
& & r_A^C = \frac{\alpha_N}{\alpha_A}r_i^C &= \frac{\alpha_N}{\alpha_A}(T_N + T_A - r_A^C) \\
&\Leftrightarrow & r_A^C\left(1 + \frac{\alpha_N}{\alpha_A}\right) &= \frac{\alpha_N}{\alpha_A}(T_A + T_N) \\
&\Leftrightarrow & r_A^C &= \frac{\alpha_N}{\alpha_A + \alpha_N}(T_A + T_N)\,.
\end{aligned}$$

The participating non-Annex I country's optimal emission reductions are given by

$$\begin{aligned} r_i^C &= T_A + T_N - r_A^C \\ &= T_A + T_N - \frac{\alpha_N}{\alpha_A + \alpha_N}(T_A + T_N) \\ &= \frac{\alpha_A}{\alpha_A + \alpha_N}(T_A + T_N) \end{aligned}$$

and the market price results as

$$p^C = \alpha_N r_i^C = \frac{\alpha_A \alpha_N}{\alpha_A + \alpha_N}(T_A + T_N)\,.$$

The participating non-Annex I country's payoff $\Pi_N^C$ is then given by

$$\begin{aligned} \Pi_N^C &= p^C(r_i^C - T_N) - C_N(r_i^C) \\ &= \frac{\alpha\alpha_N}{\alpha+1}T\left(\frac{\alpha}{\alpha+1}T - T_N\right) - \frac{1}{2}\frac{\alpha^2\alpha_N}{(\alpha+1)^2}T^2 \\ &= \frac{\alpha^2\alpha_N}{(\alpha+1)^2}T^2 - \frac{\alpha^2\alpha_N}{2(\alpha+1)^2}T^2 - \frac{\alpha\alpha_N}{\alpha+1}TT_N \\ &= \frac{\alpha\alpha_N}{\alpha+1}\left(\frac{\alpha}{2(\alpha+1)}T^2 - TT_N\right)\,. \end{aligned}$$

For the payoff to be positive

$$\begin{aligned} & & \frac{\alpha}{2(\alpha+1)}T - T_N &> 0 \\ &\Leftrightarrow & \alpha T_A - (\alpha+2)T_N &> 0 \\ &\Leftrightarrow & \frac{T_N}{T_A} &< \frac{\alpha}{\alpha+2} \end{aligned}$$

has to hold.

### Two participating non-Annex I countries with market power

The market-clearing condition that needs to hold in case of two non-Annex I countries participating in the emissions trading market is given by (3.4). Deriving the first order condition for a price-taking Annex I country (3.3) and applying the Annex I country's emission reductions given by (3.24) results in

$$\widetilde{p}^P = \alpha_A \widetilde{r}_A^P = \alpha_A(T_A - (\widetilde{r}_{N1}^P - T_N) - (\widetilde{r}_{N2}^P - T_N))\,.$$

Applying the market price we can solve the non-Annex I country's $N1$ optimization problem (3.3). Calculating the first derivative and equating it to zero yields

$$\begin{aligned}
&\alpha_N \widetilde{r}^P_{N1} - \alpha_A(T_N - \widetilde{r}^P_{N1}) - \alpha_A(\widetilde{T} - \widetilde{r}^P_{N1} - \widetilde{r}^P_{N2}) = 0 \\
\Leftrightarrow \quad & \widetilde{r}^P_{N1}(2\alpha_A + \alpha_N) = \alpha_A(\widetilde{T} + T_N - \widetilde{r}^P_{N2}) \\
\Leftrightarrow \quad & \widetilde{r}^P_{N1} = \frac{\alpha_A}{2\alpha_A + \alpha_N}(\widetilde{T} + T_N - \widetilde{r}^P_{N2})\,.
\end{aligned} \tag{B.1}$$

From symmetry between the two non-Annex I follows

$$\widetilde{r}^P_{N2} = \frac{\alpha_A}{2\alpha_A + \alpha_N}(\widetilde{T} + T_N - \widetilde{r}^P_{N1})\,. \tag{B.2}$$

Applying (B.2) to (B.1) yields

$$\begin{aligned}
& \widetilde{r}^P_{N1} = \frac{\alpha_A}{2\alpha_A + \alpha_N}(\widetilde{T} + T_N - \frac{\alpha_A}{2\alpha_A + \alpha_N}(\widetilde{T} + T_N - \widetilde{r}^P_{N1})) \\
\Leftrightarrow \quad & \left(1 - \frac{\alpha_A^2}{(2\alpha_A + \alpha_N)^2}\right)\widetilde{r}^P_{N1} = \frac{\alpha_A}{(2\alpha_A + \alpha_N)^2}\left(\alpha_A + \alpha_N\right)\left(T_A + 3T_N\right) \\
\Leftrightarrow \quad & \widetilde{r}^P_{N1} = \widetilde{r}^P_{N2} = \frac{\alpha_A}{3\alpha_A + \alpha_N}(T_A + 3T_N) = \frac{\alpha}{3\alpha + 1}(T_A + 3T_N)\,.
\end{aligned}$$

Optimal emission reductions of Annex I (3.30) result from

$$\begin{aligned}
\widetilde{r}^P_A &= T_A - (\widetilde{r}^P_{N1} - T_N) - (\widetilde{r}^P_{N2} - T_N) \\
&= T_A - 2\left(\frac{\alpha}{3\alpha + 1}(T_A + 3T_N) - T_N\right) \\
&= \frac{1}{3\alpha + 1}\widetilde{T} + \frac{\alpha}{3\alpha + 1}T_A\,.
\end{aligned}$$

Applying (3.30) to (3.26) yields a market price $\widetilde{p}^P$ of

$$\widetilde{p}^P = \alpha_A \widetilde{r}^P_A = \frac{\alpha_A}{3\alpha + 1}\widetilde{T} + \frac{\alpha_A \alpha}{3\alpha + 1}T_A\,.$$

The non-Annex I countries' payoff $\widetilde{\Pi}^P_N$ is then given by

$$\begin{aligned}
\widetilde{\Pi}^P_N =& \widetilde{p}^P(\widetilde{r}^P_i - T_N) - C_N(\widetilde{r}^P_i) \\
=& \alpha_A\left(\frac{\alpha_N}{3\alpha_A + \alpha_N}(T_A + 2T_N) + \frac{\alpha_A}{3\alpha_A + \alpha_N}T_A\right)\left(\frac{\alpha_A}{3\alpha_A + \alpha_N}(T_A + 3T_N) - T_N\right)
\end{aligned}$$

$$
\begin{aligned}
&- \frac{1}{2}\alpha_N \frac{\alpha_A^2}{(3\alpha_A+\alpha_N)^2}(T_A+3T_N)^2 \\
=&\frac{\alpha_A}{(3\alpha_A+\alpha_N)^2} \\
&\left(\left(\alpha_A^2+\frac{1}{2}\alpha_A\alpha_N\right)T_A^2-\left(2\alpha_A\alpha_N+\alpha_N^2\right)T_AT_N-\left(\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2\right)T_N^2\right).
\end{aligned}
$$

For $\widetilde{\Pi}_N^P$ to be positive the term in brackets above needs to be greater than zero:

$$
\begin{aligned}
&\left(\alpha_A^2+\frac{1}{2}\alpha_A\alpha_N\right)T_A^2-\left(2\alpha_A\alpha_N+\alpha_N^2\right)T_AT_N-\left(\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2\right)T_N^2>0 \\
\Leftrightarrow\quad &\left(\frac{T_A}{T_N}\right)^2-\frac{2\alpha_N}{\alpha_A}\frac{T_A}{T_N}-\frac{\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2}{\alpha_A^2+\frac{1}{2}\alpha_A\alpha_N}>0.
\end{aligned}
$$

This holds for

$$
\begin{aligned}
\frac{T_A}{T_N} &> \frac{\alpha_N}{\alpha_A}+\sqrt{\frac{\alpha_N^2}{\alpha_A^2}+\frac{\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2}{\alpha_A^2+\frac{1}{2}\alpha_A\alpha_N}} \\
&= \frac{\alpha_N}{\alpha_A}+\sqrt{\frac{\alpha_N(3\alpha_A+\alpha_N)^2}{\alpha_A^2(2\alpha_A+\alpha_N)}} \\
&= \frac{\alpha_N+(3\alpha_A+\alpha_N)\sqrt{\frac{\alpha_N}{2\alpha_A+\alpha_N}}}{\alpha_A}.
\end{aligned}
$$

Taking the reciprocal value yields (3.33).

### One participating non-Annex I country with market power

The market clearing condition from the previous case needs to be replaced by (3.5). Solving Annex I's optimization problem and applying Annex I's reaction function in case of one participating non-Annex I country (3.25) yields

$$p^P=\alpha_A r_A^P=\alpha_A(T_A-(r_i^P-T_N)).$$

Applying the above condition and solving the non-Annex I country's optimization problem results in a first order condition of

$$
\begin{aligned}
&\alpha_AT_A-2\alpha_A(r_i^P-T_N)-\alpha_N r_i^P=0 \\
\Leftrightarrow\quad &\alpha_A(T_A+2T_N)=(2\alpha_A+\alpha_N)r_i^P
\end{aligned}
$$

$$\Leftrightarrow \qquad r_i^P = \frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 2T_N) = \frac{\alpha}{2\alpha + 1}(T_A + 2T_N)\,.$$

Optimal emission reductions of the Annex I community are hence given by

$$\begin{aligned} r_A^P &= T_A - (r_i^P - T_N) \\ &= T_A - (\frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 2T_N) - T_N) \\ &= \frac{1}{2\alpha_A + \alpha_N}((\alpha_A + \alpha_N)T_A + \alpha_N T_N)\,. \end{aligned}$$

Market price $p^P$ is given by

$$p^P = \alpha_A r_A^P = \frac{\alpha_A}{2\alpha_A + \alpha_N}((\alpha_A + \alpha_N)T_A + \alpha_N T_N)\,.$$

The non-Annex I country's payoff $\Pi_N^P$ can be derived as

$$\begin{aligned} \Pi_N^P =& p^P(r_i^P - T_N) - C_N(r_i^P) \\ =& \frac{\alpha_A}{2\alpha_A + \alpha_N}\left((\alpha_A + \alpha_N)T_A + \alpha_N T_N\right)\left(\frac{\alpha_A}{2\alpha_A + \alpha_N}(T_A + 2T_N) - T_N\right) \\ & - \frac{1}{2}\alpha_N \frac{\alpha_A^2}{(2\alpha_A + \alpha_N)^2}(T_A + 2T_N)^2 \\ =& \frac{\alpha_A}{2\alpha_A + \alpha_N}\left(\frac{1}{2}\alpha_A T_A^2 - \alpha_N T_A T_N - \alpha_N T_N^2\right)\,. \end{aligned}$$

For the payoff $\Pi_N^P$ to be positive it is sufficient to check that the term in brackets is greater than zero

$$\begin{aligned} & \frac{1}{2}\alpha_A T_A^2 - \alpha_N T_A T_N - \alpha_N T_N^2 > 0 \\ \Leftrightarrow \quad & \left(\frac{T_A}{T_N}\right)^2 - \frac{2\alpha_N}{\alpha_A}\frac{T_A}{T_N} - \frac{2\alpha_N}{\alpha_A} > 0\,. \end{aligned}$$

This holds for

$$\begin{aligned} \frac{T_A}{T_N} &> \frac{\alpha_N}{\alpha_A} + \sqrt{\frac{\alpha_N^2}{\alpha_A^2} + \frac{2\alpha_N}{\alpha_A}} \\ &= \frac{\alpha_N}{\alpha_A} + \sqrt{\frac{\alpha_N^2 + 2\alpha_A\alpha_N}{\alpha_A^2}} = \frac{1 + \sqrt{1 + 2\alpha}}{\alpha}\,. \end{aligned}$$

Taking the reciprocal value yields (3.39).

## B.2 Proofs

### Proof of Proposition 7

*Proof.* The first derivative of the non-Annex I country's payoff with respect to $\alpha_A$ in general is given by

$$\frac{d\Pi}{d\alpha_A} = \frac{dp}{d\alpha_A}(r_i - T_N) + p\frac{dr_i}{d\alpha_A} - \frac{dC_N}{dr_i}\frac{dr_i}{d\alpha_A}\,. \tag{B.3}$$

In the competitive market the following holds

$$\frac{dC_N}{dr_i} = \alpha_N r_i = p\,.$$

Hence, the first derivative can be simplified to

$$\frac{d\Pi}{d\alpha_A} = \frac{dp}{d\alpha_A}(r_i - T_N)\,. \tag{B.4}$$

The first derivatives of the market price in a competitive market are given by

$$\frac{d\widetilde{p}^C}{d\alpha_A} = \frac{\alpha_N^2}{(2\alpha_A + \alpha_N)^2}\widetilde{T} \tag{B.5}$$

and

$$\frac{dp^C}{d\alpha_A} = \frac{\alpha_N^2}{(\alpha_A + \alpha_N)^2}T\,. \tag{B.6}$$

Applying (B.5) and (B.6) to (B.4) yields

$$\frac{d\widetilde{\Pi}_N^C}{d\alpha_A} = \frac{\alpha_N^2}{(2\alpha_A + \alpha_N)^3}\widetilde{T}\left(\alpha_A T_A - \alpha_N T_N\right)$$

and

$$\frac{d\Pi_N^C}{d\alpha_A} = \frac{\alpha_N^2}{(\alpha_A + \alpha_N)^3}T\left(\alpha_A T_A - \alpha_N T_N\right)\,.$$

The first derivatives are in both cases positive if

$$\frac{T_N}{T_A} < \frac{\alpha_A}{\alpha_N}$$

which is fulfilled for (3.1).

In the case of market power, the following first derivatives are needed to solve (B.3):

$$
\begin{aligned}
\frac{d\widetilde{p}^P}{d\alpha_A} &= \frac{(3\alpha_A^2 + 2\alpha_A\alpha_N + \alpha_N^2)T_A + 2\alpha_N^2 T_N}{(3\alpha_A + \alpha_N)^2} \\
\frac{dp^P}{d\alpha_A} &= \frac{(2\alpha_A^2 + 2\alpha_A\alpha_N + \alpha_N)T_A + \alpha_N^2 T_N}{(2\alpha_A + \alpha_N)^2} \\
\frac{d\widetilde{r}_i^P}{d\alpha_A} &= \frac{\alpha_N}{(3\alpha_A + \alpha_N)^2}(T_A + 3T_N) \\
\frac{dr_i^P}{d\alpha_A} &= \frac{\alpha_N}{(2\alpha_A + \alpha_N)^2}(T_A + 2T_N)\,.
\end{aligned}
$$

The first derivatives of the payoffs are then given by

$$
\begin{aligned}
\frac{d\widetilde{\Pi}_N^P}{d\alpha_A} =& \frac{1}{(3\alpha_A + \alpha_N)^3}\left(\alpha_A\left(3\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2\right)T_A^2\right. \\
& \left. -\alpha_N^2(\alpha_A + \alpha_N)T_A T_N - \alpha_N^2(3\alpha_A + 2\alpha_N)T_N^2\right)
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{d\Pi_N^P}{\alpha_A} =& \frac{1}{(2\alpha_A + \alpha_N)^3}\left(\alpha_A(2\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2)T_A^2\right. \\
& \left. -\alpha_N^2(2\alpha_A + \alpha_N)T_A T_N - \alpha_N^2(2\alpha_A + \alpha_N)T_N^2\right)\,.
\end{aligned}
$$

To show that the first derivatives are positive, we need to show that the terms in brackets are positive. In case of two participating non-Annex I countries, this yields the following condition:

$$
\begin{aligned}
& \alpha_A(2\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2)T_A^2 - \alpha_N^2(2\alpha_A + \alpha_N)T_A T_N - \alpha_N^2(2\alpha_A + \alpha_N)T_N^2 > 0 \\
\Leftrightarrow\quad & \frac{T_N^2}{T_A^2} + \frac{\alpha_A + \alpha_N}{3\alpha_A + 2\alpha_N}\frac{T_N}{T_A} - \frac{3\alpha_A^3 + 3\alpha_A^2\alpha_N + \alpha_A\alpha_N^2}{3\alpha_A\alpha_N^2 + 2\alpha_N^3} < 0\,.
\end{aligned}
$$

This holds for

$$
\begin{aligned}
\frac{T_N}{T_A} &< -\frac{\alpha_A + \alpha_N}{2(3\alpha_A + 2\alpha_N)} + \sqrt{\frac{36\alpha_A^4 + 60\alpha_A^3\alpha_N + 37\alpha_A^2\alpha_N^2 + 10\alpha_A\alpha_N^3 + \alpha_N^4}{4\alpha_N^2(3\alpha_A + 2\alpha_N)^2}} \\
&= \frac{-(\alpha_A\alpha_N + \alpha_N^2) + (6\alpha_A^2 + 5\alpha_A\alpha_N + \alpha_N^2)}{2\alpha_N(3\alpha_A + 2\alpha_N)} \\
&= \frac{6\alpha_A^4 + 4\alpha_A\alpha_N}{6\alpha_A\alpha_N + 4\alpha_N^2}
\end{aligned}
$$

$$= \frac{\alpha_A}{\alpha_N}$$

which is fulfilled for (3.1).

In case of one participating non-Annex I country, this yields the following condition:

$$\begin{aligned}
& \alpha_A(2\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2)T_A^2 - \alpha_N^2(2\alpha_A + \alpha_N)T_AT_N - \alpha_N^2(2\alpha_A + \alpha_N)T_N^2 > 0 \\
\Leftrightarrow \quad & \frac{T_N^2}{T_A^2} + \frac{T_N}{T_A} - \frac{\alpha_A(2\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2)}{\alpha_N^2(2\alpha_A + \alpha_N)} < 0\,.
\end{aligned}$$

This holds for

$$\begin{aligned}
\frac{T_N}{T_A} &< -\frac{1}{2} + \sqrt{\frac{1}{4} + \frac{\alpha_A(2\alpha_A^2 + 3\alpha_A\alpha_N + \alpha_N^2)}{\alpha_N^2(2\alpha_A + \alpha_N)}} \\
&= -\frac{1}{2} + \sqrt{\frac{(2\alpha_A + \alpha_N)^2}{4\alpha_N^2}} \\
&= \frac{\alpha_A}{\alpha_N}
\end{aligned}$$

which is fulfilled for (3.1).

The first derivatives with respect to $\alpha_N$ are given by

$$\begin{aligned}
\frac{d\widetilde{\Pi}_N^C}{d\alpha_N} &= \frac{\alpha_A^2}{2(2\alpha_A + \alpha_N)^3}\left((2\alpha_A - \alpha_N)T_A^2 - 8\alpha_N T_A T_N - (8\alpha_A + 12\alpha_N)T_N^2\right) \\
\frac{d\Pi_N^C}{d\alpha_N} &= \frac{\alpha_A^2}{2(\alpha_A + \alpha_N)^3}\left((\alpha_A - \alpha_N)T_A^2 - 4\alpha_N T_A T_N - (\alpha_A + 3\alpha_N)T_N^2\right) \\
\frac{d\widetilde{\Pi}_N^P}{d\alpha_N} &= \frac{\alpha_A^2}{(3\alpha_A + \alpha_N)^3}\left(-\left(\frac{1}{2}\alpha_A + \frac{1}{2}\alpha_N\right)T_A^2 - \left(\frac{27}{2}\alpha_A + \frac{15}{2}\alpha_N\right)T_AT_N - (6\alpha_A + 4\alpha_N)\,T_N^2\right) \\
\frac{d\Pi_N^P}{d\alpha_N} &= \frac{\alpha_A^2}{(2\alpha_A + \alpha_N)^2}\left(-\frac{1}{2}T_A^2 - 2T_AT_N - 2T_N^2\right)\,.
\end{aligned}$$

For the first derivatives to be positive, the terms in brackets need to be positive. In case of a competitive market, the conditions are given by

$$\begin{aligned}
& (2\alpha_A - \alpha_N)T_A^2 - 8\alpha_N T_A T_N - (8\alpha_A + 12\alpha_N)T_N^2 < 0 \\
\Leftrightarrow \quad & \left(\frac{T_N}{T_A}\right)^2 + \frac{2\alpha_N}{2\alpha_A + 3\alpha_N}\frac{T_N}{T_A} - \frac{2\alpha_A - \alpha_N}{8\alpha_A + 12\alpha_N} < 0 \\
\Leftrightarrow \quad & \frac{T_N}{T_A} < \frac{2\alpha_A - \alpha_N}{4\alpha_A + 6\alpha_N}
\end{aligned}$$

for two participating non-Annex I countries and

$$
\begin{aligned}
& (\alpha_A - \alpha_N)T_A^2 - 4\alpha_N T_A T_N - (\alpha_A + 3\alpha_N)T_N^2 > 0 \\
\Leftrightarrow \quad & \left(\frac{T_N}{T_A}\right)^2 + \frac{4\alpha_N}{\alpha_A + 3\alpha_N} - \frac{\alpha_A - \alpha_N}{\alpha_A + 3\alpha_N} < 0 \\
\Leftrightarrow \quad & \frac{T_N}{T_A} < \frac{\alpha_A - \alpha_N}{\alpha_A + 3\alpha_N}
\end{aligned}
$$

for one participating non-Annex I country.

In case of market power, it is easy to see that the first derivatives are negative for positive $\alpha_A$, $\alpha_N$, $T_A$ and $T_N$. □

**Proof of Proposition 8**

*Proof.* The first derivatives of the payoffs with respect to $T_A$ are

$$
\begin{aligned}
\frac{d\widetilde{\Pi}_N^C}{dT_A} &= \frac{\alpha_A \alpha_N}{(2\alpha_A + \alpha_N)^2} (\alpha_A T_A - \alpha_N T_N) \\
\frac{d\Pi_N^C}{dT_A} &= \frac{\alpha_A \alpha_N}{(\alpha_A + \alpha_N)^2} (\alpha_A T_A - \alpha_N T_N) \\
\frac{d\widetilde{\Pi}_N^P}{dT_A} &= \frac{\alpha_A}{(3\alpha_A + \alpha_N)^2} \left( (2\alpha_A^2 + \alpha_A \alpha_N)T_A - \left(\frac{9}{2}\alpha_A + 2\alpha_N\right) T_N \right) \\
\frac{d\Pi_N^P}{dT_A} &= \frac{\alpha_A}{2\alpha_A + \alpha_N} (\alpha_A T_A - \alpha_N T_N) \; .
\end{aligned}
$$

In all cases, the first derivatives are positive if the term in brackets is positive. For $\widetilde{\Pi}_N^C$, $\Pi_N^C$ and $\Pi_N^P$ this holds if

$$
\frac{T_N}{T_A} < \frac{\alpha_A}{\alpha_N} \, .
$$

In case of $\widetilde{\Pi}_N^P$, for the term in brackets to be positive, the following needs to hold:

$$
\begin{aligned}
& (2\alpha_A^2 + \alpha_A \alpha_N)T_A - \left(\frac{9}{2}\alpha_A + 2\alpha_N\right) T_N > 0 \\
\Leftrightarrow \quad & \frac{T_N}{T_A} < \frac{2\alpha_A^2 + \alpha_A \alpha_N}{\frac{9}{2}\alpha_A + 2\alpha_N} \\
\Leftrightarrow \quad & \frac{T_N}{T_A} < \frac{4\alpha^2 + 2\alpha}{9\alpha + 4}
\end{aligned}
$$

This is fulfilled if at least one non-Annex I country has an incentive to participate, i.e. if (3.39) holds:

$$
\begin{aligned}
& & \frac{4\alpha^2+2\alpha}{9\alpha+4} &> \frac{\alpha}{1+\sqrt{2\alpha+1}} \\
&\Leftrightarrow & 2(2\alpha+1)\sqrt{2\alpha+1} &> 5\alpha+2 \\
&\Leftrightarrow & 32\alpha^3+48\alpha^2+24\alpha+4 &> 25\alpha^2+20\alpha+4 \\
&\Leftrightarrow & 32\alpha^3+23\alpha^2+4\alpha &> 0\,,
\end{aligned}
$$

which is fulfilled for positive $\alpha$.

The first derivatives of the payoffs with respect to $T_N$ are given by

$$
\begin{aligned}
\frac{d\widetilde{\Pi}_N^C}{dT_N} &= \frac{\alpha_A\alpha_N}{(2\alpha_A+\alpha_N)^2}\left(-(\alpha_N T_A+4\alpha_A T_N+4\alpha_N T_N)\right) \\
\frac{d\Pi_N^C}{dT_N} &= \frac{\alpha_A\alpha_N}{(\alpha_A+\alpha_N)^2}\left(-(\alpha_N T_A+\alpha_A T_N+2\alpha_N T_N)\right) \\
\frac{d\widetilde{\Pi}_N^P}{dT_N} &= \frac{\alpha_A}{(3\alpha_A+\alpha_N)^2}\left(-\left(\frac{9}{2}\alpha_A\alpha_N+2\alpha_N^2\right)T_A-\left(4\alpha_A\alpha_N+2\alpha_N^2\right)T_N\right) \\
\frac{d\Pi_N^P}{dT_N} &= \frac{\alpha_A}{2\alpha_A+\alpha_N}\left(-(\alpha_N T_A+2\alpha_N T_N)\right)\,.
\end{aligned}
$$

It is easy to see that they are smaller than zero for positive $\alpha_A$, $\alpha_N$, $T_A$ and $T_N$. □

**Proof of $\widetilde{\Pi}_N^C < \Pi_N^C$ & $\widetilde{\Pi}_N^P < \Pi_N^P$**

*Proof.* In the competitive market the following applies:

$$
\begin{aligned}
\Pi_N^C-\widetilde{\Pi}_N^C =& \frac{\alpha_A\alpha_N}{(\alpha_A+\alpha_N)^2}\left(-\left(\frac{1}{2}\alpha_A+\alpha_N\right)T_N^2-\alpha_N T_A T_N+\frac{1}{2}\alpha_A T_A^2\right) \\
& -\frac{\alpha_A\alpha_N}{(2\alpha_A+\alpha_N)}\left(-2\left(\alpha_A+\alpha_N\right)T_N^2-\alpha_N T_A T_N+\frac{1}{2}\alpha_A T_A^2\right) \\
=& \left(\frac{3}{2}\alpha_A\alpha_N^2+\alpha_N^3\right)T_N^2+\left(\frac{3}{2}\alpha_A^3+\alpha_A^2\alpha_N\right)T_A^2 \\
& -\left(5\alpha_A^2\alpha_N+6\alpha_A\alpha_N^2\right)T_A T_N \\
=& \left(\frac{3}{2}\alpha_A+\alpha_N\right)(\alpha_A T_A-\alpha_N T_N)^2 > 0\,.
\end{aligned}
$$

In the market power case the following applies:

$$
\begin{aligned}
\Pi_N^P - \widetilde{\Pi}_N^P =& \frac{\alpha_A}{2\alpha_A + \alpha_N} \left( \frac{1}{2} \alpha_A T_A^2 - \alpha_N T_A T_N - \alpha_N T_N^2 \right) - \frac{\alpha_A}{(3\alpha_A + \alpha_N)^2} \\
& \left( \left( \alpha_A^2 + \frac{1}{2} \alpha_A \alpha_N \right) T_A^2 - \left( \frac{1}{2} \alpha_A \alpha_N + 2\alpha_N^2 \right) T_A T_N - \left( 2\alpha_A \alpha_N + \alpha_N^2 \right) T_N^2 \right) \\
=& \frac{\alpha_A}{(2\alpha_A + \alpha_N)(3\alpha_A + \alpha_N)^2} \left( \left( 9\alpha_A^2 + 6\alpha_A \alpha_N + \alpha_N^2 \right) \left( \frac{1}{2} \alpha_A T_A^2 - \alpha_N T_A T_N - \alpha_N T_N^2 \right) \right. \\
& - (2\alpha_A + \alpha_N) \left( \alpha_A^2 + \frac{1}{2} \alpha_A \alpha_N \right) T_A^2 + (2\alpha_A + \alpha_N) \left( \frac{9}{2} \alpha_A \alpha_N + 2\alpha_N^2 \right) T_A T_N \\
& \left. + (2\alpha_A + \alpha_N) \left( 2\alpha_A \alpha_N + \alpha_N^2 \right) T_N^2 \right) \\
=& \frac{\alpha_A (5\alpha_A + 2\alpha_N)}{(2\alpha_A + \alpha_N)(3\alpha_A + \alpha_N)^2} \left( \frac{1}{2} \alpha_A^2 T_A^2 + \frac{1}{2} \alpha_N^2 T_A T_N - \alpha_A \alpha_N T_N^2 \right)
\end{aligned}
$$

For positive $\alpha_A, \alpha_N, T_A$ and $T_N$ the term in brackets needs to be greater than zero:

$$
\begin{aligned}
& \frac{1}{2} \alpha_A^2 T_A^2 + \frac{1}{2} \alpha_N^2 T_A T_N - \alpha_A \alpha_N T_N^2 > 0 \\
\Leftrightarrow \quad & \frac{T_N^2}{T_A^2} - \frac{1}{2\alpha} \frac{T_N}{T_A} - \frac{\alpha}{2} < 0 \\
\Leftrightarrow \quad & \frac{T_N}{T_A} < \frac{1 + \sqrt{8\alpha^3 + 1}}{4\alpha}
\end{aligned}
\tag{B.7}
$$

To show that this is fulfilled we need to show that (B.7) is always fulfilled if at least one non-Annex I country faces a profitable no-lose target. This is fulfilled if (B.7) is larger than the participation condition in case of one participating non-Annex I country (4.2):

$$
\begin{aligned}
& \frac{1 + \sqrt{8\alpha^3 + 1}}{4\alpha} > \frac{\alpha}{1 + \sqrt{2\alpha + 1}} \\
\Leftrightarrow \quad & 1 + \sqrt{8\alpha^3 + 1} + \sqrt{2\alpha + 1} + \sqrt{8\alpha^3 + 1}\sqrt{2\alpha + 1} > 4\alpha^2 \\
\Leftrightarrow \quad & 1 + \sqrt{8\alpha^3 + 1} + \sqrt{2\alpha + 1} + \sqrt{16\alpha^4 + 8\alpha^3 + 2\alpha + 1} > 4\alpha^2
\end{aligned}
$$

This holds for positive $\alpha$ due to

$$
\sqrt{16\alpha^4 + 8\alpha^3 + 2\alpha + 1} > 4\alpha^2 \,.
$$

□

# C Appendix to chapter 4

## C.1 Solution algorithm

In the following we provide a formal description of the algorithm implemented to model the participation and non-participation of non-Annex I countries in no-lose targets.

Step 1 First definition of the IETM: all AI countries $(1, ...m)$ and all NAI_NLT countries $(1, ...n)$ belong to the IETM, i.e.

$$IETM := \{AI_1, ...AI_m, NAI\_NLT_1, ...NAI\_NLT_n\}$$

Step 2 Solving the optimization problems given in section 4.2.2 subject to the market clearing condition and the domestic quota and offsetting limit equations. The market prices and trading amounts of emission certificates and offsetting credits are used to calculate compliance costs $TC_i$ for all NAI_NLT countries within the IETM.

Step 3 Without loss of generality we assume

$$TC_1 > TC_2 > ... > TC_n\,.$$

If $TC_1 > 0$ then the new IETM is defined as

$$IETM := \{AI_1, ...AI_m, NAI\_NLT_2, ...NAI\_NLT_n\}$$

and go back to Step 2.

If $TC_1 \leq 0$ continue.

Step 4 Let $k = \{1, ...K\}$ be the NAI_NLT countries included in the IETM and $l = \{K + 1, ...L\}$ be the NAI_NLT countries excluded from the IETM.

For each $l$ redefine

$$IETM = \{AI_1, ...AI_m, NAI\_NLT_1, ...NAI\_NLT_K, NAI\_NLT_l\}.$$

Solve the optimization problems given by (4.1) subject to the market clearing condition and the domestic quota and offsetting limit equations. The market prices and trading amounts of emission certificates and offsetting credits are used to calculate compliance costs $TC_i$ for all NAI_NLT countries within the IETM. If for all $i \in \{1, ...K, l\} : TC_i > 0$ restart Step 4 with new IETM.

## C.2 Sensitivity analyses

This Appendix contains the results of the sensitivity analyses for the domestic quota, offsetting limit and the amount of "hot air". To save space, and since results are qualitatively similar for the other scenarios, we restrict these sensitivity analyses to the IPCC_low scenario.

Results of the sensitivity analysis for the domestic quota in the IPCC_low scenario are shown in Figure C.1. Accordingly, varying the domestic quota between 5% and 40% has no impact on the outcome. A higher domestic quota of 60% and 80% lowers the price for emission certificates and offsetting credits, because a higher domestic quota lowers the demand for certificates and offsetting credits. For a domestic quota of 80%, participation decreases from 11 to 6 NAI_NLT countries, because the lower prices render participation unprofitable (revenue effect).

Figure C.2 displays the results of the sensitivity analysis for the offsetting limit in the IPCC_low scenario. Varying the offsetting limit between 5% and 20% does not change the number of participating countries. Due to the lack of demand for offsetting credits, however, prices decrease for very low offsetting quota.

Finally, Table C.1 presents the results of varying the amounts of "hot air". Since "hot air" puts downward pressure on certificate prices and reduces demand for certificates from NAI_NLT countries, reducing "hot air" is expected to increase participation by NAI_NLT countries. Results in Table C.1 (second column) suggest that eliminating "hot air" leads to slightly higher prices, but they are not sufficient to entice additional participation by NAI_NLT coun-

| | incl. "hot air" | excl. "hot air" | excl. "hot air", adj. AI targets |
|---|---|---|---|
| Price IETM *[€/t $CO_2e$]* | 101.81 | 103.50 | 101.81 |
| Price OM *[€/t $CO_2e$]* | 101.81 | 103.50 | 101.81 |
| No. of part. NAI_NLT | 11 | 11 | 11 |
| Global reductions *[Mt $CO_2e$]* | 8 846 | 8 926 | 8 846 |

Table C.1: Sensitivity analysis for "hot air" in the IPCC_low scenario

tries. While excluding "hot air" automatically results in an increase in the global target, column 3 in Table C.1 gives results for a scenario where global emissions are kept constant and AI countries' targets are adjusted accordingly. In this scenario, prices and the number of NAI_NLT countries participating in the no-lose target scheme remain unchanged, though.

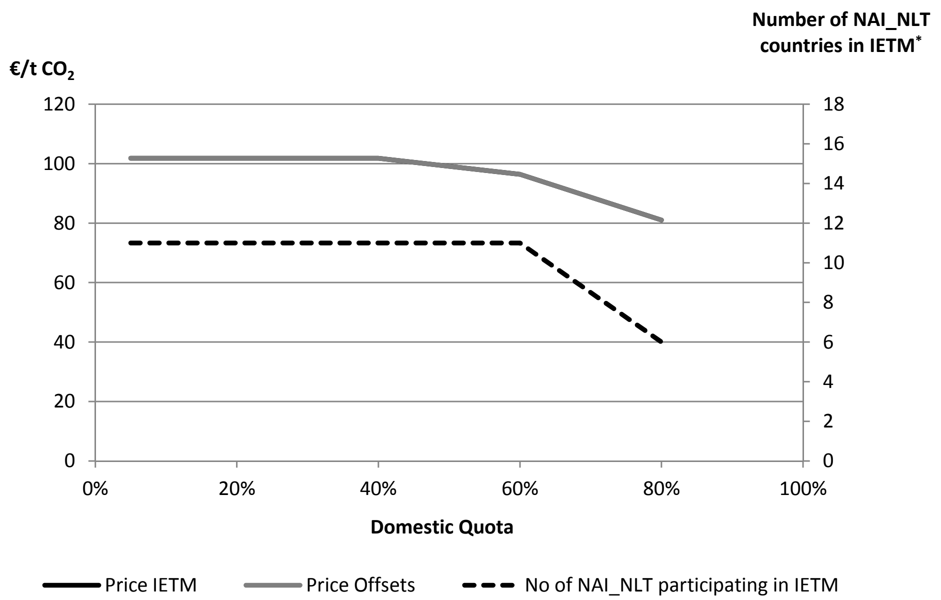


Figure C.1: Sensitivity analysis for the domestic quota in the IPCC_low scenario

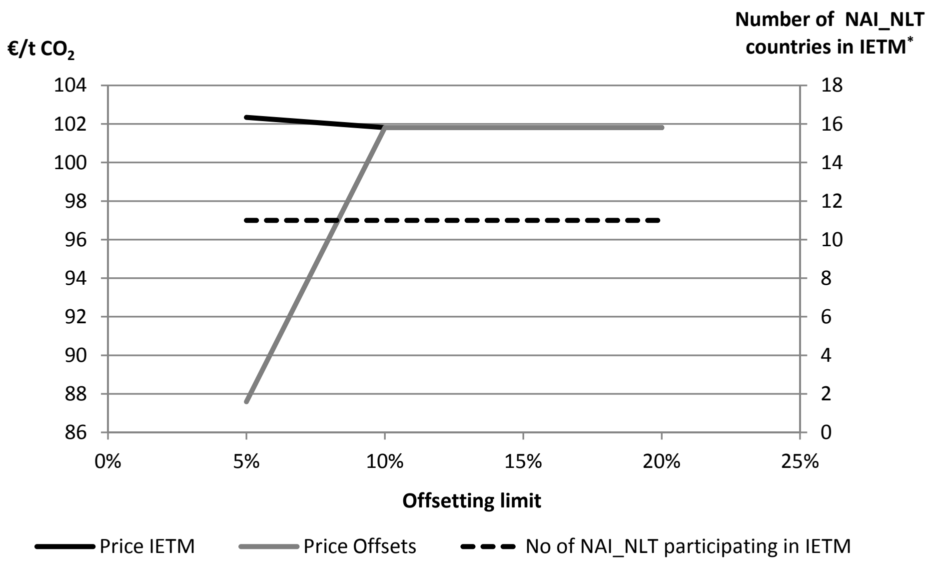


Figure C.2: Sensitivitiy analysis for the offsetting limit in the IPCC_low scenario

## C.3 Results for BIC scenarios

| Scenario | Price IETM | Price OM | No. of part. NAI_NLT | Envisaged reductions by NAI_NLT | Realized reductions by NAI_NLT | | Realized global reductions |
|---|---|---|---|---|---|---|---|
| | *[€/t $CO_2e$]* | *[€/t $CO_2e$]* | | *[Mt $CO_2e$]* | *[Mt $CO_2e$]* | *[%]* | *[Mt $CO_2e$]* |
| BIC_10 | 52.70 | 52.70 | 17* | 3 814 | 3 742 | 98 | 10 839 |
| LT_10 | 44.30 | 44.30 | 17* | 2 827 | 2 754 | 97 | 9 851 |

* All NAI_NLT countries but MEX

Table C.2: Results for the BIC_10 scenario

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No-lose targets set emission reduction targets and define incentives for meeting the target, in contrast to binding reduction targets that use penalties to ensure compliance. In this thesis, two theoretical frameworks are introduced to analyse the potential of no-lose targets to contribute to global emission reduction efforts. In order to complement the highly stylized theoretical frameworks, a quantitative analysis applying marginal abatement cost curves is conducted.

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