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Analysis of Risks and Opportunities of Linking Emissions Trading Systems

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Abstract

This final report summarises the findings of the project 'Analysis of Risks and Opportunities of Linking the EU-ETS with other Emissions Trading Systems – further development of criteria and methods'. The core objective of the project was to develop a systematic framework to assess the risks and opportunities of linking specific systems in order to assist decision-makers in identifying potential linking partners and prepare for any future linking prospects. A key focus of the project was to quantify the economic impact of linking as far as possible and develop additional qualitative assessment approaches to linking. The report is divided into four sections. The first section is an analysis of major economic theories on the benefits and risks of linking emissions trading systems. The second section then compares the findings in academic theory on linking to the rationales given by different policymakers that have considered linking. Based on these findings, an analytical framework was developed that defines seven linking objectives (grouped as environmental, economic or political) and corresponding assessment criteria and investigates their interdependencies. This analytical framework allows for both a quantitative and qualitative consideration of prospective linking ventures. The third section is dedicated to possible approaches for a quantitative analysis of linking effects. To this end, several economic models were investigated and assessed in light of their possibilities and potential limitations in showing the economic impact of linking from a quantitative perspective. In the fourth section, individual design elements of emissions trading schemes were discussed from a qualitative perspective with regard to their importance for linking. The results of this analysis indicated some critical design elements that would need to be potentially adjusted to ensure the proper functioning of a linked carbon market. The main findings of the report were summarised and presented in a separate publication 'Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS'. The detailed results of assessing selected economic models regarding their suitability for analysing linking effects are contained in Annex I in form of eleven model fact-sheets.

Kurzbeschreibung

Der vorliegende Endbericht umfasst die Ergebnisse des Vorhabens „Weiterentwicklung von Kriterien und Methoden zur Beurteilung der Chancen und Risiken eines Linkings des EU-ETS mit anderen Emissionshandelssystemen und Analysen aktueller Entwicklungen". Kernziel des Vorhabens ist die Entwicklung eines systematischen Beurteilungsrahmens für die potentielle Verlinkung von Emissionshandelssystemen weltweit, der dazu beitragen soll, mögliche Chancen und Risiken zukünftiger Linking-Vorhaben zu identifizieren und Entscheidungsträger bei der Auswahl potenzieller Linking – Partner und bei der Vorbereitung einer Linking-Initiative zu unterstützen. Der Bericht sucht ferner, ökonomische Auswirkungen des Linking soweit wie möglich zu quantifizieren und weitere qualitative Bewertungsansätze zu entwickeln. Er gliedert sich in vier Abschnitte. Ausgangspunkt ist eine Analyse ökonomischer und weiterer relevanter Theorien zu Nutzen und Risiken einer Verlinkung von Emissionshandelssystemen. Die sich hieraus ergebenden möglichen Ziele für ein Linking werden mit empirischen Erkenntnissen zur Motivation für ein Linking verschiedener Handelssysteme verglichen. Darauf aufbauend wurde ein analytischer Rahmen entworfen, der sieben Ziele und entsprechende Bewertungskriterien aus ökonomischer, ökologischer und politischer Sicht definiert und in ihre Wirkungszusammenhänge und Wechselbeziehungen untersucht. Der analytische Rahmen ermöglicht eine quantitative und qualitative Betrachtung möglicher Linking-Vorhaben. Der dritte Abschnitt ist einer möglichen quantitativen Bewertung der Linking-Effekte gewidmet. Zu diesem Zweck wurden verschiedene ökonomische Modelle untersucht und in ihren Möglichkeiten und Grenzen bewertet, die ökono-

mischen Auswirkungen eines Linkings darzustellen. Im vierten Abschnitt wurde die Relevanz einzelner Designelemente eines Emissionshandelssystems für ein erfolgreiches Linking qualitativ erörtert. Auf diese Weise werden Erkenntnisse darüber gewonnen, welche Elemente eines Emissionshandels für einen funktionierenden gemeinsamen Markt potenziell angepasst werden müssten und welche in dieser Hinsicht unproblematisch erscheinen. Die zentralen Ergebnisse des Berichts wurden in einem Leitfaden „Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS" zusammengeführt, der separat veröffentlicht wurde. Annex I umfasst die Einzelergebnisse der Modellanalyse, in welcher eine Auswahl ökonomischer Modelle darauf hin evaluiert wurde, inwieweit sie sich für die Analyse der Auswirkungen eines Linkings eignen.

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List of Abbreviations

ARB	Air Resources Board
AUD	Australian Dollar
BAU	Business as Usual
CDM	Clean Development Mechanism
CGE	Computable General Equilibrium
DEHSt	German Emissions Trading Authority
EC	European Commission
EEA	European Economic Area
EITE	Energy-intensive, trade-exposed
ETS	Emissions trading system (or Emissions trading scheme)
EU	European Union
EUR	Euros
FOEN	Swiss Federal Office for the Environment
GDP	Gross Domestic Product
GEM	Global Equilibrium Model
GHG	Greenhouse gas
ICAP	International Carbon Action Partnership
IEA	International Energy Agency
INDC	Intended Nationally Determined Contributions
JI	Joint Implementation
LULUCF	Land use, land-use change and forestry
MAC(C)	Marginal abatement costs (curves)
MRV	Monitoring, reporting and verification
MSR	Market Stability Reserve
MtCO2e	Metric tons of carbon dioxide equivalent
NDC	Nationally Determined Contributions
NETS	Sector not covered by emissions trading system
PE model	Partial equilibrium model
PIK	Potsdam Institute for Climate Impact Research
PMR	Partnership for Market Readiness
RCA	Revealed comparative advantage
REDD	Reducing Emissions from Deforestation and Forest Degradation
RGGI	Regional Greenhouse Gas Initiative

RWS	Relative world shares
ToT	Terms of trade
UN	United Nations
USD	US Dollar
WCI	Western Climate Initiative

Summary

This final report summarises the key findings of the project 'Analysis of Risks and Opportunities of Linking the EU-ETS with other Emissions Trading Systems – further development of criteria and methods'. The core objective of the project was to develop a systematic framework to assess the risks and opportunities of linking specific emissions trading systems in order to assist decision-makers in identifying potential linking partners and prepare for any future linking prospects. A key focus of the project was to quantify the economic impact of linking as far as possible and develop additional qualitative assessment approaches to linking.

The project, which was undertaken by adelphi and the Wuppertal Institute from 2014-2017, was structured into six work packages the results of which are reproduced in this final report. The first section is an analysis of major economic theories on the benefits and risks of linking emissions trading systems. The second section then compares the findings in academic theory on linking to the legal and rhetorical rationales given by different policymakers that have considered linking. Based on these findings, an analytical framework was developed that defines seven linking objectives (grouped as environmental, economic or political) and corresponding assessment criteria and investigates their interdependencies. This analytical framework allows for both a quantitative and qualitative consideration of prospective linking ventures. The third section is dedicated to possible approaches for a quantitative analysis of linking effects. To this end, several economic models were investigated and assessed in light of their capabilities and potential limitations in showing the economic impact of linking from a quantitative perspective. In the fourth section, individual design elements of emissions trading schemes were discussed from a qualitative perspective with regard to their importance for linking. The major design elements and characteristics of ten emissions trading systems were analysed and compared. The results of this analysis indicated some critical design elements that would need to be potentially adjusted to ensure the proper functioning of a linked carbon market.

The main findings of the project were summarized and presented in form of a manual 'Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS', which was presented and discussed with a broader audience in Bonn alongside the UNFCCC intersessional negotiations in May 2017. The analytical framework developed in this project was exemplary applied to a hypothetical link between the EU ETS and the Korean ETS. Insights from this process were integrated into the manual (working packages 5 and 6).

Early results were also presented at an international conference at the University of Leuven on 8-9 February 2016 on 'The Global Turn to Greenhouse Gas Emissions Trading: Experiments, Innovation, Actors, Drivers and Consequences'.

Economic theories for linking emissions trading systems

There is a significant body of literature on the topic and around 50 sources were analysed for this project. The first section covers findings from environmental economics, trade theory, political economy, and game theory. Given the very specific foci of each of these theories, each can only partially illuminate certain risks and opportunities of linking. Environmental economics focuses more generally on the benefits of emissions trading in correcting market failures, while trade theory focuses specifically on the effects of terms of trade and the trading relationship of potential linking partners. Political economics and game theory seek to look at the potential preferences and motivations of domestic policymakers and how this affects both the efficiency and acceptability of the design and operation of their respective systems. In particular, the im-

portance of creating acceptable compromises and trade-offs are emphasized in order to get domestic stakeholder acceptance of linking and emissions trading more broadly.

Derivation of an analytical framework for assessing linking projects

Against the background of the findings from the academic literature in the first section, the second section provides insights on the legal and rhetorical rationale of decision-makers in order to identify the objectives for linking in the respective emissions trading systems. The following systems were assessed: the EU ETS, the Australian Carbon Pricing Mechanism, California cap-and-trade program, New Zealand ETS, RGGI and the Swiss ETS. Based on this, an analytical framework was developed that comprises seven linking objectives, as well as suggestions for assessment criteria and indicators. The objectives can be grouped in three dimensions - environmental, economic and political. As these objectives are of very general nature, one or two specific assessment criteria were identified. In order to address the possible effects of linking as concrete as possible, each criterion is then operationalised with "operationalised criteria" or "indicators". These operationalised criteria or indicators can help to quantify or qualitatively assess the potential linking effects with regard to the specific objective concerned. Altogether, 26 indicators were identified and listed in the report, where in some cases one indicator can be used to assess several objectives.

Linking objective		
1.	Ensure environmental integrity	Environmental
2.	Achieve long-term abatement targets	
3.	Reduce mitigation cost	Economic
4.	Reduce competitive distortions	
5.	Increase market stability and liquidity	
6.	Maintain/increase acceptance of ETS and of linked market	Political
7.	Support global cooperation on climate change	

adelphi, 2017

From the **environmental dimension**, ensuring environmental integrity and achieving long-term abatement targets were identified as key linking objectives. While environmental integrity can largely be assured by the existence of a robust MRV framework (ensuring 'a tonne is a tonne'), comparable offset standards and stringency of enforcement, the objective of achieving long-term abatement targets is more complex and can be evaluated using two assessment criteria: (sufficient) incentives for low-carbon investments and more generally the long-term stability of the political and regulatory environment. To measure the extent, to which these criteria are fulfilled by a concrete linking partner (or not) several quantitative or qualitative indicators can be used, for instance the historic carbon level in the emissions trading schemes before linking, the cap stringency or the annual cap reduction, the availability of long-term mitigation targets and commitments, the availability and compatibility of safeguards against oversupply and the political and public acceptance of emissions trading.

The **economic dimension** has three major objectives: reducing (short-term) mitigation cost, reducing competitive distortions and increasing market stability and liquidity. Whereas some of the relevant indicators to assess whether these criteria are fulfilled have to be quantified by economic modelling, for instance the expected change of the carbon price before linking compared to the developments after linking, expected net capital flows, expectations on a possible relocation of production and investment, other indicators can be assessed using empirical data, for instance the trade exposure of the covered sectors or the stability of the historic price level. Some other indicators, where a quantitative assessment is not possible, must be qualitatively assessed, for instance differences in allocation methods and or the availability and compatibility of safeguards against oversupply.

The **political objectives** include maintaining or increasing the acceptance of ETS and linking, as well as supporting global cooperation on climate change. The objectives of this dimension cannot be quantified, as relevant indicators focus on factors that are hard to measure such as the level of public support for linking and the reliability of your potential partner's climate policies.

Possibilities of quantifying the economic effects of linking ex-ante

The third section examines methods for quantifying the economic effects of linking from an ex-ante perspective. Relevant economic indicators, their influence on assessment criteria and their impact on linking were identified and their interrelations examined. The analysis distinguishes between indicators that can be empirically quantified and those that have to be quantified by economic modelling. Most of the economic indicators to evaluate the effects of a bilateral linking cannot be measured empirically, but need to be modelled by aid of economic modelling. Therefore, types and families of typical economic models which are currently available on the market were examined to which extent they can be used for an ex-ante quantification of the relevant indicators for linking. General and specific model requirements were identified. The screening of typical available economic models confirmed that no model covers all aspects connected with linking alone. Eleven economic models that were principally deemed suitable for analysing the economic effects of linking have been assessed: six CGE models (Aim-CGE, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE), one macro-econometric model (E3ME) and four PE models (POLES, PRIMES, REMIND-R, TIMES-Markal). Whereas the overall approach and the most important results of the analysis are included in section three of this report, more details on the individual models can be found in annex I.

The third section also addresses two additional issues that arose during the discussion: First the question whether dynamic efficiency, which relates broadly to the question how a change in the permit price affects different (in terms of structure and stage of development) economies, should and could be *operationalised* as an additional criterion. Second, the question whether marginal abatement cost curves (MACCs), which determine to a large extent the permit price, have to be considered *explicitly in modelling*. Both questions are discussed in additional separate subchapters of this report.

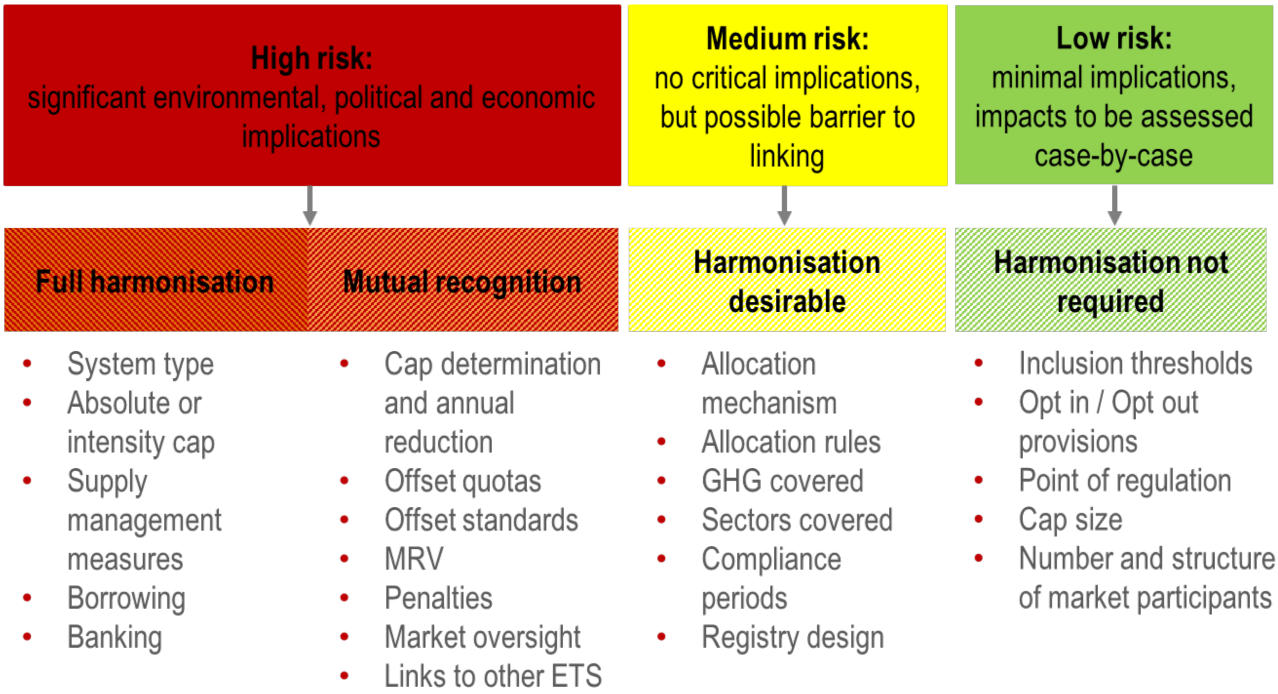
Qualitative assessment of the impact of differences in ETS design elements on linking

In the fourth section, important ETS design elements are analysed which need to be considered with respect to their potential effects on linking and harmonisation requirements. Certain design elements need to be harmonized in order to create a functioning joint market with a minimum of trade distortions and in which a "tonne is a tonne" of emissions reduced across the whole system. Additionally, policy makers must also pay close attention to design features that would automatically be imported into the other scheme as a result of linking. Such automatic propagation may come with significant environmental, political and economic implications that could undermine the goals and policy preferences of the respective linking partners (for instance the linking of a mandatory system with a voluntary system).

Accordingly, key ETS design features are assessed based on the potential political, economic and environmental implications they can have on a linked market. They are then categorised as high, medium or low risk design features and based on this assessment, the extent to which these features should be harmonised is also outlined.

The **'high risk' group** for which full harmonisation may be necessary in order to ensure a properly functioning common market includes six design elements: the system type (mandatory or voluntary), cap nature (absolute or intensity based), supply management measures (i.e. safeguards against oversupply), borrowing and banking. In addition, there is another group of design elements that have potentially high risks for a common carbon market, but harmonisation is not possible for different reasons. This concerns for instance the determination of the cap and the annual cap reduction, offset quotas and standards, MRV, penalties, market oversight and links with other ETS. Where harmonization of such critical design elements is not possible, partners can mutually accept and recognize the differing design features. All these critical design elements represent the environmental policy objectives of the respective jurisdictions and **require a joint vision and level of ambition** for a successful link to be established.

In addition, there are a number of design elements that do not need to be addressed as they contain medium or low risks.



adelphi, 2017

This risk categorisation of design elements is based on existing literature and practical experiences with linking. The importance and harmonisation requirements of certain design features will likely vary for each linking scenario. Policy priorities, institutional structures and political cultures will each have a role to play; linking will also require compromise and trade-offs for both linking partners. However, the results of this assessment may provide a useful template for policymakers in the early stages of linking negotiations or when considering linking prospects for their own system.

A manual for decision making on bilateral linking

The findings of the first four sections form the basis of a separate publication, 'Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS', which was published separately[1]. The manual provides decision-makers with a three-step process to assess the effects of linking with a specific linking partner. In the pre-assessment phase, policymakers should identify and weigh their objectives for linking (see three dimensions of linking objectives identified in chapter 2). At the same time, any potential risks this link may have should also be considered. Policymakers can then prioritise key objectives and risks to focus on during the linking negotiations. For instance, if ensuring environmental integrity is a key objective of linking, certain design features such as MRV and offsets are very important. If linking is pursued to create a level playing field with their linking partner, policymakers should focus on allocation methods and the impact linking would have on the carbon price.

Having determined and weighed objectives and criteria, the first step of the the assessment phase, is to identify a feasible assessment approach. One major challenge of an ex-ante assessment of linking may be the lack of (sufficient) quantitative and qualitative data. Where no empirical data is available, a rough estimate is not possible. In this case, economic modelling may be a solution. The manual explains which indicators can be assessed using empirical data, for which indicators qualitative data have to be analyzed and which indicators can be only quantitatively analyzed by aid of economic modelling. Parallel to the quantitative assessment, the major design features of the one system have to be compared with the other system. The risk categorization of chapter 4 is explained in a general way. By categorising the major design features into risk groups (high, medium and low), policymakers can prioritise ETS design features in the linking negotiation. Harmonisation needs will however vary on a case by case basis and will be influenced by the policy priorities, institutional structures and political cultures of the linking partners. As a final step, the manual helps policymakers identify the most likely design of the common market and whether or not linking will be beneficial based on the key objectives and risks identified by the policymakers in the pre-assessment phase.

[1] The manual can be downloaded from DEHSt's website: https://www.dehst.de/SharedDocs/downloads/EN/emissions-trading/Linking_manual.pdf?__blob=publicationFile&v=3

Zusammenfassung

Der vorliegende Endbericht umfasst die wesentlichen Ergebnisse des Vorhabens „Weiterentwicklung von Kriterien und Methoden zur Beurteilung der Chancen und Risiken eines Linkings des EU-ETS mit anderen Emissionshandelssystemen und Analysen aktueller Entwicklungen“. Kernziel des Vorhabens war die Entwicklung eines systematischen Rahmens für die Bewertung von Chancen und Risiken einer Verknüpfung (Verlinkung) von Emissionshandelssystemen, der Entscheidungsträger dabei unterstützen soll, potenzielle Linking-Partner zu identifizieren und sich auf künftige Linking-Initiativen vorzubereiten. Ein wesentlicher Schwerpunkt des Projektes war es, ökonomische Auswirkungen des Linking soweit wie möglich zu quantifizieren und weitere qualitative Bewertungsansätze zu entwickeln.

Das Vorhaben, das adelphi und das Wuppertal Institut 2014 bis 2017 durchgeführt haben, gliedert sich in Einzelnem in sechs Arbeitspakete deren Ergebnisse in diesem Endbericht abgebildet sind. Der erste Abschnitt umfasst eine Analyse relevanter ökonomischer Theorien zu den Vorteilen und Risiken einer Verlinkung von Emissionshandelssystemen. Im zweiten Abschnitt werden die Forschungserkenntnisse mit den in der politischen Praxis von einzelnen Handelssystemen geäußerten Motivationen für ein Linking. Auf diesen Erkenntnissen aufbauend wurde ein analytischer Rahmen entworfen, der sieben Ziele und entsprechende Bewertungskriterien aus ökonomischer, ökologischer und politischer Sicht definiert und ihre Wirkungszusammenhängen und Wechselbeziehungen untersucht. Dieser analytische Rahmen ermöglicht sowohl eine quantitative wie auch eine qualitative Betrachtung möglicher Linking-Vorhaben. Der dritte Abschnitt ist möglichen Ansätzen für eine quantitative Analyse von Linking-Effekten gewidmet. Zu diesem Zweck werden verschiedene ökonomische Modelle untersucht und mit Blick auf ihre Möglichkeiten und Grenzen bewertet, die ökonomischen Auswirkungen eines Linkings quantitativ darzustellen. Im vierten Abschnitt werden die Designelemente von Emissionshandelssystemen qualitativ hinsichtlich ihrer Relevanz für ein erfolgreiches Linking erörtert. Wesentliche Ausgestaltungsmerkmale von zehn Emissionshandelssystemen werden zusammengestellt und verglichen. Als Ergebnis dieser Analyse werden einige kritische Designelemente identifiziert, die für einen funktionierenden gemeinsamen Markt angepasst werden müssten.

Die zentralen Ergebnisse des Projektes wurden in Form eines Leitfadens (Manual) „Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS” aufbereitet, das im Rahmen eines internationalen Fachgesprächs parallel zu den Klimaverhandlungen im Mai 2017 in Bonn vorgestellt und diskutiert wurde. In das Manual sind zudem die Einsichten aus der exemplarischen Anwendung des im Projekt entwickelten Analyserahmens auf eine fiktive Verlinkung der Emissionshandelssysteme in der EU und in Südkorea eingeflossen (Arbeitspakete 5 und 6).

Erste Ergebnisse des Projekts wurden auch im Rahmen der internationalen Konferenz „The Global Turn to Greenhouse Gas Emissions Trading: Experiments, Innovation, Actors, Drivers and Consequences“ der Universität Leuven am 8 und 9 Februar 2016 vorgestellt.

Ökonomische Theorien zur Verlinkung von Emissionshandelssystemen

Die Literatur zum Thema Linking hat sich entlang verschiedener Theorien im letzten Jahrzehnt stark ausdifferenziert und für das Forschungsvorhaben wurden etwa fünfzig Quellen ausgewertet. Der erste Abschnitt des Berichts beleuchtet Erkenntnisse aus den wesentlichen Theorien der Umwelt- und Entwicklungsökonomie, der Außenwirtschaftstheorie, der Spieltheorie sowie der Politischen Ökonomie und Institutionenökonomie.

Die Theorieansätze setzen deutlich unterschiedliche Schwerpunkte und können folglich jeweils nur Teilaspekte der Chancen und Risiken eines Linkings beleuchten und erklären. Während die Umweltökonomie grundsätzlich die Vorteile des Emissionshandels bei der Korrektur von Marktversagen in den Vordergrund rückt, fokussiert die Außenwirtschaftstheorie auf die Handelsbeziehungen der Linking-Partner und Terms of Trade-Effekte. Die Politische Ökonomie und Spieltheorie versuchen mögliche Präferenzen und Motivationen von Entscheidungsträgern zu erklären und darzustellen, wie auf diese Weise Akzeptanz und Effizienz der Ausgestaltung und Umsetzung des jeweiligen Emissionshandelssystems beeinflusst werden. Besonders hervorgehoben wird dabei die Bedeutung sensibel ausbalancierter Zielkonflikte und akzeptabler Kompromisse, um die Akzeptanz der nationalen Stakeholder für ein Linking und generell für das Emissionshandelssystem zu erhalten.

Herleitung eines Analyserahmens zur Bewertung von Linking-Vorhaben

Vor dem Hintergrund der theoretischen Erkenntnisse aus dem ersten Kapitel leistet das zweite Kapitel eine empirische Bestandsaufnahme von legislativen Kriterien und öffentlich geäußerten Motivationen für ein Linking, um die jeweilige Zielsetzung eines Linking-Vorhabens herauszuarbeiten. Untersucht werden der EU-ETS, das australische Carbon Price System, der kalifornische Emissionshandel, das neuseeländische ETS, RGGI und das schweizerische ETS. Hierauf aufbauend wurde ein Analyserahmen entwickelt, der sieben Linking-Ziele und Bewertungskriterien definiert, in ihren Wirkungszusammenhängen beschreibt und Vorschläge zur Operationalisierbarkeit mittels Indikatoren umfasst. Die sieben Ziele können den Dimensionen ökologisch, ökonomisch, politisch zugeordnet werden. Für diese Ziele wurden jeweils ein bis zwei Bewertungskriterien identifiziert. Um die möglichen Effekte eines Linkings so konkret wie möglich zu adressieren, wurde jedes Bewertungskriterium soweit wie möglich mit einem Indikator operationalisiert. Diese operationalisierten Kriterien bzw. Indikatoren können helfen, mögliche Linking-Effekte im Hinblick auf die jeweilige Zielstellung qualitativ oder quantitativ zu bewerten. Insgesamt wurden 26 Indikatoren identifiziert und im Bericht aufgeführt, wobei in manchen Fällen ein Indikator für die Bewertung verschiedener Ziele verwendet werden kann.

Linking Ziele		
1.	Sicherstellung der Umweltintegrität	ökologisch
2.	Erreichung der langfristigen Treibhausgasminderungsziele	
3.	Reduktion der (kurzfristigen) Minderungskosten	ökonomisch
4.	Abbau von Wettbewerbsverzerrungen	
5.	Verbesserung von Marktstabilität und -Liquidität	
6.	Ausbau der Akzeptanz des Emissionshandels als zentrales Klimaschutzinstrument	politisch
7.	Beitrag zur internationalen Klimaschutzzusammenarbeit	

adelphi, 2017

In der **ökologischen Dimension** wurden zwei Schlüsselziele für ein Linking identifiziert: Sicherstellung der Umweltintegrität und die Erreichung der langfristigen Treibhausgasminderungsziele. Während die Integrität wesentlich durch die Existenz eines robusten MRV-Rahmens („eine Tonne ist eine Tonne“), vergleichbarer Offset-Standards und einem stringenten Vollzug sichergestellt werden kann, ist die Zielstellung hinsichtlich Erreichen der Langfristziele komplexer und kann mit Hilfe von zwei Schlüsselkriterien bewertet werden: der (ausreichenden) Anreizwirkung für emissionsarme Investitionen und allgemeiner der langfristigen Stabilität des politischen und regulativen Umfelds. Um abzuschätzen, inwieweit diese Kriterien von einem konkreten Linking-Partner bzw. einem konkreten Linking-Vorhaben erfüllt sind, können verschiedene quantitative und qualitative Indikatoren verwendet werden, zum Beispiel das historische Preisniveau in den beiden Emissionshandelssystemen vor dem Linking, die Stringenz des Cap und der jährlichen Cap-Reduktion, das Vorhandensein langfristiger Minderungsziele und –Verpflichtungen, das Vorhandensein von Schutzmaßnahmen gegen eine Überschusssituation wie auch die politische und öffentliche Akzeptanz des Emissionshandelssystems generell.

Die **ökonomische Dimension** konstituiert sich aus drei Zielen: Reduktion der (kurzfristigen) Minderungskosten, Abbau von Wettbewerbsverzerrungen sowie Verbesserung von Marktstabilität und -Liquidität. Einige der relevanten Indikatoren um abschätzen zu können, inwieweit diese Kriterien bei einem Linking erfüllt werden, können nur mit Hilfe ökonomischer Modelle quantifiziert werden wie beispielsweise die Entwicklung des Kohlenstoffpreises nach einem Linking, erwartete Netto-Kapitalflüsse, mögliche Produktions- und Investitionsverlagerungen. Andere Indikatoren können mit Hilfe empirischer Daten abschätzt werden, z.B. die Handelsintensität der vom ETS erfassten Sektoren oder die Stabilität des historischen Preisniveaus. Bei weiteren Indikatoren ist eine Quantifizierung nicht möglich, sie müssen qualitativ bewertet werden, z.B. Unterschiede bei den Allokationsverfahren oder das Vorhandensein und die Kompatibilität von Schutzmaßnahmen gegenüber einer Überschusssituation.

Als **politische Zielsetzungen** sind besonders der Erhalt bzw. der Ausbau der Akzeptanz des Emissionshandels als zentrales Klimaschutzinstrument sowie der Beitrag zur internationalen Klimaschutzzusammenarbeit relevant. Gerade diese Dimension erweist sich mit Blick auf die Operationalisierungen und Quantifizierbarkeit als herausfordernd, weil die entsprechenden Indikatoren wie die öffentliche Unterstützung für Linking oder die Verlässlichkeit der Klimaschutzpolitik des Linking-Partners schwierig zu messende Größen darstellen.

Möglichkeiten der ex-ante Quantifizierung der ökonomischen Auswirkungen eines Linkings

Im dritten Kapitel werden Methoden zur ex-ante Quantifizierung der ökonomischen Auswirkungen eines Linkings untersucht. Relevante ökonomische Kennziffern, ihr Einfluss auf die Bewertungskriterien und ihre Effekte auf ein Linking wurden identifiziert und ihre Wechselbeziehungen untersucht. Außerdem wurde geprüft, welche Indikatoren quantifiziert werden können bzw, inwiefern sie durch eine Modellierung bzw. empirische Betrachtung erfassbar sind. Die meisten ökonomischen Indikatoren für die Bewertung von Linking-Effekten können nicht empirisch gemessen werden, sondern müssen mit Hilfe einer ökonomischen Modellierung berechnet werden. Daher wurden Typen und Familien gängiger ökonomischer Modelle, die gegenwärtig verfügbar sind, daraufhin untersucht, inwieweit sie für eine ex-ante Quantifizierung der relevanten Linking-Kriterien bzw. - Indikatoren eingesetzt werden können. Allgemeine und spezifische Modellanforderungen wurden beschrieben. Ein Screening der Modelllandschaft bestätigt, dass kein Modell alle Bereiche vollständig abdeckt. Elf ökonomische Modelle, die prinzipiell geeignet schienen, die ökonomischen Effekte eines Linkings abzubilden, wurden vertieft untersucht: sechs allgemeine Gleichgewichtsmodelle (AIM-CGE, EPPA-EU, GEM-E3, G-cubed, IMACLIM_R und PACE), ein makroökonometrisches Modell (E3ME) und vier partielle Gleichgewichtsmodelle (POLES, PRIMES, REMIND-R, TIMES-Markal). Die allgemeine Ansatz wie auch die wichtigsten Ergebnisse der Modellanalyse sind in Abschnitt 3 dieses Berichts enthalten, während Einzelheiten zu den untersuchten Modellen im Annex I zu finden ist.

Abschnitt 3 adressiert darüber hinaus zwei weitere Fragen, die während der Diskussionen im Projekt auftraten: zunächst die Frage, inwieweit dynamische Effizienz als zusätzliches Kriterium operationalisiert werden könnte. Zweitens, die Frage ob Grenzvermeidungskostenkurven (VKKs), die den Zertifikatspreis wesentlich beeinflussen, explizit bei der Modellierung berücksichtigt werden müssen. Beide Fragen werden als Exkurs in zwei separaten Unterabschnitten diskutiert.

Qualitative Bewertung der Auswirkung einer unterschiedlichen Ausgestaltung von Emissionshandelssystemen bei einem Linking

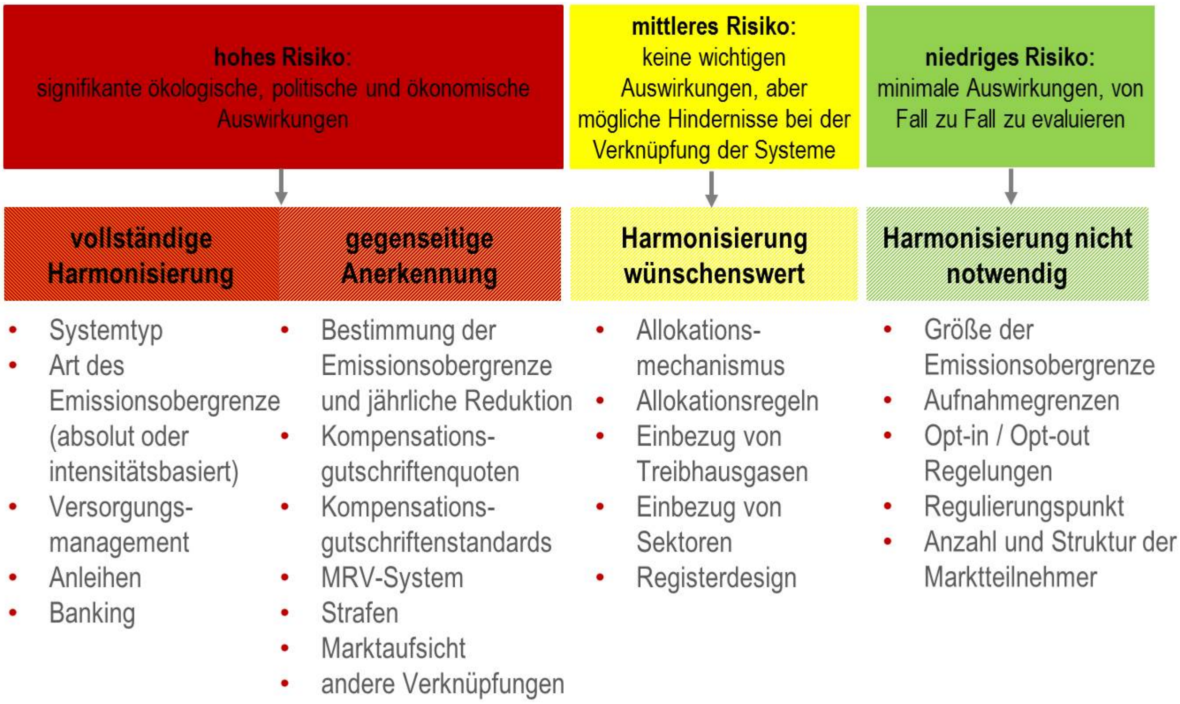
Im vierten Kapitel werden zentrale Ausgestaltungsmerkmale von Emissionshandelssystemen analysiert, die hinsichtlich ihrer möglichen Auswirkungen bei einer Verknüpfung von Handelssystemen und den Bedarfen nach einer Harmonisierung untersucht werden müssen. Einige Designelemente müssen harmonisiert werden, um einen funktionierenden gemeinsamen Markt mit minimalen Wettbewerbsverzerrungen herzustellen, in dem die Umweltintegrität („eine Tonne ist eine Tonne“) gewährleistet ist. Außerdem verdienen Designelemente, die bei einem Linking automatisch in das andere System importiert werden, besondere Beachtung. Denn eine automatische Übernahme von (nicht erwünschten) Designelementen könnte bedeutende ökologische, politische und ökonomische Folgen haben und Zielen und Präferenzen der Linking-Partner zuwiderlaufen (z.B. die Verlinkung eines verpflichtenden Systems mit einem freiwilligen System).

Entsprechend sind einzelne Ausgestaltungsmerkmale eines Emissionshandelssystems hinsichtlich der politischen, ökonomischen und ökologischen Implikationen, die sie innerhalb eines gemeinsamen Marktes für die Handelspartner haben können, zu bewerten. Sie können **in drei Risikokategorien ‚niedrig‘, ‚mittel‘ und ‚hoch‘** eingestuft werden. Abhängig von der Risikoeinschätzung muss ein Ausgestaltungsmerkmale mehr oder weniger stark vor einem Linking harmonisiert werden.

Zu der Gruppe von Elementen **mit einem hohen Risiko**, für die eine vollständige Harmonisierung der zu verknüpfenden Systeme notwendig erscheint, um einen funktionsfähigen Markt zu gewährleisten, zählen sechs Elemente: Der Systemtyp (verpflichtend oder freiwillig), die Art des Caps (absolut oder intensitätsbasiert), Maßnahmen zur Angebotssteuerung (d.h. Schutzmaßnahmen gegen eine Überschusssituation) sowie Regeln für das Banking und Borrowing von Zertifikaten.

Hinzu kommt eine weitere Gruppe von Elementen, deren Ausgestaltung **mit hohen Risiken** für den resultierenden Markt einhergehen kann, bei denen eine vollständige Harmonisierung aus verschiedenen Gründen aber nicht möglich ist. Dies betrifft beispielsweise die Festlegung des Caps und der jährlichen Cap-Reduktion, Offsetquoten und –standards, MRV-Regeln, Strafzahlungen, Art der der Marktaufsicht und Links mit anderen Systemen. Wo eine Harmonisierung dieser kritischen Ausgestaltungsmerkmale nicht möglich ist, kann eine gegenseitige Anerkennung der Regeln ausreichend sein Diese kritischen Ausgestaltungsmerkmale sind eng mit den ökologischen Politikzielen verknüpft und erfordern daher **eine gemeinsame Vision** und **ein gemeinsames Verständnis über das Ambitionsniveau**, um einen erfolgreichen gemeinsamen Markt herzustellen.

Zusätzlich gibt es eine Reihe von Ausgestaltungsmerkmalen, die auch nach einer Verlinkung unterschiedlich sein können, da sie lediglich mit mittleren oder geringen Risiken einhergehen.



adelphi, 2017

Die Risikokategorisierung der Ausgestaltungsmerkmale basiert auf der bestehenden Literatur sowie praktischen Erfahrungen. Die Bedeutung einzelner Merkmale und ihrer Harmonisierungserfordernisse wird sich im Einzelfall entsprechend der politischen Prioritätensetzung, der institutionellen Verfasstheit sowie der politischen Kultur der Systeme unterscheiden. Die Ergebnisse der Bewertung zentraler Ausgestaltungselemente, die im Rahmen des Projektes vorgenommen wurde, können in einem frühen Stadium der Linking-Verhandlungen für eine systematische Risikoeinschätzung hilfreich sein.

Eine Handreichung zur Entscheidungsfindung bei einem bilateralen Linking

Die Erkenntnisse der ersten vier Kapitel bilden die Grundlage der bereits separat veröffentlichten Publikation „Considering the Effects of Linking Emissions Trading Schemes – A manual on Bilateral Linking of ETS"[2]. Das Manual bietet Entscheidungsträgern einen dreistufigen Ansatz, um die Auswirkungen eines Linkings mit einem konkreten Partnersystem abzuschätzen. In einer Vorphase der Entscheidungsfindung sollten die spezifischen Beweggründe für die Verlinkung mit dem anderen System identifiziert und gewichtet werden (vgl. die drei Dimensionen der Linking-Ziele in Kapitel 2). Gleichzeitig müssen mögliche Risiken eines Linking identifiziert werden. Schließlich sollten die Schlüsselziele und Risiken festgelegt werden, auf denen man sich in den Linking-Verhandlungen konzentrieren sollte. Ist die Bewahrung der Umweltintegrität ein zentrales Ziel beim Linking, müssen die Qualität des MRV-Systems des potentiellen Partners und die Offsets genau untersucht werden. Wenn der Abbau von Wettbewerbsverzerrungen angestrebt

[2] Die Publikation kann von der Website der DEHSt runtergeladen werden: https://www.dehst.de/SharedDocs/downloads/EN/emissions-trading/Linking_manual.pdf?__blob=publicationFile&v=3

wird, stehen Fragen der Allokationsmethoden und die Entwicklung des Kohlenstoffpreises nach einem Linking im Fokus.

Nach der Festlegung und Gewichtung von Zielen und Kriterien, muss in der eigentlichen Bewertungsphase zunächst ein angemessener Bewertungsansatz identifiziert werden. Bei einer ex-ante Bewertung eines Linkings ist die Verfügbarkeit ausreichender quantitativer und qualitativer Daten oft eine große Herausforderung. Ohne empirische Daten ist selbst eine grobe Abschätzung nicht möglich. In diesem Fall kann ökonomische Modellierung eine Lösung sein. Das Manual erläutert, welche Indikatoren mi Hilfe empirischer Daten bewertet werden können, welche Indikatoren qualitativ untersucht werden können und welche Indikatoren nur mit Hilfe ökonomischer Modellierung quantitativ analysiert werden können. Parallel zur quantitativen Analyse müssen wesentliche Ausgestaltungsmerkmale in dem einen System mit den Eigenschaften des anderen Systems verglichen werden. Hier wird auf die Risikokategorisierung in Kapitel 4 zurückgegriffen. Die Einteilung der Designelemente in verschiedene Risikoeinstufungen (hoch, mittel, gering) ermöglicht eine Fokussierung auf die kritischen Ausgestaltungsmerkmale im Rahmen der Linking-Verhandlungen. Die tatsächlichen Harmonisierungsbedarfe hängen stark vom konkreten Einzelfall ab und werden von einer Reihe übergeordneter politischer Faktoren wie auch der institutionellen Stabilität oder politischen Kultur beeinflusst. In einem letzten Schritt kann das Manual dabei helfen, ein Szenario für das wahrscheinlichste Design eines gemeinsamen Marktes zu entwerfen und abzuschätzen, ob ein Linking im konkreten Fall vorteilhaft sein könnte, d.h. ob die von den Entscheidungsträgern gesetzten Ziele und Prioritäten der Vorabschätzungsphase bei einem Linking tatsächlich erreicht würden.

1 Linking of Emission Trading Systems – An Economic Literature Review

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1.1 Introduction

The setting up of an ETS as an instrument to reduce greenhouse gas emissions comprises at least two major economic questions that are closely tied to each other:

- How should the system be optimally designed with regard to core design features in order to address the specific economic framework conditions and to maximise its benefits, while minimising undesired negative economic effects?
- How does the political negotiation process affect the system's design and implementation and what are the implications for theoretically expected economic effects?

Economic theory suggests that a global carbon market with a uniform price signal would be the optimal instrument to address global political emission reduction objectives and to minimise or even heal market distortions. However, this does not seem to be politically achievable in the short to midterm. Hence, the bottom-up direct linking of smaller markets created by separately developed national or regional (e.g. EU-wide) ETS appears to be the second best, but currently most promising option to create larger and more efficient markets and to start a process toward a global carbon market. Flachsland et al. (2009) term the linking of independent ETS as "imperfect substitutes for top-down architectures". Efficiency of the "imperfect substitute" here relates to the goal of introducing a global ETS: To achieve the most cost-efficient emissions reductions with the least competitive distortions.

Several authors (IETA, 2006; Edenhofer et al., 2007; Flachsland, 2008; Anger et al., 2009; Mehling & Haites, 2008) stress four arguments in favour of linking: Increased market liquidity through an increased number of market participants, higher cost-efficiency through a larger number of mitigation options, a more robust price signal and reduced distortions through converging carbon prices. Estimates show that the total abatement cost savings from creating a global carbon market with trade across all countries and sectors could halve abatement costs compared to non-trading (Flachsland et al., 2009b, based on Russ et al., 2009). However, an 'allowance price paradox' appears to apply in the case of linking ETS (Zetterberg 2012): Where the potential for economic cost reduction of a linked system is high due to high price differences in the pre-linked systems, the political incentive for linking might be low. Constituents in the high price system may not be willing to pay for emission reductions and associated financial flows to the low price system. This indicates trade-offs in the different categories of criteria to assess linking options.

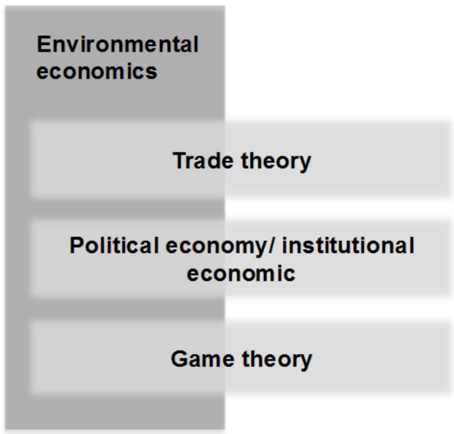
Linking risks exist if the underlying systems are 'incompatible'. Incompatibility relates to differences in key design features of the individual pre-linked systems (Jaffe and Stavins, 2007). Examples are price caps, non-compliance penalties, borrowing, banking, allowance life, nature of the emissions caps (absolute or intensity-based), and length of the compliance period (Baron & Bygrave, 2002; Bodansky, 2002; Haites, 2003; Ellis & Tirpak, 2006; Sterk et al., 2006; Mace et al., 2008).

In the following paper relevant areas of economic theory are described in terms of their contribution to understanding the conditions and effects of linking as an instrument to create larger carbon markets. These areas are concepts of environmental economics, trade theory, political economy, and game theory. Furthermore, the report also comprises an annex showing the results of a screening of ETS linking literature in relation to the different foci (evaluation criteria, economic indicators and design options) of this research effort.

Studies assess the impact of direct linking[3] of two ETS by using qualitative, model-based or empirical approaches. Most of the linking literature is qualitative in nature and cannot be assigned to one particular field of economic theory. However, in most cases it is grounded on the rationale of environmental economics to set up a preferably large ETS, in order to prevent market failure by limiting negative externalities to the environment (see chapter 1.2).

Fig. 1 illustrates the basic relation of different approaches from economic theory to evaluate linking of ETS. The general rationality of environmental economics is discussed under chapter 1.2. There is a large body of literature on direct linking, which comprises empirical or theory-based approaches as well as descriptive work. Due to the underlying rationality used, trade theoretical approaches, political economy / institutional economic approaches as well as game theoretical approaches can be understood as sub-fields of environmental economics. These approaches will be discussed separately in chapters 3-5. Chapter 6 summarises the findings.

Figure 1: Interaction of different approaches from economic theory to evaluate ETS linking



Wuppertal Institut, 2017, own compilation

1.2 Environmental economics

The starting point for environmental economists is the concept of market failure and the resulting negative externalities. The internalisation of these effects is one of the main concerns in environmental economics when public goods are excessively exploited, such as the pollution capacity of the atmosphere. Environmental economics posit that if the environmentally harmful behaviour is priced, actors are given an incentive to modify their behaviour and an efficient allo-

[3] Indirect linking occurs when two or more ETS are linked to a common third system, such as the CDM.

cation can be reached (Pareto optimality). This can be achieved by price as well as quantity solutions. In the case of quantity solutions, the amount of negative externality is regulated. For instance, a quantity-based solution for greenhouse gas emissions would limit the total amount of emissions released into the atmosphere. Pollution allowance certificates are issued and polluters obliged to surrender certificates or "allowances" for every unit of the emitted pollutant.

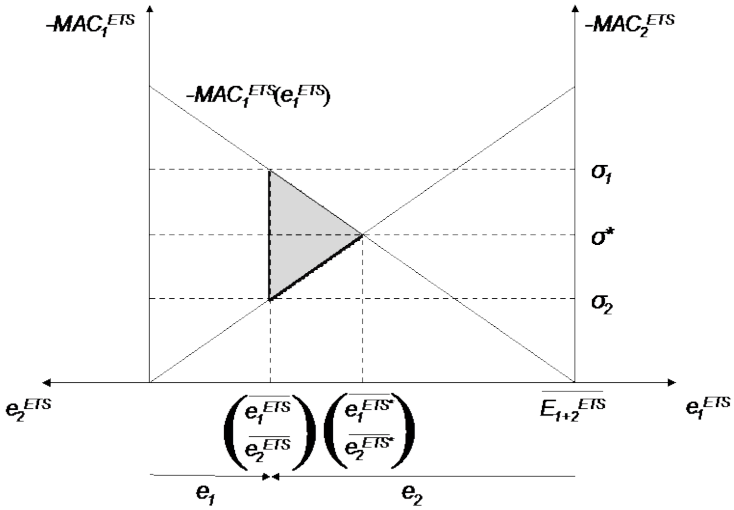
In contrast, with a price solution (e.g. via taxation), the price is fixed and the amount emitted would depend on the reactions of the polluters to the price increase (price elasticities of demand). The price increase necessary in order to obtain a target emissions level has to be calculated on the basis of assumptions on the abatement cost of mitigation options and market behaviour, and hence faces different kinds of calculation uncertainties.

The idea of trading emission certificates is based on the Coase theorem, originally a microeconomic theorem that was then adapted to environmental economics (for a graphical adaptation to linking see below). The theoretical argument is that when parties are equally informed, property rights are allocated and no transaction costs exist, private bargaining between individuals corrects externality problems and leads to an optimal outcome (Perman et al., 2003). Due to the decentralised pricing on free markets, governmental regulations are not needed.[4] If certificates are scarce (through setting emissions caps and distribution rules), the price of allowances changes according to the cost structure (marginal abatement costs, MAC). Through the internalisation of external costs, the economic behaviour of the market participants is guided towards an efficient optimum. Therefore, in theory emissions trading is an efficient instrument to reduce emissions.

The basic rationality of linking ETS is often explained with an extended version of the Coase theorem. Looking at a simple two country/system model with systems having similar marginal abatement cost curves ($MAC_{1,2}$), but emissions caps e with differing degrees of ambition (e.g. $e_2>e_1$), and thus differing allowance prices ($\sigma_1>\sigma_2$), allowance prices will converge and finally equalise as a result of linking (for a graphical presentation see Figure 2)

[4] However, in the case of complex markets such as an ETS, these markets only exist due to governmental regulation and setup of this market.

Figure 2: Efficiency gains in an international ETS with two systems of equal MACs:



Source: Wuppertal Institut, 2017, own depiction based on terminology of Alexeeva-Talebi and Anger (2007) and subsequent Figure 3, With e_n = national emission levels; MAC_n = national marginal abatement costs; p, σ^* = (equilibrium) price

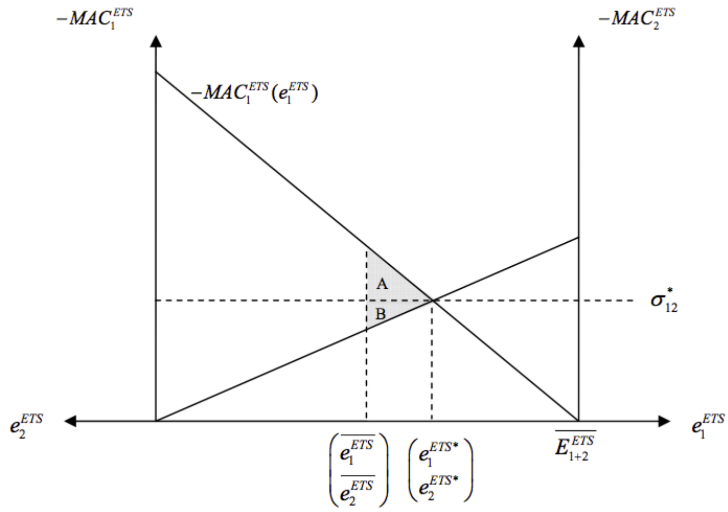
The emissions levels within each system change as a result of linking, but the overall emissions level across the linked system remains unchanged (E_{1+2}) and trading results in a welfare gain for both systems. The less ambitious system 2 will perform additional emissions reductions and sell the surplus allowances (benefits for system 2: revenues from sold allowances minus the additional costs of abatement due to higher allowance prices). The more ambitious system 1 will emit more than before linking and import the respective amount of allowances (benefits for system 1: reduction of abatement costs due to lower prices minus the costs for purchased allowances). In the case of a simple partial equilibrium setting, welfare gains are always positive, i.e. linking induces a Pareto improvement, meaning that none of the countries/systems are worse off and at least one benefits compared to the situation before linking. However, benefits can be distributed unevenly, e.g. if the slope of individual MAC curves differ (Flachsland et al. 2009, see as well following graphs).

Alexeeva-Talebi and Anger (2007) illustrate the effects of linking multiple systems with different pre-linking MAC curves, outlining the standard economic argument of benefits from trading. The issue can be explained in two steps.

They display again two countries “1” and “2” with (for simplicity) linear but different marginal abatement cost (MAC^{ETS}) curves that give economic impacts for the country sectors depending on national emission levels (e^{ETS}). MACs are assumed to be higher for region 1 than 2 (see differing slopes).

In a first step it can be depicted in a standard economic Coase model (see Figure 3), that if in the status quo, both countries have identical emission targets in their national ETS (emit the same amounts), carbon prices are higher in the high-cost system 1 than in system 2. Linking of both systems leads to a convergence of prices together with inter-system certificate trading and resulting efficiency gains (areas AB). This is a very simplified version of an existing multi-country ETS such as the EU-ETS.

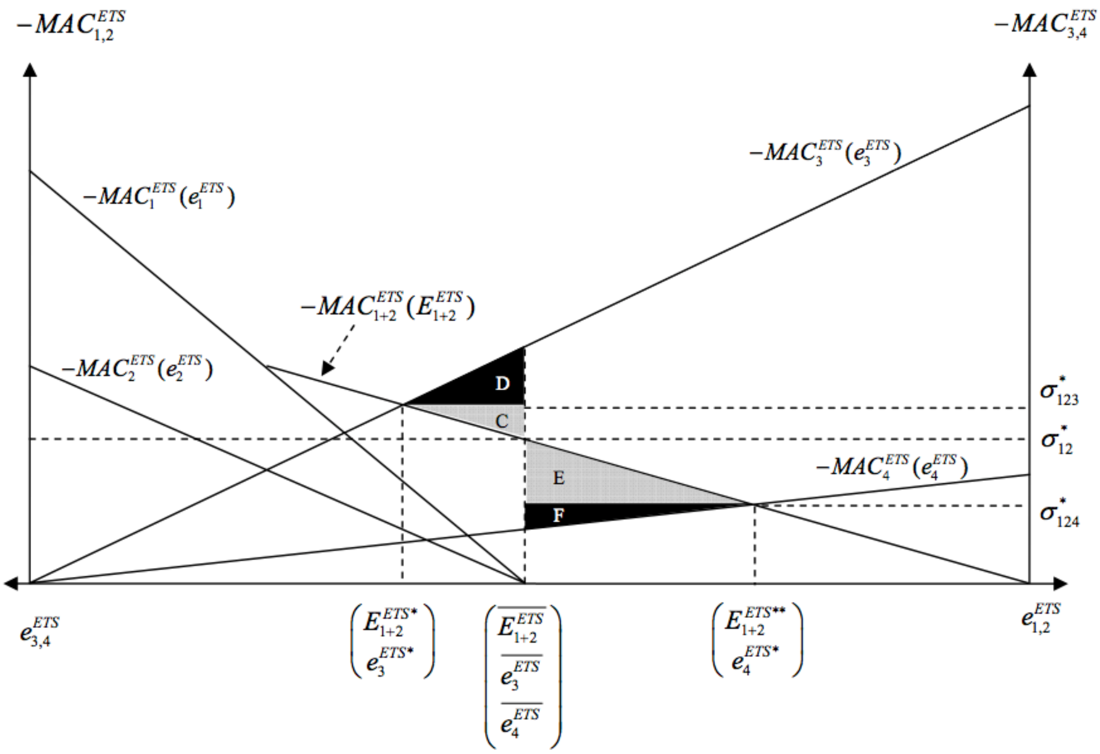
Figure 3: Sectoral efficiency gains in an international emissions trading scheme



Source: Alexeeva-Talebi and Anger (2007), p. 4. With e_n = national emission levels; MAC_n = national marginal abatement costs; $\sigma*$ = (equilibrium) price

In a second step, the effect of linking this combined system (aggregated curve MAC_{1+2}) to a high-price (country 3: MAC_3) or low-price (country 4: MAC_4) system can be presented in a similar diagram (see Figure 4). Linking to the high-cost country 3 leads to rising carbon prices (from σ*12 to σ*123) and lower emission levels in region 1+2, while permits are exported to country 3. In contrast, if the joint system is linked to the low-cost country 4, prices fall to σ*124 and emissions in region 1+2 increase as permits are imported from country 4. Yet overall, from a linked system perspective, Figure 3 outlines efficiency gains through areas CD/EF.

Figure 4: Additional efficiency gains from linking ETSs



Source: Alexeeva-Talebi and Anger (2007), p. 6. With e_n = national emission levels; MAC_n = national marginal abatement costs; $\sigma*$ = (equilibrium) price

A review of environmental economics literature suggests that the assessment of potential bi- or multilateral linking cannot be differentiated from a discussion or analysis of institutional matters (e.g. design options, political feasibility). For instance, the literature discusses the economic implications of different sector coverage in two pre-linked systems (e.g. Marschinski et al., 2012). ETS design features discussed in the literature can be found in the annex.

Moreover, different perspectives have to be distinguished when the effects of linking are discussed as this may affect the criteria considered and the results reached. The two most important perspectives are: (a) linked systems perspective (1+2) and (b) individual systems/country perspectives and associated distributional aspects (1, 2)[5]. For instance, from a linked systems' perspective (e.g. EU and Swiss ETSs), formally linking a high-price country with a low-price country is favourable in terms of efficiency. However, from the individual countries' viewpoint the picture might differ. Though the low-price country benefits from selling allowances and associated additional financial flows, the high-price country experiences financial outflows despite being able to access an increased number of low-price certificates (short-term abatement options). Some countries may be concerned about the financial outflow from their jurisdiction post-linking. Moreover, intra-country distributional effects can also occur as companies located in one individual system might profit or lose from linking, e.g. a buyer in an ex ante

[5] Many more evaluation perspectives are in principle possible, e.g. final customer perspective, governmental perspective.

high-price country will profit from linking as linking would lower the cost of allowances (Edenhofer et al., 2007).

Additionally, although the general expectation is that price volatility and hence uncertainty decrease with a bigger market, it is also possible that price shocks and volatility are imported from other markets (Flachsland et al., 2009 based on McKibbin, 2008).

1.3 Trade theory

As the name suggests, ETS and the linking of such systems are all about trading and the possible gains and losses from trading. However, the theory on emissions trading is based on standard economics and environmental economics (markets and Coase theorem) as covered in section 1.2. When ETS are integrated into open economics models, this is a rather complex venture of how emissions trading affects the terms of trade (ToT; prices of major export goods relative to import goods) and real trade flows. This section first presents the basic trade-theoretical models and several approaches as to how such modelling has been undertaken and their respective findings.

The general economic literature on trade theory is very much focused on production factor endowments, production structures, resulting comparative advantages in the production of goods, consequent world supply and demand curves, resulting trade flows and ToT effects.

Standard trade theory textbooks include several basic models, such as the Ricardo model[6] focusing on comparative cost advantages (one production factor, two goods) and the Heckscher-Ohlin model[7] focusing on relatively different production factor endowments across countries. In what is often called the 'standard trade model', the first two models are integrated to encompass supply side factors (factor endowments, production functions and resulting production possibility frontiers) and demand side factors (aggregate relative world demand). With this model, the effect of changes in factor endowments or production structures (e.g. sectoral growth) on the ToT can be analysed, as well as stylised policy changes like international transfers, tariffs and export subsidies.

The Potsdam Institute for Climate Impact Research (PIK) found that price distortions in international goods markets can be minimised when trading partners have linked ETSs as the convergence of MACs neutralise ToT effects (Edenhofer et al., 2007). Furthermore, a single price for emissions permits reduces the incentive for industries to move to carbon-low-cost regions if systems are linked ("carbon leakage", see also Flachsland, 2010).

Copeland and Taylor (2003) find that changes in world prices – i.e. ToT effects – matter to production, consumption and real income levels. However, they underline that trade in internation-

[6] The basic Ricardian model includes only one production factor (usually labour) producing two goods with different levels of productivity in each sector. If labour productivities differ between two countries (home and foreign), comparative advantages result and trade allows for higher consumption levels. The model is usually extended to allow for the production of more goods (multi-good Ricardian model).

[7] A second theoretical model focuses on the differences in resource endowments. In this model – often called the Heckscher-Ohlin theory after its developers – the relative abundance of production factors and the technology of production is the driver of comparative advantages and resulting trade. In this model, two production factors can be used for the production of two goods. From factor endowments and production structures, result possible combinations of goods production, "national production possibility frontiers". Relative (one good to the other) supply and demand curves converge in the case of trade due to factor price equalisation. Changes in relative goods prices in turn lead to different optimal combinations of goods production (on the production frontier curve) and after trading to an enhancement of consumption possibilities (see e.g. Krugman & Obstfeld 2009, 73).

ally mobile goods is an implicit trade in internationally immobile factor services. Consequently, they stress that

> "international markets can play a major role in determining the response in unconstrained countries to emission reductions, the benefits of emission permit trade, and the efficiency of various emission reduction trajectories. Without a complete understanding of the role that international markets can play in this process, we have little hope of measuring the role they may actually play. A serious consideration of international economics may therefore be a necessary condition for future empirical and theoretical work examining the costs of international environmental agreements" (Copeland and Taylor 2003, p. 39).

Alexeeva-Talebi and Anger (2007) integrate real goods trade and emissions trading into an extended trade model with two sectors: One with capped emissions (ETS) and one without an ETS (NETS). They apply a Computable General Equilibrium (CGE) model calibrated with empirical data for MAC curves, caps, production, consumption and trade[8] to analyse the effects of linking the EU ETS to other regions (Japan, Canada, Russia, USA and Australia). Their simulation for the EU finds that linking to other systems would lead to falling EU permit prices (due to lower MACs or more generous caps in linked systems, p. 15).

Two indicators for international competitiveness are analysed: Revealed comparative advantage (RCA) (comparing the trade performance of an ETS/NETS sector with the performance of all sectors within the respective region) and relative world trade shares (RWS, relating the trade performance of an ETS/NETS sector in a region to the performance of ETS/NETS sectors across the world).

They find that linking the EU-ETS to the other countries affects the ToT; however this was highly contingent on the linking partner and analysis has to be done from a country perspective and by sectors covered/not covered in the ETS (ETS/NETS) which renders the issue highly complex (for more details on this model and their results see separate Box 1 and Figure 5).

Box 1: Effects modelled by Alexeeva-Talebi and Anger (2007) and explanations

In the CGE framework of this modelling exercise, heterogeneous effects have various reasons, e.g. the model implementation of Kyoto target compliance: Economies are split in two parts. Sectors covered by the ETS with a generous cap and relatively low MACs and non-covered sectors with high MACs that have to carry the abatement burden shifted from ETS sectors, implemented in the model with a carbon tax. Consequently, for instance, although there would be no substantial impact on overall EU-ToT, sectors covered by the ETS gain comparative advantage relative to NETS sectors (due to generous caps and resulting higher abatement costs through taxation in NETS sectors). This implies national inefficiencies in abatement burden allocation among sectors (p. 21), which is differently pronounced across countries and explains differences in ToT effects. As well, countries have varying Kyoto targets, cap stringencies and different abatement costs.

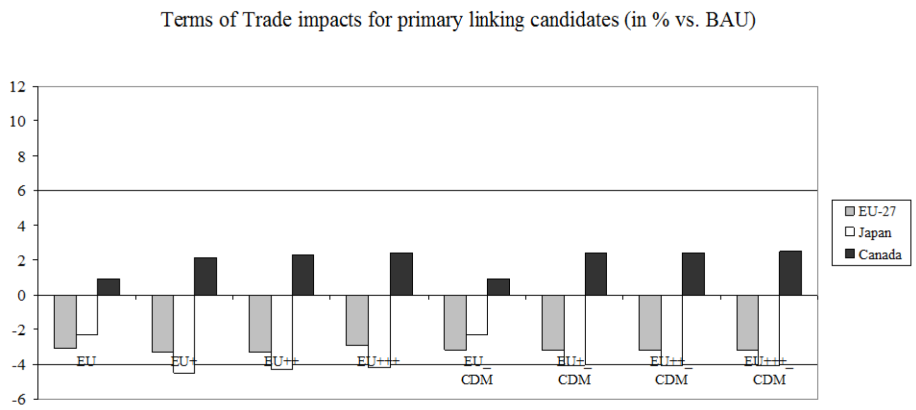
In the paper, they subsequently model the effects of expanding the EU-ETS-coverage by other countries in three scenarios (EU+, EU++, EU+++). Scenarios comprise the following countries:

[8] The model is based on consistent accounts of national production and consumption, trade and energy flows for 2001 provided by the GTAP 6 database (Dimaranan and McDougall, 2006). For emission reduction targets, they refer to EU documents (20% reduction by 2020 vs. 1990, assuming a tightening of Kyoto emission targets from 7% to 20%), other Kyoto ratifiers (Canada, Japan, Russia) are assumed to tighten targets by 5% below Kyoto commitments, Australia and the United States are assumed to commit to conservative targets of 32% and 17% above their respective non-binding Kyoto targets (Alexeeva-Talebi and Anger 2007, p. 10).

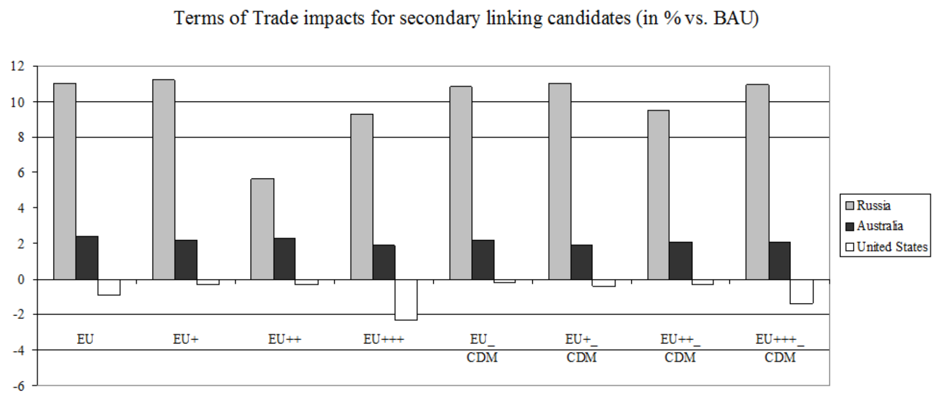
- EU: EU-27
- EU+: additionally Japan, Canada
- EU++: additionally Russian Federation
- EU+++: additionally United States, Australia

Every geographical enhancement (linking) decreases permit prices further (p. 15). Modelled effects on international competitiveness are depicted in figure 5. For a detailed explanation of the effects see Alexeeva-Talebi and Anger (2007, p. 17-21).

Figure 5: Economy-wide and sectoral competitiveness indicators by region, sector and scenario



(a)



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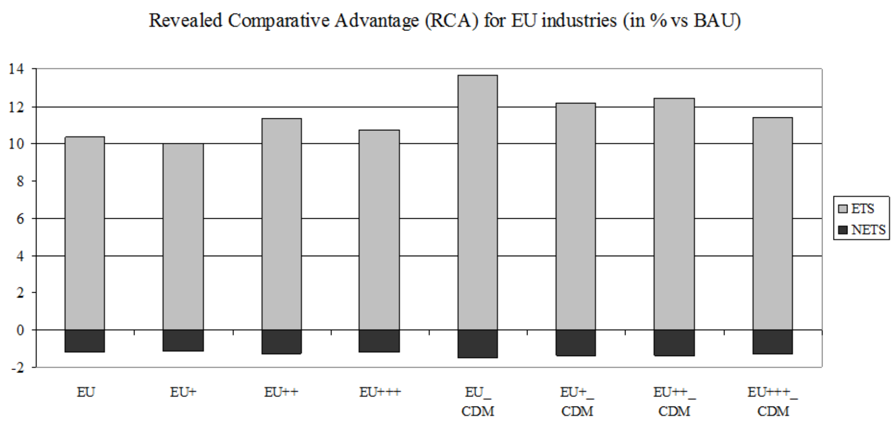
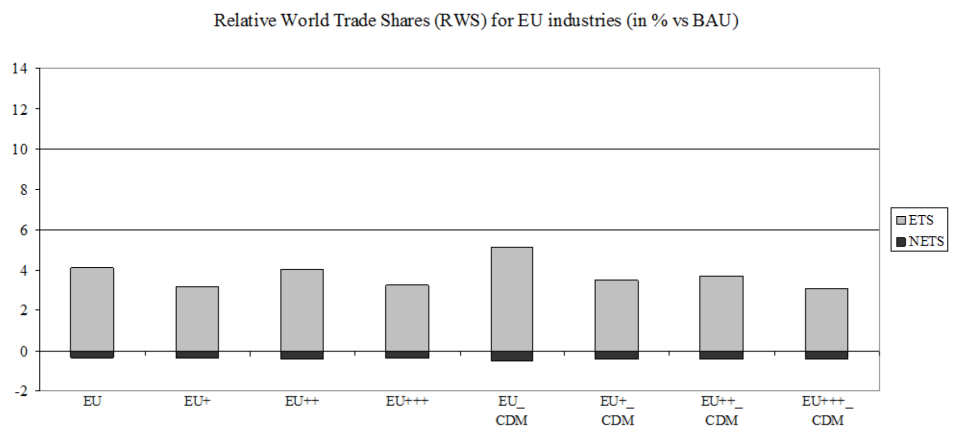


(c)



(d)

Alexeeva-Talebi and Anger, 2007

In a second paper, Anger (2008) focuses exactly on these differences and inefficiencies caused by the fact that not the entire economy is covered by an ETS. As the abatement burden is inefficiently shared between covered and non-covered sectors (ETS caps excessively generous), these inefficiencies will be manifest in a linked system as well.

Marschinski et al. (2012) also show that effects are not always advantageous. In some scenarios, linking can also have negative effects on individual systems if not all economic sectors are covered by the national/regional ETS. Based on an analytic Ricardo-Viner type general equilibrium model, they analyse the effects of ETS linking on carbon leakage, welfare (gains-from-trade and terms-of-trade contributions) and competitiveness[9]. They find that intensity emissions targets, as discussed for the case of China, will lead to carbon leakage and should politically not be seen as a substitute for an absolute cap. In the case of linking the EU ETS to a hypothetical US system, carbon leakage is not found to occur because of fixed limits on total emissions. For country-specific effects, see Box 2.

Box 2: Modelling effects of Marschinski et al. 2012

Based on the assumption that the (implicit) price of emissions in both sectors in the EU (ETS-covered sector and non ETS-covered, but taxed sector) is the same and higher than in the US, they argue that linking the US and the partial EU ETS system can create or increase distortions. Because of falling permit prices, competitiveness distortions in the EU between the ETS-covered sector (ETS) and the non ETS-covered, but taxed sector (NETS) rise. Based on the analytical framework, they also formally show that distortions between the EU's NETS sector and its US counterpart could potentially increase because the emission tax differential may become greater, e.g. if the output of the good, which is taxed in the EU/not covered by the EU-ETS, has increased in the US after linking.

The ToT effect therefore depends on the abatement instruments applied in the NETS sector and the country's trade specialisation, i.e. its export and import position. Negative EU-ToT effects can occur if the EU export goods covered by the EU-ETS and the relative price to other goods decreases as Anger (2008) and Marschinski (2012) assume. If the ToT effect is negative, then the overall welfare effect might become negative.

1.4 Political economy / institutional economics

Studies with a political economy perspective on linking ETS consider the effect of national and sub-national conditions on linking. Political economists look at the preferences of domestic policy decision makers and domestic stakeholders as well as their power to enforce their individual interests as important factors in the linking process. As a result, the analytical lens of political economy offers some insights on a number of potential risks and negative side effects that can be expected when ETS link. From a political economy perspective, there are only a few potential positive aspects to be expected from linking.

[9] They adopt and extend a simple short- to mid-term view of the Ricardo-Viner two-country-two-sector model. The Ricardo-Viner defines capital (C) as a sector-specific factor (i.e. input can only be used by this sector and transferability to other sectors is neglected) and labour (L) as mobile between sectors in a standard trade model setting (L is exogenous, but L_1 and L_2 are endogenous). As an adoption of the basic model, they model fossil fuels as mobile, while other input factors (L, C) are immobile among sectors. Scenarios considered deal with the linking of the EU ETS with a hypothetical US (Waxman-Markey Bill) and Chinese ETS. As the EU ETS only covers 40% of its greenhouse gas (GHG) emissions, they assume one sector of their model to be a cap-and-trade sector with exogenous maximal fossil fuel intake (sector X) and sector Y to be regulated by a resource tax for the EU. Four linking scenarios are considered: (1) EU ETS and sector X in China, (2) EU ETS and sector Y in China, (3) EU ETS and sector X in China, with China under a national emission intensity target, (4) EU ETS and an economy-wide US ETS.

Several qualitative studies have included a political economy analysis (Betz & Jotzo, 2009; Flachsland et al., 2009; Burtraw et al., 2013; Green et al., 2014). Burtraw et al. (2013) looked at the potential political challenges of linking and aligning design elements of an ETS, concluding that political preferences may result in closer alignment of design features than absolutely necessary for a functioning market. This 'over-alignment' may also positively or negatively affect the level of ambition.

Unlike traditional economic theory, which posits that an ETS is an economically efficient instrument to combat climate change, political economists generally see an ETS as a policy resulting from hard-won political compromises and promises to key domestic stakeholders. However, if the system is linked with another ETS, certain design features would likely have to be adjusted and harmonised, potentially very (politically) significant ones. Such adjustments may undermine these nationally established promises and compromises. Additionally, the changes in real emission levels within a jurisdiction (and resulting financial flows between jurisdictions) may be criticised by the public even though it may be desirable from an economic and global system perspective. As such, support for the ETS or the linking process may wane when previous consensus is called into question (Metcalf and Weisbach, 2010). Indeed, as Burtraw et al. (2013) state, linking "would come with political economy consequences, as some interests will benefit and some will lose" (p. 4). As a result of changing winners and losers, various stakeholders may push to renegotiate the existing domestic compromises and question the achievements of the ETS thus far.

The role of related domestic policy objectives is a common topic considered in political economy analysis. Flachsland et al. (2009) focus on the loss of the related secondary benefits associated with a domestic ETS, such as domestic abatement, reduced pollution and job creation. If linking leads to an anticipated outsourcing of these benefits, then linking may become a less attractive option.

On the other hand, it is also acknowledged that linking, by levelling the playing field among linking jurisdictions, can help the wider public and domestic business stakeholders to accept an ETS. Linking may theoretically decrease competitive distortions among linked jurisdictions as linked entities would be subject to the same carbon price and it would also signal to the public that its domestic leaders, as well as other linked jurisdictions, are committed to fighting climate change. Therefore the willingness to raise overall ambition of the mitigation efforts may raise. Again, this may have an positive effect on joint agreements on emission reduction targets or the interest of countries to demonstrate their international leadership on the issue.

Within the linked jurisdictions, those who will benefit from the new market price will support linking, this often depends on allocation methods. For instance, if the link lowers the market price, buyers will support linking as linking lowers their cost of compliance. When prices rise as a result of linking, this will benefit sellers, who will receive more money for their allowances. Additionally, if auctioning is a feature of the system with the higher post-linking price, the regulator will likely support linking as this will generate additional auctioning revenues (Burtraw et al., 2013, Flachsland et al., 2008).

Green et al. (2014) look at international and domestic political obstacles to linking and further explore some of the risks already mentioned above. However, the findings are somehow contradictory to the above mentioned findings on potential benefits: Four potential obstacles are emphasised: (1) linking may lower levels of ambition, (2) potential objections to financial transfers between linked developed and developing countries,[10] (3) the interdependency of linking and the need for regulatory coordination compromises the jurisdiction's regulatory autonomy, and (4) the risk that linking may undermine competing domestic objectives such as encouraging domestic low-carbon innovation and investment.

1.5 Game theory

The design and implementation of multinational policies are marked by the highly strategic behaviour of the involved parties. This is true for any international agreement and particularly for international climate policy and its instruments. Instruments for climate mitigation like ETS also have to be developed in processes of international cooperation among sovereign states. Assuming that states behave rationally according to their self-interests, two fundamental success factors for cooperative state behaviour are: (1) states are better off with global instruments than without them (Pareto optimum), (2) the process and design of the instrument prevent states from making strategic decisions according to the prisoner's dilemma and free rider behaviour.

According to the prisoner's dilemma, an individually rational choice following the best private interests will lead to a collectively suboptimal result. In order to achieve full cooperation and avoid the prisoner's dilemma, incentives to free ride have to be reversed (Dixit & Nalebuff, 1991, Barret, 2003). Free riding in this context relates to the overexploitation of public goods while others refrain from overexploitation. Establishing an ETS can be understood as a game where several "players" (states) behave strategically. Equally, bilateral linking negotiations can also be understood as such a game, but with only two players.

Game theory attempts to determine, both mathematically and logically, the actions that players should take in order to secure the best outcomes for themselves. It is a formal way to analyse interactions among a group of rational agents that behave strategically. Research in game theory focuses on how groups of people interact. The games are defined negotiation processes and can be applied to any potential issue negotiated among different parties, e.g. regarding problems of the Commons like global warming (Dutta, 1999). The games share the common feature of interdependence, i.e. the outcome for each participant (negotiating party) depends on the choices (strategies) of all the other participants. There are two main branches of game theory differentiated by a general assumption as to how participants will behave: cooperative and non-cooperative. Non-cooperative game theory deals largely with how individuals interact with one another in an effort to achieve their own goals. Cooperative game theory assumes that they choose and implement their actions jointly.

In so-called zero-sum games, the interests of the players are in conflict, so that one player's gain will always be another's loss. More typical however, are games with the potential for either mutual gain (positive sum) or mutual harm (negative sum), as well as some conflict. Recent re-

[10] When linking countries with very different levels of economic development and therefore very different abatement costs, linking would result in large financial flows from developed to developing countries. The concentration of financial flows from Europe to a small group of emerging economies (mainly China) through the CDM was heavily criticized, especially for the lack of funds flowing to least developed countries. Further it may be in the economic interest of developed countries to retain investment in their countries to foster their own transition to a low carbon economy. Such financial transfers through a link may be a point of critique for other similar reasons as the CDM. Many developing countries maintain that developed countries have an obligation to provide climate finance because of their much higher historical emissions regardless of the existence of such a mechanism (or link); that climate finance should not be tied to a mechanism that allows them to take credit for the abatement that they pay for in developing countries (and then do less at home) making it (depending on the caps) "an emission shifting rather an emission reduction mechanism" (Chung, 2007), and that such a linking mechanism thereby allows developed countries to pick developing countries' "low hanging fruit" get credit for it, and at the same time leave the most expensive mitigation options in the developing countries for them to later pay for themselves (Ott & Sachs, 2000).

search has focused on games that are neither zero sum nor purely cooperative. In these games the players choose their actions separately but their links to others involve elements of both competition and cooperation.

Explanatory approaches like the prisoner's dilemma explain strategic behaviour and are related to other economic theories, e.g. collective decision making in public choice theory. Addressing strategic behaviour. Barret (2003) defines credibility and legitimacy, as well as individual and collective rationality as success factors for international treaties. Their successful enforcement and implementation needs both strategic manipulation of incentives and compliance.

Duscha et al. (2015, p. 5) discuss the effect of applying equity principles in international climate negotiations and their effect on cooperative behaviour. For situations characterised by the prisoners dilemma and free-riding they discuss that normative motivated equity principles applied as allocation rules such as "equal per capita emission" or "historical responsibility" hinder cooperation compared to more pragmatic rules such as grandfathering.

Game theory has been considered in some studies assessing bilateral linking to better understand behaviour in the design process. Strategic behaviour in ETS processes according to game theory has been considered by Flachsland et al. (2009) and analysed by Helm (2003), the latter of whom found that linking creates an incentive for permit sellers to relax their cap in order to sell even more permits. As a consequence, linking creates a distributional shift in favour of the seller countries.

Carbone et al. (2009) have used a game-theoretic Global Equilibrium Model (GEM) and systematically assessed bilateral linking. The model consists of two components: the GEM determines regional abatement costs and international trade flows. The sub-model of strategic interactions between regional governments determines the membership and emission levels of permit-trade agreements. Carbone et al. (2009) describe the model as follows: The GEM considers six regions (USA, Japan, Western Europe, China, Former Soviet Union, and „Rest of the World"). Within each regional economy goods are produced in the sectors coal, crude oil, electricity, natural gas, refined oil, energy intensive goods and other manufactures and services. Modelling details focus on the energy sectors and hence the direct effects of emission policies. The general assumption in the game-theoretic sub-model of strategic interactions is that countries are guided by self-interest in the design processes of abatement polices. In the game, regions are confronted with a proposal specifying the potential members of a trading coalition. By assuming that coalition proposals arise exogenously, a mechanism was introduced by which coalition members can block the access of others into the trading regime[11]. Country decisions about participation in that trading system and of their initial permit endowment are made non-cooperatively. Therefore trading is crucial. Results show that these assumptions lead to substantially different levels of welfare and emissions. That means, a priory, it is not clear whether participation will result in significant environmental gains. Carbone et al. find, that emissions trading agreements can be effective in terms of net greenhouse gas emission reductions under these assumptions and that small groups of countries perform better than larger groups of countries. Hence, permit-trading can be successful in inducing developing countries to participate in carbon abatement. The authors conclude that the best coalitions combine China with Western Europe: This represents a combination of low abatement cost (China) with the highest valuation for abatement and willingness to act as financier. The essential success factor is not the existence of binding abatements targets, but of differences in abatement cost structure and cheap abatement options. The

[11] Carbone et al. (2009, p. 270) state that such a mechanism is common in many international treaties such as WTO, EU and NATO.

results also indicate that coalitions (and global abatement) may benefit from excluding certain countries from membership.

1.6 Summary

This report describes some areas of economic theory, namely, concepts of environmental economics, trade theory, political economy, and game theory, in terms of their contribution to understanding the conditions and effects of linking as an instrument to create larger carbon markets. The review is based on a screening of ETS linking literature and complemented by literature on related economic theory.

Economic theory generally suggests that a global carbon market with a uniform price signal would be the optimal instrument to address global political emissions reduction objectives and to minimise or even heal market distortions. However, that is not politically achievable in the short to midterm. Hence, the bottom-up direct linking of smaller markets created by separately developed national or regional (e.g. EU-wide) ETS appears to be the second best, but currently most promising option to create larger and more efficient markets and to start a process toward a global carbon market. Estimates show that the total abatement cost savings from creating a global carbon market with trade across all countries and sectors could halve abatement costs compared to a situation where no trading occurs.

However, the “allowance price paradox” appears to apply in the case of linking ETS: When large price differences exist between systems, the potential for economic cost reduction is high, but the political incentive for linking appears low. This indicates trade-offs in the different categories of criteria to assess linking options. In the literature, four arguments in favour of linking are stressed:

1 increased market liquidity through an increased number of market participants,

2 higher cost-efficiency through a larger number of mitigation options,

3 a more robust price signal and

4 reduced distortions through converging carbon prices.

The review condensed different perspectives on linking (see also table 1). Environmental economics posits that if the environmentally harmful behaviour resulting from market failure is priced, actors will be incentivised to modify their behaviour and a more efficient allocation will be reached. This argument is the basis of every ETS design and implementation and ETS linking discussion and represents the arguments of the above four bullet points. However the literature review has shown that an evaluation of linking should also cover the perspectives of both individual countries/systems as well as the risks and benefits for the linked system as a whole. An extension of the Coase theorem was used to emphasise the importance of the marginal cost structure for linking. In addition, the characteristics and details of individual pre-linking systems are key in determining which actors will be affected by linking and to what extent. The literature review also revealed that the distributive effects of linking depend on the perspective, i.e. impact level, considered: Whereas from a linked systems’ perspective formally linking a high-price country with a low-price country is favourable in terms of overall economic system efficiency, from the individual countries’ viewpoint the picture might differ. Though the low-price country benefits from selling allowances and associated additional financial flows, the high-price country experiences financial outflows despite being able to access an increased number of low-price certificates. This might be an domestically undesired effect. Furthermore, domestically undesired intra-country distributional effects might also occur at company level.

Trade theory highlights the interaction of inter-ETS trade. However, how consequent financial flows interact with real goods trade is highly complex and can, for instance, affect the ToT and real trade flows. Therefore, whether linking offers any advantages in terms of trade depends on the underlying economic structures and political decisions (e.g. on emissions caps or ETS characteristics) of individual countries/systems and therefore there will be winners and losers of linking. In addition, because ETS cover only parts of the emissions, the efficiency of the abatement burden sharing between ETS and Non-ETS sectors plays an important role. When linking systems, national inefficiencies can therefore be exported, increased or mitigated.

Political economists look at the preferences of domestic political decision makers and domestic stakeholders as well as their power to enforce their interests as important factors in the linking process. Adding a critical view to the linking debate, the analytical lens of political economy offers some insights on a number of potential obstacles when two or more systems are linked. Most importantly, consensus on previous policies by affected stakeholders and the public may wane. On the other hand, associated positive effects may result from bilateral cooperative linking as it may induce a feedback reaction on attempts to raise overall ambition of mitigation efforts: Literature acknowledges that linking, by levelling the playing field among linking jurisdictions, can help the wider public and domestic business stakeholders to accept an ETS. Decreasing competitive distortions and the political signal to the public that its domestic leaders, as well as other linked jurisdictions, are committed to fighting climate change help raise awareness and acceptance of mitigation policies.

Game theory argues from the perspective of countries as “players” and points out that the design and implementation of multinational policies are marked by strategic behaviour of the involved parties following individually rational considerations. This is also true for any international agreement and particularly for international climate policy, because instruments for climate change mitigation such as a linking of ETSs also have to be developed in processes of international cooperation among sovereign states. Game simulation shows that permit-trading can be successful in inducing developing countries to participate in carbon abatement. A conclusion is that the best coalitions combine China with Western Europe: This represents a combination of low abatement cost (China) with the highest valuation for abatement and willingness to act as financier. The essential success factor is not the existence of binding abatements targets, but of differences in abatement cost structure and cheap abatement options. The results also indicate that coalitions (and global abatement) may benefit from excluding certain countries from membership in the linked system.

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Table 1: Economic perspectives related to linking of ETSs.

Area	Basic interest	How is linking addressed	Which assessment criteria of a linked ETS are affected
Environmental economics	What are appropriate instruments to address negative externalities?	Selection of instrument Design of instrument	Economic efficiency Environmental integrity
Trade theory	What are the trade impacts of introducing instruments?	Impact analysis of linking of ETS based on country specific economic structures and ETS characteristics	Economic efficiency
Political economy	What influences decision making processes and how are past decisions affected by new developments?	(Re-)Negotiation within a jurisdiction whether to link bilaterally – based on stakeholder's interests and their effect on the decision making process	Political acceptability
	Decision making influences design	Operationalisation of design options influenced by linking negotiation	Economic efficiency Environmental integrity
Game theory	What is the influence of strategic behaviour on decision making?	Strategic behavioural routines in linking negotiations	Economic efficiency Environmental integrity Political acceptability

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The economic theories explored in this section all contribute to an understanding of how the general assessment criteria "economic efficiency", "environmental integrity" and "political acceptability" are addressed and may be affected by linking specific systems. The criteria, indicators and design options discussed in the reviewed ETS linking literature (see Annex) provide first input for the subsequent work packages. However additional research is needed to gain further insights into the interdependent effects of linking.

1.8 Literature overview by relevance for subsequent work packages

1.8.1 Literature on assessment criteria for linking ETS (relevance for chapter 2)

Assessment Criterion	Sources
Effect on GDP/consumption	Alexeeva-Talebi & Anger, 2007; Vöhringer, 2012
Dynamic (Efficiency)	Alexeeva-Talebi & Anger 2007
	Alexeeva-Talebi & Anger 2007 Edenhofer et al., 2007 Flachsland et al., 2009
Competitiveness	Alexeeva-Talebi & Anger, 2007 Marschinski et al., 2012 Edenhofer et al., 2007
Political attractiveness	Anger, 2008 Flachsland et al., 2009 Metcalf & Weisbach, 2010 Burtraw et al., 2013
Emissions	Vöhringer ,2012
Market liquidity	Flachsland et al., 2009
Environmental effectiveness	Edenhofer et al., 2007 Flachsland et al., 2009 & 2009b
Financial flows	Zetterberg, 2012 Flachsland et al., 2009
Market concentration	
Terms-of-Trade effect	Edenhofer et al., 2007 Marschinski et al., 2012 Flachsland et al., 2009
Carbon leakage	Edenhofer et al., 2007 Marschinski et al. 2012
Security of investment	Edenhofer et al., 2007
Distributional aspects	Flachsland et al., 2009
Political aspects	Betzt & Jotzo, 2009 Flachsland et al., 2009 Burtraw et al., 2013 Green et al., 2014

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1.8.2 Literature on economic indicators (operationalised assessment criteria) with linking relevance (relevance for chapter 3)

Economic Indicator	Sources
Emissions cap	Alexeeva-Talebi & Anger, 2007 Marschinski et al., 2012 Edenhofer et al., 2007
Offsetting permission	Alexeeva-Talebi & Anger, 2007
Marginal abatement costs	Alexeeva-Talebi & Anger, 2007 Edenhofer et al., 2007
Domestic emissions	Alexeeva-Talebi & Anger, 2007
(Future) Certificate price	Alexeeva-Talebi & Anger, 2007 Flachsland et al., 2008 Flachsland et al., 2009 Edenhofer et al., 2007 Marschinski et al., 2012
Certificate trade	Alexeeva-Talebi & Anger, 2007
Trade (goods)	Alexeeva-Talebi & Anger, 2007 Marschinski et al., 2012
Prices of goods	Marschinski et al., 2012
Price volatility	Flachsland et al., 2008 Edenhofer et al., 2007
Transaction costs	Flachsland et al., 2009b based on Jaffe & Stavins, 2008

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1.8.3 Literature on design options and their impact on the linkability of ETSs (relevance for chapter 4)

Design option	Sources
Sectoral coverage	Anger, 2008 Marschinski et al., 2012 Metcalf & Weisbach, 2010 Tuerk et al., 2009 Ahlberg et al., 2013 Jaffe & Stavins, 2007
Caps (type: absolute, relative, stringency of targets)	Marschinski et al. 2012 Flachsland et al., 2009b Sterk et al., 2009
Mid- to long-term caps	Flachsland et al., 2009
Internal efficiency of regulation	Anger, 2008
Facility inclusion thresholds	Vöhringer, 2012 Tuerk et al., 2009 Metcalf & Weisbach, 2010 Burtraw et al., 2013
Price containment mechanisms	Edenhofer et al., 2007 Olmstead & Stavins, 2011 Sterk et al., 2009 Metcalf & Weisbach, 2010 House of Commons, 2015 Burtraw et al., 2013
Banking/Borrowing	Edenhofer et al., 2007 Flachsland et al. 2009 & 2009b Tuerk et al., 2009 Sterk et al., 2009
Int. clearing centre	Edenhofer et al., 2007 Schüle & Sterk, 2007 Marcu, 2014 Mehling & Haites, 2008
MRV	Flachsland et al., 2009 Burtraw et al., 2013 Sterk et al., 2009 Tuerk et al., 2009 Bodansky et al., 2014
Registry	Flachsland et al., 2009b Burtraw et al., 2013
Penalty and enforcement	Flachsland et al., 2009b Tuerk et al., 2009 Sterk et al., 2009 Jaffe & Stavins, 2007

	Burtraw et al., 2013 Zetterberg, 2012

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2 Review and further development of criteria to evaluate a direct link

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with input by Christiane Beuermann, Dorothea Hauptstock, Johannes Thema

2.1 Introduction:

The first chapter reviewed the current status of academic theory on linking emissions trading systems (ETS) including the general rationale and risks of such links. In this second working paper we turn our attention towards policymakers and their perspective towards linking. Policymakers must consider many factors, from their own institutional contexts to their jurisdiction's rationale for establishing an ETS. Though academic theory may suggest certain universal advantages and disadvantages to emissions trading in general, policymakers' reasons to implement and link ETS may vary significantly. It is therefore relevant to examine the legal and rhetorical rationales given by different policymakers in different jurisdictions to understand the requirements and criteria, explicit or circumstantial; they may apply in considering a linking partner.

This chapter will review and summarize linking objectives, criteria and requirements of existing ETS (chapter 2 and Annex) thereby complementing academic theory reviewed in the first work package. The result will then be used to develop an overall assessment framework that combines environmental, economic and political dimensions of linking (chapter 3). In the following chapters we will then further explore in detail how specific linking objectives can be assessed based on key assessment criteria and their potential operationalization (chapter 4-11).

Table 2: Overview of Rationale and Linking Criteria/Factors of Selected ETS's

Jurisdiction	Main Rationale Stated	Explicit Linking Criteria
European Union	• reduce mitigation cost • increase market liquidity • more stable carbon price • levelling the international playing field • supporting global cooperation on climate change	• Annex B country • ratified Kyoto Protocol • compatible • mandatory • absolute emissions cap
Australia	• reduce mitigation costs	• internationally or

	• step towards a global carbon market (allowing for cheapest abatement opportunities) • greater flexibility for business • boost market confidence and certainty	mutually acceptable mitigation commitments • robust and comparable MRV mechanism • broad compatibility of design and market rules
Switzerland	• more liquid market • more abatement options • greater flexibility to meet targets • encourage trade and price formation • alleviate competitiveness concerns [between businesses in Switzerland and the EU]	
California	• reduce emissions to help achieve the AB 32 mandate[12] • maximize emission reductions through coordinated sub-national efforts • enhancing individual actions through a collaborative effort • provide greater flexibility to California businesses by offering a wider range of emissions reduction opportunities • greater market liquidity • maximize the additional environmental benefit	• reduction ambition and offset requirements at least as strict, if not stricter, than California • not undermine California ability to enforce its rules • strict enforcement of applicable laws and regulations • link would not impose a liability on California
New Zealand	• greater liquidity • align international carbon prices • reduce emissions at least cost • close economic relationship	
RGGI		• Reduction target of 2.5% per year until 2020 • Newcomers must set up regulatory programme consistent with the RGGI model rule • mutual recognition of permits [all permits eligible in all

[12] AB 32 mandates California reduce its GHG emissions to 1990 levels by 2020.

		participating states] • substantial share of permit auction revenue must be invested in projects that benefit consumers, especially concerning sustainable energy • pay fair share in implementing [joint] scheme

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In addition, there are a number of secondary factors that may influence a linking decision:

The EU considers as important

- No price floor / ceiling[13]
- Quantitative limits for acceptance of international offsets
- Exclusion of certain offsets (nuclear, industrial gas, large hydro projects)

California (and partly also RGGI) outlines

- Likely limited to sub-national jurisdictions in US and Canada
- Extensive harmonization
- Common registry
- Common auctions

2.2 Analytical framework

The aim of this paper is to develop a transparent and systematic overall assessment framework that can be used to evaluate the potential chances and risks of linking two emission trading systems. The prospect of a full bilateral link between two (or maybe more) independent emissions trading systems is considered, but the analytical framework could also be used for a restricted link (e.g. with limited trading quota), or for unilateral and or indirect links.[14] Based on the re-

[13] This holds likely also true for price ceilings, although there is a lack of actual precedence to test questions of price ceilings.

[14] In the case of a direct link between at least two emissions trading systems, the emission allowances are mutually accepted to fulfil allowance surrender obligations. An indirect link of several emission trading systems can work, for example, by an accounting system such as the Clean Development Mechanism (CDM) in which states accept carbon credits (offsets) generated elsewhere in their emissions trading schemes. A unilateral linking describes the acceptance of emission allowances of one system in another.

view of arguments in favour of linking and the goals and criteria of political decision makers analysed in the previous chapter, we identified seven main linking objectives which can be pursued ex-ante from the perspective of each linking partner evaluating the other. The objectives can be grouped in three dimensions as environmental, economic and political (see table below).

Table 3: Linking objectives and categories

Linking objective	
1) Ensure environmental integrity	Environmental
2) Achieve long-term abatement targets	
3) Reduce mitigation cost	Economic
4) Reduce competitive distortions	
5) Increase market stability and liquidity	
6) Maintain/increase acceptance of ETS and of linked market	Political
7) Support global cooperation on climate change	

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In order to evaluate to what extend each of the objectives would be achieved through linking with potential partners, we suggest specific assessment criteria which will serve as a basis for the further assessment of pro and cons of linking two or more systems. For each of the assessment criteria we then select one or several “operationalised” criteria. These are variables which will help to quantify or qualitatively assess potential linking outcomes with regard to the specific objective. The variables must be quantified or qualitatively defined more precisely before they can be assessed. While we give some examples, how the variables could be quantified or qualitatively defined, this is a complex, political task, where individual preferences and interests play a major role. Finally, for each of the operationalised criteria examples of additional influencing factors are provided as appropriate (see the tables below).

In the following chapters we will then outline the specific hypotheses guiding the assessment. Where applicable, potential conflicts or overlaps among the different objectives are explained: conflicting objectives usually occur between different dimensions, e.g. between environmental and economic objectives. There should be a clear causal relationship between the identified criteria and linking: thus, we excluded effects, such as distributional or welfare-related impacts, that can in principal be associated with linking, but have an extremely complex impact chain or where the cause-effect-chain is unclear. In the following tables we summarise the key results when applying the assessment framework to the seven objectives organised according to the dimensions (environmental, economic, and political).

Table 4: Environmental Objectives of Linking

Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Environmental objectives:			
1. Ensure environmental integrity "A ton is a ton"	**Environmental integrity**	[Mutually accepted][15] MRV standards/thoroughness	
		[Mutually accepted] offset standards (qualitative)	
		[High/sufficient] stringency of enforcement	Administrative and enforcement capacities
2. Achieve long-term abatement targets	**Incentives for low-carbon investments**	[Sufficiently high] historic carbon price level	Role of ETS in domestic climate policy mix
		[Equal/comparable] Cap stringency / cap reduction factor as measured by degree of divergence from Business as Usual emissions/No-ETS- pathway (including quantitative offset limits)	Role of ETS in domestic climate policy mix Scope of ETS Abatement potentials and costs, degree of divergence from Business as Usual emissions/No-ETS pathway
		Availability of [ambitious, fair] long term mitigation targets and commitments	Stage of development of economy of linking partner
		Availability and compatibility of safeguards against oversupply (e.g. price based or volume based supply control)	Level of Auction price floors, Market Stability Reserve Provisions, ad-hoc supply interventions such as backloading

[15] The contents in brackets are an example of the data or benchmark of the indicator / operationalized criteria, which depends on the subjective weighting and assessment of the policymaker in a linking decision process.

	Stability of the political/regulatory environment	Availability of [ambitious, fair] long-term mitigation targets and commitments	
		[High] political support of ETS [across all major political parties/in government and opposition]	General political stability
		Acceptance of the ETS with stakeholders and the broader public	

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Table 5: Economic Objectives of Linking

Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Economic Objectives			
3. Reduce mitigation costs	**Mitigation costs (short-term, static)**	Expected change [decrease] of carbon price (before and after linking)	Relative abatement potentials and costs (difference between linked systems)
4. Reduce competitive distortions	**Competitiveness and Carbon Leakage risk in relation to Linking Partner**	[High] trade exposure of ETS sectors	Trade intensity, importance of linking partner as trading partner or competitor
		[Significant] differences in free allocation methods	Other state measures influencing competition e.g. subsidies, access to finance
		[Significant] difference of carbon price level before linking	
		Expected net capital flows	
	Competitiveness and Carbon Leakage risk in relation to Third Countries	[High] trade exposure of ETS sectors	Trade intensity, importance of third countries as trading partner or

			competitor
		Expected relocation of production and investment (after linking)"	
		Expected change of carbon price (before and after linking)	
		Expected net capital flows	
5. Increase market stability	**Market liquidity and stability**	Number of market participants (before and after linking) relative to market size and number of trades	
		Carbon price stability (before linking)	
		Availability and compatibility of safeguards against oversupply	

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Table 6: Political Objectives of Linking

Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Political objectives			
6. Maintain / increase acceptance of ETS and of linked market	**Domestic Support of ETS and linking**	Relevance of changes to ETS Designs required for linking	Important design features e.g. allocation methods, access to offsets, supply control measures
		Political, stakeholder and public support of estimated impacts of linking (balance of “winners and losers”)	
7. Support global cooperation on climate change	**Signal for international climate policy**	Reliability as [ambitious] climate policy partner	
	Vehicle for international carbon finance	Expected net capital flows	Relative size of the system Relative abatement potentials and costs

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2.3 Linking objective I: Ensure environmental integrity

(Environmental) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Ensure environmental integrity	**Environmental integrity**	[Mutually accepted][16] MRV standards/thoroughness	
		[Mutually accepted] Offset standards (qualitative)	
		[High/sufficient] Stringency of enforcement	Administrative and enforcement capacities

Rationale behind the objective: the jurisdiction wants to ensure environmental integrity, namely, that real emissions in the linked market meet or stay under a set target. This implies, for instance, that all targeted emissions are reported, for each ton emitted, an allowance is submitted and cancelled, a tonne of CO2 in one system is equal to a tonne in the other system and there is no double counting of allowances and emission reductions.

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2.3.1 Assessment Criteria: Environmental Integrity

Main Hypothesis

An ETS shows environmental integrity when there are sufficiently high MRV provisions, standards and compliance enforcement ensuring that a 'ton is a ton'. Theoretically, linking two systems with high environmental integrity merely shifts where emissions reductions take place within the linked system and the total level of emissions under the linked system would remain the same (Jaffe & Stavins, 2007). However, deficits in the environmental integrity of one linking partner can undermine the environmental integrity of the whole linked entity / both emissions trading systems. As long as there is sufficient evidence that emissions in the linked market meet, or stay under the set target, the environmental integrity of the ETS has not been compromised.

Ultimately, if linking partners are interested in preserving the environmental integrity of their carbon market, certain design features must either be harmonised or perceived as equally trustful. Most importantly, implementing similar MRV procedures, equal treatment of offset limits and the application of stringent compliance provisions among the linking partners prior to linking can help ensure the environmental goals of both systems are not undermined by linking.

Operationalised Criteria: MRV Standards / thoroughness

Ensuring robust and credible MRV standards in a linked system is vital to ensure mutual trust and the environmental integrity of the system (Flachsland et al., 2009; Edenhofer et al., 2007). Not only is the availability of sufficiently robust MRV provisions needed, but their actual enforcement is required to make sure the environmental integrity of the system is not challenged. Although complete harmonisation is not vital to linking[17], comparatively robust standards ('a tonne is a tonne' principle) are very important because any system with weak standards would undermine the credibility and effectiveness of the entire linked system. Even though not re-

[16] The contents in brackets are an example of the data or benchmark of the indicator / operationalized criteria, which depends on the subjective weighting and assessment of the policy maker in a linking decision process.

[17] The example of the EU-Norway link highlights that slight differences in MRV arrangements do not pose an environmental integrity barrier to linking.

quired for functioning of the linked market, having identical MRV standards and processes would greatly reduce the risk of double counting (i.e. where entities gain allowances in both jurisdictions for the same reduction in emissions) (Flachsland et al., 2008; Tuerk et al., 2009). Comparably robust MRV standards should ensure that a tonne of emissions reduced in one system is the same as a tonne of emissions reduced in the other system (DEHSt, 2013)[18].

Operationalised Criteria: Offset standards

The decision on qualitative offset standards, or which offset projects to accept, represents the policy preferences on the types of projects that domestic decision makers deem acceptable. If a system has excluded a type of project that is accepted in a potential linking partner's jurisdiction this would imply such offsets will be available to all participants of the linked market. As an example, if companies in system A purchased offsets that system B does not recognise, those companies can use their offsets for compliance thus "freeing up" allowances they would otherwise have bought on the market (Sterk et al., 2009; Zetterberg, 2012; Burtraw et al., 2013). If projects with questionable environmental integrity are accepted in one of the systems, this can therefore have a negative impact on the overall environmental integrity of the linked market.

That is why different offset provisions can represent a significant obstacle to linking (Burtraw et al., 2013; Zetterberg, 2012; Tuerk et al., 2009; Flachsland et al., 2008; Sterk et al., 2006). For instance, the EU does not accept offset credits from land use, land-use change and forestry (LULUCF) due to concerns about the permanency of the emissions reductions (Tuerk et al., 2009). The EU's refusal to accept such credits has played a major role in its linking negotiations. Switzerland, which is currently negotiating a link with the EU, has modified its offset regulations to exclude LULUCF offsets. This may have also been an issue for a link between the EU and Australia (had the latter not abolished its ETS), as the Australian system accepted land-use and agricultural offsets (Hawkins & Jegou, 2014).

Operationalised Criteria: Stringency of enforcement

Compliance with the ETS should be credibly enforced in both potential linking jurisdictions. This is important not only for equity concerns for business entities in both jurisdictions but is also necessary to build trust and confidence in the linked market. Apart from the level of penalties, stringency of enforcement is strongly influenced by the administrative and enforcement capacities of each jurisdiction.

If linking occurs in a situation where the penalties for non-compliance in one system are lower than the overall carbon price (or where non-compliance is generally not sufficiently sanctioned), entities in this system would have an incentive to sell their allowances and pay the penalty (Haites & Mullins, 2001), thus jeopardizing the environmental effectiveness of the linked system. Empirical evidence also highlights the importance of aligning compliance provisions. For instance, under the planned EU-Australia link, Australia was prepared to amend its original penalty for non-compliance from a fine of 1.3 times the fixed allowance price to double the average auction price of allowances for that year, mirroring the EU's penalty regime. Switzerland also amended its penalties to match the fines in the EU ETS (Hawkins & Jegou, 2014).

2.4 Linking objective II: Achieve long-term abatement targets

(Environmental)	Assessment Crite-	Operationalised Criteria	Influencing factors

[18] During negotiations for a linked EU-Australian system, aligning MRV systems was not a large issue as both parties used the Kyoto Protocol accounting system and both are Annex I parties applying similar IPCC MRV guidelines. Nevertheless, the requirements for e.g. verification were quite different in both systems, the decisive factor was mutual trust in the other parties institutions and processes

Objective	ria		
Achieve long-term emissions abatement targets	**Incentives for low-carbon investments**	[Sufficiently high] Historic carbon price level	Role of ETS in domestic climate policy mix
		[Equal/comparable] Cap stringency / cap reduction factor as measured by the degree of divergence from a Business as Usual emissions/No-ETS pathway (including quantitative offset limits)	Role of ETS in domestic climate policy mix Scope of ETS Abatement potentials and costs
		Availability of [ambitious, fair] long term mitigation targets and commitments	Stage of development of economy of linking partner
		Availability and compatibility of safeguards against oversupply (e.g. price based or volume based supply control)	Auction price floors, Market Stability Reserve Provisions, arbitrary market interventions
	Stability of the political/regulatory environment	Availability of [ambitious, fair] long-term mitigation targets and commitments	
		[High] Political support of ETS [across all major political parties/in government and opposition]	General domestic discussion on climate policy
		Acceptance of the ETS with stakeholders and the public	

Rationale behind the objective: The jurisdiction wants to ensure long-term emissions abatement targets will be achieved in a linked market since achievement of domestic targets in each jurisdiction is not guaranteed. Therefore, the linking partners have to agree upon common mitigation targets. To achieve this common target, sufficient abatement incentives have to be provided after linking and there must be confidence about the long-term mitigation pathway.

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2.4.1 Assessment Criteria: Incentives for low-carbon investments

Main Hypothesis

When two systems link, the carbon prices[19] in both jurisdictions will converge, as the price will drop in the jurisdiction with the higher pre-linking price and increase in the jurisdiction with the lower pre-linking price. Although the cap may be achieved at lower costs in the short term, in the long term, a (relatively) low carbon price may not be as efficient. However, this will also depend on the average level of the new carbon price. Furthermore, the system with a higher pre-linking

[19] "Carbon price" in this paper refers to the allowance price, not to other fiscal instruments such as a CO2 tax.

carbon price may be pursuing long-term mitigation objectives that require a high price (Green et al., 2014; Grosjean et al., 2014; Flachsland et al., 2009). This could lead to conflicting objectives with lowering the carbon price. For instance, the EU sees the ETS as a vehicle for driving low-carbon investments (EC, 2015) and both California's Global Warming Solution Act (2006) and the WCI aim to stimulate low-carbon innovation (Tuerk et al., 2009).

The extent to which an ETS can provide sufficient and reliable incentives for low-carbon investments is debatable (Taylor, 2012) and depends on a number of factors, including a strong carbon price signal[20]. Still, many authors (including the ETS directive 2009/29//EC itself) put forward the argument of a strong carbon price as an incentive for investment in low-carbon technologies.

Operationalised Criteria: (Historic) Carbon price level

For jurisdictions that want their ETS to drive domestic low-carbon investment, a strong carbon price signal is essential. The higher the carbon price, the stronger the incentive will be for participants to invest in low-carbon technology. Increasing prices of greenhouse gas intensive products will also encourage the transition to a greener and cleaner economy. If linking is likely to lower a jurisdiction's carbon price, this may undermine a jurisdiction's domestic decarbonisation goal and may make it reluctant to pursue linking. For instance, California has pointed to the EU's low carbon price as one reason for not pursuing a transatlantic link (Ranson & Stavins, 2014). When assessing historic price levels, influencing factors such as jurisdictions' climate policy mix should be taken into consideration, as they will continue to affect the linked market. Complementary strong climate change polices, such as regulatory frameworks for energy efficiency or renewable energy deployment, affect the mitigation cost and the carbon price and are likely to cause a reduction of the carbon price.

Operationalised Criteria: Cap stringency / cap reduction factor

The stringency of the cap (plus the amount of offset credits that are allowed into the system) describes the relation between the emissions reduction target compared to a scenario without ETS (business as usual). Thus, the stringency of the cap is not only determined by the percentage-level of the target, but also by the abatement potentials and costs as well as by the drivers of emissions (e.g. demographic and economic development) and other implemented climate policy instruments. The resulting carbon price is an indicator for the stringency of the system.

A common understanding of the desired cap stringency is key for the linking decision. Linking a stringent system (with a higher carbon price) with a more lax one will result in an increase in emissions in the more stringent system as entities covered by the ETS can buy up the cheaper allowances in the lower priced system until the carbon price in both systems equalise. If domestic emissions reductions are considered a political priority,[21] linking with a less ambitious system would undermine the achievement of such domestic policy goals. Here it is again important to consider the role of the ETS in the relevant policy mix as an influencing factor.

[20] Innovation and investment also suffer from an additional number of market failures that are not necessarily addressed by a carbon price, such as knowledge spillovers. For instance, a firm that invests in innovation creates new knowledge. Although firms can use patents to protect their investment, they cannot entirely prevent other firms from benefitting off their innovation. These 'knowledge spillovers' or benefits to society are often much greater than the direct benefit to the firm. This also creates information uncertainty, as the return on investment of these innovations is also often unclear.

[21] Some jurisdictions' political priority of domestic emission reductions is also reflected in the UNFCCC/Kyoto principle of supplementarity, where use of flexibility mechanisms must be "supplemental" to domestic actions to limit or reduce their emissions, which some parties have defined to be less than 50% of the overall goal.

Theory suggests that a link could also give a system an incentive to be less ambitious in the future: it could increase the amount of allowances to be supplied to the linked system in order to generate additional revenue after systems link.

Generally, if a system is linked with an ETS that has a generous or relatively loose pre-linking target relative to "business-as-usual" (i.e. an oversupplied market with a low carbon price), it would reduce the environmental effectiveness of the linked market as it would introduce a large amount of cheap allowances into the joint system undermining abatement incentives. In fact, depending on the relative size of the systems, aggregate emissions may even rise as a result of linking as the lack of ambition in one system is imported into the linked system reducing the price signal and overall abatement efforts. Such "hot air" may also reduce long-term abatement efforts if installations may bank cheap allowances for future compliance, undermining the environmental effectiveness of the system in the future.

On the other hand, from an economic perspective, the greater the difference in carbon price between systems before linking, the greater the efficiency gains from linking, at least in a static, short-term perspective. Thus, there is an inherent trade-off between environmental (achieving emissions reductions) and economic (reducing mitigation cost) priorities.

A clear statement that an ambitious, pre-linking mitigation goal is a precondition for linking may persuade countries with less stringent targets to adopt more ambitious targets in order to be considered as a potential linking candidate.

The role of offsets deserves particular attention in the discussion of cap stringency as credits imported into an ETS increase the admitted amount of emissions, thus weakening the cap. If the price of offsets is lower than the carbon price on the linked market, participants will be incentivised to rely on the cheaper offsets for compliance purposes. The case of New Zealand is a useful example. Initially, the New Zealand ETS allowed for the unrestricted use of CDM credits. The crash of CDM prices led to a decline in the New Zealand carbon price (Ranson & Stavins, 2014), removing the incentive for domestic abatement. Since mid-2015, New Zealand has banned the use of international credits and the carbon price has consequently increased. The widespread use of quantitative limits by existing ETS suggests that this is a key concern for policymakers (Ranson & Stavins, 2013). Linking negotiations have demonstrated that policymakers have preferred to harmonise these limits as well, with both Australia and Switzerland adjusting their limits on CDM credits to reflect the EU ETS (Hawkins & Jegou, 2014).

Operationalised Criteria: Availability of long-term targets or commitments

The existence of long-term targets in both systems can help shore up investor confidence in the linked carbon market. Establishing a long-term emissions reduction pathway reflected by a stringent ETS cap can also be evidence of policymakers' commitment to emissions trading. It can also increase investor confidence by signalling the political stability of the investment landscape for clean technology.

Operationalised Criteria: Availability and compatibility of safeguards against oversupply

More and more emissions trading systems have introduced measures to ensure a minimum carbon price signal or minimum scarcity and to protect the system from an oversupply of allowances (as when the cap is set too high or there is an external economic shock reducing economic activity and emissions). RGGI, California and Québec have price floors, this is also reflected in Ontario's plans for its ETS that it intends to link to California and Québec. Korea has given policymakers the power to intervene to reduce the number of offsets eligible for compliance and has provisions to introduce a price floor. In contrast to the concept of price floors, the EU has decided recently to rely on quantity based supply management. A Market Stability Reserve (MSR) has been established to be operational from 2019 to remove excess allowances from the market and to adjust supply to fluctuating demand. If the amount of allowances in circulation (the surplus) is higher than a certain threshold, supply at auctions is automatically reduced and allowances not auctioned are put into the MSR.

Depending on the availability and design of supply management measures in a potential partner system, the effectiveness of these measures may be reduced after linking. Minimum auction prices, as can be found in RGGI, California, Quebec and in Ontario's proposals, automatically reduce the supply of additional allowances coming onto the market when auction prices do not meet a certain level. Linking with another (oversupplied) system would mean that market participants may have an alternative supply of allowances at a cheaper price: If two systems were to link and one system had a minimum auction price, entities would be incentivised to purchase emissions in the other system until the minimum price level is reached. Thus, the higher minimum auction price of one system may not take effect in the short-term if the other system has a lower or no minimum auction price.

Whereas the provisions for minimum auction prices and their development in the future are clear, the exact effect of the European market stability reserve on prices is (yet) unclear as the MSR follows a quantity based approach to supply management. How to align or combine different approaches to supply management in an ETS could therefore be an issue during linking negotiations.

The question how to extend and design the MSR in case of linking with another ETS needs further investigation. To be effective, the MSR mechanism must probably apply to the whole linked market, e.g. must account for (cumulative) demand and supply in both emission trading systems. Depending on the size of the two linked markets, it could turn out that the established thresholds to reduce or increase auctioned allowances are no longer appropriate for the linked market. The linking agreement between the EU ETS and the Swiss ETS may provide some first experiences for dealing with the MSR in a linked carbon market.

2.4.2 Assessment Criteria: Stability of the political/regulatory environment

Main Hypothesis:

Following Australia's decision to repeal its ETS despite advanced linking negotiations with the EU, jurisdictions may be more likely to look at the political and regulatory environment of a potential linking partner. If an ETS has a low level of domestic support and is a politically contentious subject, other governments may be dissuaded from engaging in linking discussions with that system as it could lead to policy uncertainty in both jurisdictions and potentially jeopardize long-term mitigation targets. Alternatively, systems would be more likely to link with a system that has a relatively stable, reliable climate policy with broad public support. If the ETS is a politically polarising topic supported by a government with a slim governing majority, this could endanger the stability and reliability of the linked market.

Alternatively, jurisdictions may want to pursue linking in order to stabilise their own system. Linking with the EU would have further entrenched the Australian ETS by binding it to an international commitment (Campbell & Voros, 2012; Lake, 2013).

Operationalised Criteria: Availability of long-term policy targets and commitments

The existence of formal (and credible) long-term mitigation and cap reduction targets can be an indicator for a relatively stable and reliable climate policy. Long-term mitigation targets and road maps, for instance, through the INDC (Intended Nationally Determined Contributions) submissions or via national legislation, formally signal a commitment to climate change and thus help build confidence in the commitment to emissions trading. Nevertheless, as the Australian case shows, the existence of long-term targets alone may not be enough to guarantee the long-term existence of the system.

Operationalised Criteria: Political support of ETS

If most of the relevant political actors in the government and the opposition support the domestic ETS, it is more likely to be a long-term policy instrument and there is less risk that it may be abolished in case of a change in government.

Another factor that could affect the stability of the ETS is the competitiveness of the elections. This refers to the question, whether the stability of the political environment – and support for the ETS – is certain and basically independent of a change in government.[22] If all political parties support emissions trading, the outcome of national elections will also not have a strong impact on the future of the ETS.

Linking systems means that a certain level of emission reductions of a jurisdiction with higher abatement costs will not take place within its borders. Thus, linking results in a lower level of domestic political control over emissions reductions. For example, if a jurisdiction has ambitious long-term mitigation targets, linking can jeopardize the achievement of these targets in case the potential linking partner has less ambitious mitigation targets/lower abatement costs. This might be an argument against linking for some political parties with a strong position on domestic emissions reductions.

Operationalised Criteria: Acceptance of the ETS with stakeholders and the public

If the government has a strong level of support from the general public and key stakeholders for its domestic ETS and linking, this will make the linking process much easier. It may also allow it more flexibility in terms of the details of the final linked market design. However, if the government already has a low level of public support for their domestic ETS, linking may be difficult to implement unless the government can show substantial advantages would be derived from linking.

If linking undermines certain political compromises made in the initial design of the ETS, the level of support from stakeholder groups affected by linking, e.g. ETS sectors or consumers, is likely to drop. Conversely, depending on the final design, linking may also benefit certain stakeholders. Although the overall level of public support is also important, governments must ensure that they take key stakeholders into consideration as they can be a powerful force to drum up support for or opposition against the ETS.

2.5 Linking objective III: Reduce mitigation cost

(Economic) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Reduce mitigation costs	**Mitigation costs (short-term, static)**	Expected change [decrease] of carbon price (before and after Linking)	Relative abatement potentials and costs (difference between linked systems)

Rationale behind the objective**:** The jurisdiction wants to reduce the costs for mitigation in the country/in the system by linking, i.e. buy allowances from a system where mitigation is

[22] For instance, in Australia during the linking negotiations with the EU, the looming parliamentary election and the fact that the then Labor government was a minority government put the Australian ETS on relatively shaky ground. Furthermore, the opposition party also made the ETS a major focus of the national elections, campaigning for the abolition of the Carbon Pricing Mechanism.

cheaper due to differences regarding the abatement potential and costs.

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2.5.1 Assessment Criteria: Mitigation Costs

Main hypothesis:

According to economic theory, linked systems are more efficient than single markets by offering cheaper overall mitigation options to the system as a whole, at the least, in the short term (statically). The greater the difference in the carbon price, the greater the overall cost savings from linking. For achieving long term mitigation targets, the dynamic efficiency is more relevant (see objective II: Achieve long-term abatement targets). Because of the complexity and number of factors affecting dynamic efficiency, this study concentrates on the short term static mitigation cost aspect of a potential link.

Operationalised criteria: Expected change of carbon price

The overall average prevailing carbon price[23] of a system is a function of the cap and the marginal cost of abatement (price of various options and number of those options) in a given country. With a similar nominal level of cap ambition (in terms of similar percentage target from a given base year) or a similar scarcity compared to a Without-ETS-situation, a system with a large number of cheap abatement opportunities ("low hanging fruits") will have lower carbon prices. Conversely, a system with a limited number of cheap or much more expensive abatement opportunities will have higher carbon prices. If the marginal abatement costs in both systems are the same and the caps provide for similar scarcity (i.e. the carbon price level is the same), there will be no cost savings through linking. However, if marginal abatement costs differ, a linked carbon market will be more cost-efficient as emission reductions will take place where they are cheapest. Entities in the higher priced system purchase allowances from the cheaper system until the prices converge. This not only lowers the cost of compliance for entities in the previously higher priced system, but also increases costs in the previously lower cost system triggering more abatement there. At least in the short-term perspective, this reduces overall costs and increases cost efficiency for the same amount of abatement. However, the link causes a financial flow from the previously higher cost system to the previously lower priced system.

Assuming that marginal abatement costs are lower in developing countries, linking systems between a developed and developing country promises the largest (short-term) cost savings (Green et al., 2014).

To determine the cost savings of linking, the total abatement costs in two separate systems can be compared to the costs of the same reductions in the linked system. If the abatement costs in the linked market are lower, linking increases cost-efficiency, at least in a short-term, static perspective.

2.6 Linking Objective IV: Reduce competitive distortions

(Economic) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Reduce competitive distortions	**Competitiveness and Carbon Leakage risk in relation**	[High] trade exposure of ETS sectors	Trade intensity, importance of linking partner as trading partner or competi-

[23] Carbon price refers to the allowance price (not to other fiscal instruments such as a CO2 tax).

	to Linking Partner		tor
		[Significant] differences in free allocation methods	Other state measures influencing competition e.g. subsidies, access to finance
		[Significant] difference of carbon price level before linking	
		Expected net capital flows	
	Competitiveness and Carbon Leakage risk in relation to third countries	[High] trade exposure of ETS sectors	Trade intensity, importance of third countries as trading partner or competitor
		Expected relocation of production and investment (after linking)	
		Expected change of carbon price (before and after linking)	

Rationale behind the objective: The jurisdiction wants to reduce competitive distortions by linking with a potential partner where intensive trade between the ETS sectors and a risk of carbon leakage exist. Through a joint market a more even level-playing-field should be created.

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2.6.1 Assessment Criteria: Competitiveness and carbon leakage risks in relation to linking partner

Main Hypothesis

Competitiveness concerns arise regardless of whether the jurisdiction links or not (Tuerk et al., 2009; Sterk & Schüle, 2009). Linking could result in a new carbon price - higher for one and lower for the other partner. This may shift the positions with respect to competitiveness of the participants under the linked system. The new carbon price is likely to affect the manufacturing costs of business, which can either boost or reduce their competitiveness compared to the pre-linking situation. These concerns are particularly acute for energy-intensive, trade-exposed (EITE) sectors because of their high energy costs and dependence on international trade (Lanzi et al., 2013).

Linking can reduce competitiveness concerns within the linked market as both systems would be subject to an "even playing field" meaning the same carbon price (Jaffe & Stavins, 2007; Zetterberg, 2012; Haites, 2013). This reduces distortions due to different carbon prices above all the risk that businesses will shift their production to the jurisdiction with the lower pre-linking carbon price (carbon leakage risk in relation to linking partner). Not all companies will be equally affected in terms of their competitiveness. This will depend on various factors: the extent that the industry's products are traded between the linking jurisdictions; the greenhouse gas intensity[24] of the products; and the extent to which they can reduce their emissions (Parker & Blodgett, 2008). For energy-intensive sectors with products that are extensively traded with the linking partner's jurisdiction, the reduced risk of carbon leakage will be much more significant than for those sectors with lower levels of trade with the linking partner (or which trade with other jurisdictions).

Differences in (free) allocation approaches may also affect competitive positions of ETS sectors, e.g. if one of the linking partners has much more generous free allocation than the other one. However, under a common cap, there should be no risk that total emissions rise as a result of production relocations.

Competitiveness issues can also arise at the sectoral and firm level. Namely, a higher carbon price after linking will give low-emission businesses a competitive advantage (Reinaud, 2008)

Although linking may reduce the risk of carbon leakage within the joint carbon market, it may increase the risk of carbon leakage with third countries, especially if the carbon price rises as a result of linking. Thus, jurisdictions will probably consider the specific trade relations in emission-intensive sectors.

Operationalised Criteria: Trade exposure of ETS sectors

The extent to which companies actually compete with the producers from the linking jurisdiction in their home market and internationally, as well as the extent to which producers can pass through the carbon price to consumers will affect their competitive position. The greater the trade exposure of the ETS sectors between the linking jurisdictions, the more positive the effect of linking would be, as all ETS companies will face a common carbon price and competitive distortions would be reduced. At the same time, companies in the jurisdiction with a lower, pre-linking carbon price will be challenged with the higher carbon price. . Conversely, if the potential partners are competitors, linking would put both competitors on equal footing with regards to the carbon price. This would be more beneficial to the linking partner whose carbon price is reduced as a result of linking.

The importance of the potential linking partner as trading partner and/or competitor is therefore relevant for evaluating the impact of linking on competitiveness: if there is intensive trade between the ETS sectors of the linking partners, linking can reduce competitive distortions and help to create a more even level-playing-field. If there is more intensive trade or competition with third countries, the impact of linking on competitiveness is probably not significant.

Operationalised Criteria: Differences in allocation methods

Allocation methods can have a large impact on the extent to which various industries are actually exposed to a carbon price and to changes in the carbon price. More generous free allocation in one system can maintain competitive distortions between the potential linking partners. By examination or evaluation of the differences in (free) allocation methods prior to linking such a situation can be addressed proactively. It should be noted, though, that not only free allocation, but also tariffs, national subsidies and other state measures may influence the respective competitiveness situation.

Operationalised Criteria: Difference of carbon price level before linking

[24] The greater the greenhouse gas intensity of a product, the greater the effect of the carbon policy on businesses will be. Energy intensity is often used as a proxy for greenhouse gas intensity, taking also in consideration what energy sources are used for generation

The greater the difference between pre-linking carbon prices the larger the potentially existing competitive distortions in the ETS sectors (see also discussion on the effect of trade exposure above). A single (or at least very similar) price as a result of linking will therefore, reduce distortions in relation to the linking partner. If the systems had similar prices beforehand, linking will have little or no effect on the competitiveness or carbon leakage risk of related industries. On the other hand, an increase of the carbon price due to linking may increase the risk of companies' relocating their production outside the linked system.

Operationalised Criteria: Expected net capital flows

When systems link, participants in the system with an initially higher carbon price will purchase cheaper allowances from the other jurisdiction until prices equalise; as a result, the jurisdiction with an initially lower carbon price will see an increase in capital inflows. Depending on how allowances are allocated, this could make the jurisdiction more competitive as it has more capital to invest. This is also related to the total relative size of the two systems. Substantial capital outflows may raise objections from the net buyer of allowances as this means an outflow of capital which may have otherwise been available for domestic investments. If the jurisdiction with the initially lower carbon price is smaller compared to the partner with the higher price, the net financial flows are smaller (and therefore maybe more acceptable to the net buyer).

From a climate financing perspective, the outflow of capital may be evaluated as positive in case the capital flows are counted towards international climate financing commitments. Thus, there is a trade-off between competitiveness concerns associated with an outflow of capital and international carbon financing.

2.6.2 Assessment Criteria: Competitiveness and carbon leakage risk in relation to third countries

Main Hypothesis

Carbon leakage risk concerns may also arise with third (not linked) countries. Principally, there is a risk that businesses could relocate production and related emissions outside of the linked carbon market because of a higher carbon price (Ranson & Stavins, 2013). As a consequence, emissions in the jurisdictions affected by the carbon price decrease, but emissions in third countries rise. In case production in third countries is less efficient or more carbon-intensive, even total emissions may rise. After linking, the jurisdiction with the initially higher carbon price will become more competitive, as their carbon price will drop. But the jurisdiction with the initially lower carbon price may become less competitive, as their carbon price will increase (Tuerk et al., 2009; Hawkins & Jegou, 2014; Newell et al., 2014).

The actual impact on the competitiveness of domestic industries therefore depends to a large extend on the relative importance of the linking partner and third countries as trading partner and/or competitor. Therefore, the focus of the research should concentrate on the net effect, i.e. the reduced carbon leakage risk in relation to a linked system needs to be compared to a potential increased carbon leakage risk to non-linked systems.

The risk of carbon leakage must also be put in perspective. The carbon price is just one factor that affects production costs and for non-EITE sectors, energy costs make up a relatively small percentage of production costs (IEA, 2013). For investment decisions of EITE-sectors prices and availability of energy and raw materials as well as a favourable investment environment are more important than carbon costs (Droege 2013). The impact of a carbon price on competitiveness is also quite limited, with the Stern Review estimating a USD 30 carbon price in the UK would only increase consumer costs by 1% and less than 0.05% of industries would face a 5%

increase in production costs (Stern Review, 2006). Carbon leakage concerns can also be addressed by policy measures, e.g. free allocation of allowances.

Similar to measuring competitiveness and innovation, measuring carbon leakage is difficult as establishing a counter-factual scenario is problematic. However, there are a number of proxy indicators that can be used: trade exposure; the closure and/or relocation of covered emitters, as well as expected change in carbon price.

Operationalised Criteria: Trade exposure of ETS sectors

The risk of carbon leakage will vary depending on the trade intensity of the linked ETS sectors with third countries and the extent to which producers can pass through the carbon price to consumers. Sectors that can more easily pass on the additional cost to consumers will be less at a competitive disadvantage than those sectors that cannot pass on such costs. If the ETS sectors face little exposure to international competition with parties in third countries, the risk of carbon leakage is low.

Operationalised Criteria: Expected relocation of production and investment (to be assessed after linking)

The number of entities from ETS covered sectors that have closed down or relocated outside of the linked carbon market can be used as a proxy for carbon leakage. However, it is hard to determine whether the closure is due to the increase in the carbon price or as a result of other factors, such as demand shifts, as well as labour costs, concentration of skilled labour, corporate taxes, or resource costs. Furthermore, not all plants and factories are internationally mobile (Stern Review, 2006). Finally, as this can only be determined after a link has been concluded, this makes it unsuitable to use as a potential linking criteria.

Operationalised Criteria: Expected change of carbon price

A change in the carbon price has similar competitiveness and carbon leakage concerns in relation to third countries and jurisdictions as it does in relation to a linking partner. The jurisdiction with a previously lower carbon price will become exposed to a higher risk of carbon leakage and stronger competition with producers outside the linked system. Companies which faced higher carbon prices before linking will have their competitive position improved and have a stronger incentive to keep their production and investment in the linked system. The extent to which the carbon leakage risk will change with the linking depends therefore on the relative difference of the carbon prices before the link.

2.7 Linking objective V: Increase market stability

(Economic) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Increase market stability	**Market liquidity**	Number of market participants (before and after linking) relative to market size and number of trades	
		Carbon price stability (before Linking)	
		Availability and compatibility of safeguards against oversupply	

Rationale behind the objective: The jurisdiction wants to increase the stability of the market through linking since a larger market with more diverse participants is assumed to reduce the carbon price volatility and increase the market liquidity of the overall system. As a result, the market is expected to be less vulnerable to systematic risks and significant price fluctuations

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2.7.1 Assessment Criteria Market Liquidity

Main Hypothesis:

Linking creates a larger carbon market with more participants in sum. A larger market with more diverse participants is assumed to reduce the carbon price volatility, which is a reason why smaller markets with fewer participants may find linking attractive (Hawkins & Jegou, 2014). Additionally, a larger, more competitive market tends to reduce the market power of larger emitters and their ability to manipulate their market. For smaller markets, like Switzerland and New Zealand, access to a more liquid market was an important reason for pursuing linking. Also, Norway had a relatively small carbon market with few participants before the EEA-countries joined the EU ETS (Iceland, Liechtenstein and Norway). Linking to the EU allowed them to join a more liquid carbon market, more robust to manipulation.

Operationalised Criteria: Number of market participants relative to market size and number of trades

By creating a bigger carbon market with more market participants, the joint carbon market should increase the market liquidity of the overall system and therefore make it less vulnerable to systematic risks and significant price fluctuations. As more market participants enter the joint carbon market, trading activity is likely to increase, thereby increasing the expected trading volume and liquidity of the joint system. This will, however, also depend on the kind of players admitted to trade in the linked market (e.g. compliance companies, financial institutions etc.).

Operationalised Criteria: Carbon price stability (before Linking)

Normal price volatility is an indicator that the market is driven by demand and supply, as opposed to a strictly regulated market with a state-controlled carbon price. In theory, a more liquid, linked market can reduce daily or longer-term fluctuations in the carbon price. However, linking can also increase a system's vulnerability to systematic risk if it links with a larger system that experiences significant price fluctuations. In this case, the price volatility may be imported (Ranson & Stavins, 2014). If an ETS has experienced significant price fluctuations[25], like the EU ETS during the financial and Eurozone crisis, this may restrain a potential linking partner from linking. Exposure to currency shocks, like the 30% jump the Swiss franc experienced in January 2015 when the central bank abandoned its currency peg against the euro, may also caution against linking. This risk is particularly acute for the smaller linking partner, as conditions in the larger system are likely to dictate developments in the joint carbon market.

Operationalised Criteria: Availability and compatibility of safeguards against oversupply

Safeguards against oversupply of allowances or other measures to ensure a stable carbon price signal help increase the market stability in an emissions trading system. As discussed in section 5.1, many systems implemented measures to support market stability. Whereas most systems (e.g. RGGI, California/ Québec, Guangdong and South Korea) tend to have price-based instruments for supply control (e.g. minimum auction prices combined with a price containment reserve), the EU has decided to introduce a volume-based supply control mechanism, the so-called Market Stability Reserve. If these measures are compatible in terms of their design and political ambition of linking partners, they can improve stability of the linked market. Otherwise, availability of such measures might complicate linking negotiations.

2.8 Linking objective VI: Maintain / increase acceptance of ETS and linked market

(Political) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Maintain/increase acceptance of ETS and of linked market	**Domestic Support of ETS and Linking**	Relevance of changes to ETS Designs required for Linking	Compatibility of substantial design features (e.g. allocation methods, access to offsets, supply control instruments)
		Political, stakeholder and public support of estimated impacts of Linking (balance of "winners and losers")	
Rationale behind the objective: The jurisdiction wants to maintain or even increase domestic acceptance of ETS and of the carbon market by linking. Since there may not only "winners" but also "losers" as a consequence of linking, the linking negotiations need to be carried out in a way to ensure overall domestic stakeholder support which may be especially difficult in case important design elements need to be harmonized and thus renegotiated domestically.			

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2.8.1 Assessment Criteria: Domestic Support

Main Hypothesis:

Before linking, certain design features may have to be amended in one or both systems in order to create a functioning joint carbon market. However, these design elements may have resulted from hard-won political compromises in order to ensure domestic stakeholder support. If this consensus is called into question, the level of support for the ETS may wane. As linking can affect the level of domestic support for the ETS, governments have to carefully consider the implications of the final linking design on domestic stakeholders.

Operationalised Criteria: Relevance of changes of ETS design required for linking

If emissions trading systems are not developed as part of a common framework from the outset (such as in the Western Climate Initiative or the Swiss and the EU ETS), a jurisdiction can design its own approaches to emissions trading and may develop features that are not compatible with the design of a potential linking partner. The greater the difference in the design elements of systems the more challenging it will be for the jurisdictions to negotiate and sufficiently align their systems for linking. Some design elements, e.g. MRV, sector and gas coverage, point of regulation, may not require full harmonisation for linking. However, if certain elements differ significantly, adjustments may be necessary: for instance, a different cap nature and stringency, allocation methods, borrowing provisions, offset provisions or price control mechanisms need to be harmonized and might pose an obstacle for political agreement and domestic support for linking.

Operationalised Criteria: Political, stakeholder and public support of estimated impacts of linking

As with most policy interventions, there may be "winners" and "losers" as a consequence of linking. Stakeholders who will benefit from linking (financially or politically) will support the process, and those who would have to potentially bear certain losses, will oppose it. From a political economy point of view, net buyers in the system with a higher pre-linking carbon price (e.g. compliance entities who have to buy allowances) and net sellers in the system with a lower pre-linking price (e.g. governments auctioning allowances, compliance entities selling surplus free allowances) would likely support linking as they would be the main beneficiaries.

Therefore, governments must ensure that the interests of key stakeholders are considered as they can be a powerful force supporting or opposing the link.

In addition, a linked market means that a certain level of emission reductions of a jurisdiction with higher abatement costs will not take place within its borders. Thus, linking results in a lower level of domestic political control over emissions reductions. This might be an argument against linking for some political parties and civil society organizations with a strong focus on domestic emissions reductions.

2.9 Linking objective VII: Support global cooperation on climate change

(Political) Objective	Assessment Criteria	Operationalised Criteria	Influencing factors
Support global cooperation on climate change	**Signal for international climate policy**	Reliability as [ambitious] climate policy partner	
	Vehicle for international carbon finance	Expected net capital flows	Relative size of the system Relative abatement potentials and costs
Rationale behind the objective: The jurisdiction wants to support global cooperation on climate change by linking and expanding its climate protection efforts. Linking may encourage other jurisdictions to act on climate change themselves and can contribute to an regulatory environment that provides some safety for political and economic decisions.			

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2.9.1 Signal for international climate policy

Main Hypothesis:

Linking systems can send a strong political signal for climate action, highlighting the jurisdiction's commitment to climate change. Even if the main scope is a regional one like in the case of North America (California/Quebec), the approach can motivate other subnational jurisdictions to act on climate change themselves or push their governments to do so.

The linked California-Québec system has helped to showcase both actors as regional frontrunners in climate change and carbon pricing. Additionally, Ontario's recent announcement of a cap-and-trade program which it intends to link with California and Québec has also put pressure to consider greater action on other Canadian provinces and restart debates about climate policy in Canada. For the EU, linking its system would strengthen its position and legitimacy in international climate negotiations (Zetterberg, 2012). More specifically, linking can make emissions trading, or more generally, climate policy, more attractive for other jurisdictions by showcasing a collective, cost-effective means of tackling climate change. Theoretically, as linking can deliver significant cost savings by reducing emissions where it is cheapest, this could also encourage policymakers to adopt more ambitious mitigation targets.

Operationalised Criteria: Reliability as ambitious climate policy partner

If a jurisdiction is interested in linking as a means of supporting strong, international climate action, they may want to select a linking partner with an equally (if not more) ambitious and reliable climate policy. By linking with such partners, this can signal the jurisdiction's commitment to climate action to the international community. In addition, linking can signal a jurisdiction's commitment to emissions trading as a key climate instrument for mitigation. The reliability of potential linking partners in terms of their climate change policy may be assessed by the availability of long-term policy targets and commitments the domestic support of emissions trading and climate change action (discussed in section 5.2) and by their active participation in international partnerships and forums on carbon pricing, and other collaborative climate measures with different jurisdictions.

2.9.2 Vehicle for international carbon finance

Main Hypothesis:

International carbon finance can play a key role in supporting both the mitigation and adaptation projects for the transition to a low-carbon economy. Given the significant cost of such a transformation and the scarcity of direct government funding (especially in developing countries), leveraging the private sector can be a means of filling this funding gap. By implementing an ETS and creating a larger, linked carbon market with developing countries, this can be another way of directing private capital towards low-carbon investment in developing countries.

The larger the difference in the pre-link carbon prices, the larger the capital flow between jurisdictions after linking. This is also dependent on the overall comparative size of the two systems. A smaller system linking with a larger system will have less potential for capital flows than two large systems linking. Nevertheless, from the perspective of the smaller system, such changes in the net capital flow can be significant which may increase the interest in linking.

Operationalised Criteria: Net Capital Flows

The size and direction of capital flows between linked emissions trading systems are mainly determined by the relative size of the markets to be linked and by abatement potentials and cost. From a climate financing perspective, the outflow of capital may be evaluated as positive in case the capital flows can be counted towards international climate financing commitments. Thus, from the perspective of the buyer-country, there is a trade-off between competitiveness concerns associated with an outflow of capital and international carbon financing.

For many developing countries, developed countries are obliged to provide financial support and achieve ambitious reductions domestically at the same time. If financial resources are mobilized to finance mitigation activities in developing countries instead of developed countries, this may undermine the climate change mitigation architecture under the UNFCCC. Accordingly, clarification is needed how the financial transfers and emissions reductions achieved in a linked carbon market are counted towards the mitigation goals of the linking partners.

2.10 The relevance for further work on linking

This chapter has analysed the goals and priorities of ETSs that have pursued or discussed the issue of linking. The research has mainly considered the perspectives of both linking partners. Building on the key lessons drawn from the academic literature on ETS (see chapter 1), this paper has identified key assessment linking criteria, as well as hypotheses as to how they can influence the carbon market. Initial results show key criteria that can be categorised along three target dimensions: environmental, economic, and political. The environmental dimension is focusing on the two objectives to ensure environmental integrity of the market and to support the achievement of long-term abatement targets. The economic dimension aims at reducing mitigation cost and competitive distortions and to increase market stability and liquidity. From a political perspective, the linking of carbon markets can help to maintain or even increase the acceptance of emissions trading. In addition, the linking of markets can help to support global cooperation on climate change.

The examination of objectives and related linking criteria has also raised the possibility of conflicting goals. For instance, linking a high priced system with a very low priced system may result in significant cost savings through the carbon market by opening up a wider (and cheaper) range of abatement options. However, if the higher priced system is interested in a certain level of domestic abatement (and related low-carbon technology development or deployment) or encouraging strong, coordinated climate action, they may choose a partner with a carbon price and climate targets more closely aligned with their own. This would reduce the potential (short-term) cost savings, but more likely would help to achieve (domestic) long-term mitigation and decarbonisation targets.

In addition, proposals for the operationalization of these criteria were presented. These variables can help to quantify or qualitatively assess potential linking outcomes with regard to the objectives. However, some criteria may prove difficult to measure and isolate due to a very complex causal effect chain for which a number of influencing factors need to be taken into consideration. The ex-ante assessment of the possible impact of linking on some criteria may be difficult and prone to uncertainty. Hence, criteria need to be further refined and defined in a way that they can be clearly measured – either quantifiably or qualitatively. Criteria must also be weighed, especially when there are conflicting objectives. This is a complex, political task, where individual preferences and interests play a major role. The proposed list of variables can provide the basis for policymakers to develop a better understanding of which criteria best reflect their policy preferences and goals when considering a potential linking partner. This process also requires that t relative importance of one criteria vis-à-vis others needs to be assessed.

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3 Economic Assessment Criteria for ETS direct linking – Towards a quantification of effects

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3.1 Outline of this chapter

The objective of this report is to point to potential approaches that in future enable a criteria-based ex-ante quantitative (“pre-linking”) analysis of the effects of a direct linking of two individual ETS. By definition, there exist no empirical data for a quantitative assessment of effects ex-ante. Therefore, historical empirical data and, where economic interdependencies between the different influencing factors are more complex, economic modelling are required for an ex-ante assessment of effects. However, the target of this report is not to develop one single economic model to quantify these effects. Instead, with the target to prepare for a comprehensive assessment of linking, central economic variables affected by and affecting linking are first described with respect to the assessment criteria (chapter 2). In addition, the landscape of (European) models covering these operationalised assessment criteria is analysed and strengths and weaknesses of different modelling approaches with regard to criteria and regional coverage are identified.

Work package 3 of this project consists of three analytical steps. Step 1 identifies the inventory of relevant economic assessment indicators (termed “operationalised assessment criteria[26]”) based on the economic assessment criteria of work package 2. The economic objectives associated with the assessment criteria are „static efficiency/ reduction of mitigation cost“, „reduction of competitive distortions“ and „increase of market stability/market liquidity“. Step 2 identifies interdependencies (direct and indirect effects) between the economic assessment criteria and determines the effects that linking of ETS might have on these. Step 3 describes existing economic models as well as their applicability, i.e. their potential to integrate the identified indicators when assessing the effects of linking two ETS.

In discussions of preliminary drafts of work package 3, two additional issues arose: First the question whether dynamic efficiency, which relates broadly to the question how a change in the permit price affects different (in terms of structure and stage of development) economies, should and could be *operationalised* as an additional criterion. Second, the question whether marginal abatement cost curves (MACCs), which determine to large extend the permit price, have to be considered *explicitly in modelling*. This relates to the question whether changes in differences in permit price levels are sufficient to determine linking effects. Both questions are discussed in additional separate subchapters of this report and results are integrated into other chapters and conclusions where appropriate.

As a result, work package 3 delivers an overview of identified economic models most appropriate to assess the effects of linking the European ETS with other ETS. As the concrete adaptation of such economic models is beyond the scope of this research, it might be commissioned in future research projects. The selection and recommendation which economic models are best suited for such an adaptation depends strongly on the political priorities regarding regional cov-

[26] In publications following this research project, however, the term „operationalised assessment criteria“ might be difficult to understand without the context of the research project and especially, without knowing the analysis in work package 2. Therefore, in these publications the common term „indicator“ have been used.

erage, the choice of most relevant assessment criteria and prioritised operationalised economic assessment criteria (endogenous/exogenous). Hence, work package 3 provides an orientation on the existing model landscape suitable for assessing the impacts of linking in principle, and on the scope and magnitude of the necessary model modifications. We understand this as a significant step towards a quantification of effects of direct linking of ETS.

Hence, this chapter is organised as follows: Section 2 identifies the operationalised assessment criteria and describes their linking-related interdependencies. Section 3 provides an overview of existing economic models (model families, modelling approaches and model types). More details on the examined models can be found in the Annex. Section 4 identifies the requirements to adapt models to the ETS linking objective. Section 5 evaluates the models according to the coverage of assessment criteria and the coverage of regions in different existing economic models. Section 6 discusses the role of marginal abatement cost curves for the assessment of linking effects. Section 7 presents findings on the potential to assess dynamic efficiency of linking and section 8 concludes.

3.2 Economic Linking Objectives: Economic assessment criteria and indicators for estimating the effects of linking

Work package 2 identified environmental, economic and political objectives with corresponding assessment criteria for the analysis of the effects of direct linking of ETS. The three economic objectives analysed here are:

- static efficiency/ reduction of mitigation cost,
- reduction of competitive distortions and
- increase of market stability/market liquidity.

In order to enable for a quantification of these objectives, the assessment criteria for each objective from WP2 are first operationalised. In a second step, the interdependencies of the selected economic assessment criteria are analysed in order to give an overview and to make the complexity of the effects visible.

3.2.1 Economic objectives, the associated assessment criteria and formulas for quantification

In search for a reasonable assessment of the effects of linking, Chapter 2 selected main economic objectives and outlined the nexus between the economic objectives and the potential assessment criteria. The economic objectives cover a broad range of aspects and are usually not directly observable. Therefore, WP2 identified appropriate assessment criteria for evaluating the impact of linking on economic objectives. For measuring the assessment criteria, they need to be operationalised, i.e. a measurable proxy for the criterion has to be defined, which is the subject of this section. The correlations between assessing the effects of linking, the selected objectives and the identified assessment criteria are explained in detail in Chapter 2. The way how the proxy is then measured depends on the available data for quantification. Sometimes, the value is directly observable in empirical quantitative and qualitative data, sometimes this is not possible and it has to be modelled. Where empirical quantitative data and output from economic modelling are an option, the question of interest decides about which data to use. When the situation at the point in time pre-linking should be used for the assessment, empirical quantitative data should be used. When a linking-induced change is of interest, economic modelling needs to be used since it provides output regarding the ex-post state of the economies.

When data for the measure itself is not readily available, it might be necessary to compute the value with a pre-defined formula. Table 7 provides an overview over the economic objectives, associated assessment criteria, operationalised criteria and the corresponding proposed formulae for their quantification as well as remarks on data availability.

As a result, twelve operationalised criteria have been identified of which six can only be quantified by economic modelling. For four operationalised criteria, empirical quantitative data are available and for two operationalised criteria only empirical qualitative data are available.

The potential quantification of each operationalised assessment criterion will be explained subsequently. There will be no further explanation of why which assessment criterion and which operationalised criterion are suitable for evaluating the impact of a link on certain economic objectives, since this has been part of Chapter 2.

In the description following the tabular overview, (operationalised) assessment criteria that are also included in the analysis of interdependencies, see chapter 2.2, appear in bold and red font.

Table 7: Economic objectives, assessment criteria, operationalised criteria (indicators), formula for quantification & first overview of data availability

Objective	Assessment Criteria	Operationalised Criteria (Indicator)	Quantification
Economic objectives			
3. Static efficiency/ Reduce mitigation costs	**3. Mitigation costs in ETS-sectors (short-term, static)**	3.1 Expected change [decrease] of permit price (before and after linking)	Economic Modelling: $\Delta CP_i = CP_{linked} - CP_r$
		3.2 Expected change [increase] in economy-wide production (GDP) (before and after linking)[27]	Economic Modelling: $\Delta GDP_r = GDP_{r,linked} - GDP_r$

[27] This report focuses on mitigation costs for the ETS-sectors. However, the expected change in economy-wide production has been added to the operationalised assessment criteria from AP2 for two main reasons: First, linking-induced changes in the production of the non-ETS sectors, i.e. due to changes in the competitiveness of ETS-sectors in relation to non-ETS-sectors, due to changes in the prices of intermediate products or due to changes in demand for certain products, might have a serious effect on the mitigation costs for ETS sectors. Second, changes in the production of the entire economy and the non-ETS sectors might have large effects on the overall structure of the economy, the amount of available economically reasonable abatement options and hence the MACC, which in turn influences the permit price. These two interdependencies between the non-ETS sectors and the ETS-sectors are better reflected in changes in the economy-wide production than solely in changes of ETS-sectors' production. Overall, the effects of linking on the ETS-sectors are considered explicitly in objective 4. If still required, an additional operationalised assessment criterion regarding the change in production of ETS-sectors could be added to objective 3. Such a criterion would be analogous to the assessment criterion 4b.2 with the corresponding operationalised assessment criterion 4b.2i.

4. Reduce competitive distortions	**4a Competitiveness and Carbon Leakage risk in relation to Linking Partner**	4a.1 [High] trade exposure of ETS sectors in relation to linking partner	Empirical quantitative data for domestic ETS sectors in relation to partner ETS sectors: $TE(rel.to\ partner)_{i,r} = \frac{EX(to\ partner)_{i,r}}{GVA_{i,r}}$ *Main Databases: GTAP (v.9: 1160-5940, v.7 and older: free access), EXIPOL (free access), UN Comtrade (free access)* *Further databases with industry- or regional focus: Eurostat Structural Business Statistics (free access); Eurostat External Trade Data (free access), AMECO (free access), UN Industrial Commodities Statistics (paid access, cf. http://unstats.un.org/unsd/industry/publications.asp)* Alternatively: Economic modelling for future expected trade exposure ETS sectors after linking
		4a.2 [Significant] differences in free allocation methods	Empirical qualitative data
		4a.3 [Significant] difference of permit price level before linking	Empirical quantitative data *Databases global coverage: Thompson Reuters/Point Carbon EIKON (Covers global carbon markets: EU-ETS, US markets (WCI and RGGI), China, South Korea, New Zealand and other emerging carbon market as well as CDM and other offset markets, paid access), Bloomberg New Energy Finance Carbon Market Analysis (paid access)* *Databases regional coverage: EEX (EU-ETS, paid access), California Carbon Dashboard (California ETS, free access), www.szets.com, www.cbeex.com.cn, www.cneeex.com, www.cnemission.com, www.chinatcx.com.cn/tcxweb/, www.hbets.cn, http://222.178.87.205/index.html (Chinese regional markets)* *Data from private market analysts and carbon traders: Argus (paid access), ICIS (paid access), Climate Connect (paid access), Intercontinental Exchange ICE (paid access)* *No data from ETS that do not exist to date (Mexico, Turkey, country-level China)* *Issue with data from China (and to smaller extend from other ETS): no data on exchange market-distorting OTC-trading*
		4a.4 Expected net capital	Economic Modelling:

		flows (from seller to buyer)	$NCF = (CAP_s - E_{s,linked}) * CP_{linked} = (E_{b,linked} - CAP_b) * CP_{linked}$
	4b Competitiveness and Carbon Leakage risk in relation to third countries	4b.1 [High] trade exposure of ETS sectors in relation to similar sectors in all third countries together	Empirical quantitative data: $$TE_{i,r} = \frac{EX_{i,r}}{GVA_{i,r}}$$ *Main Databases: GTAP (v.9: 1160-5940, v.7 and older: free access), EXIPOL (free access), UN Comtrade (free access)* *Further databases with industry- or regional focus: Eurostat Structural Business Statistics (free access); Eurostat External Trade Data (free access), AMECO (free access), UN Industrial Commodities Statistics (paid access, cf. http://unstats.un.org/unsd/industry/publications.asp)* Alternatively: Economic modelling for future expected trade exposure
		4b.2 Expected relocation of production and investment (after linking)	Economic modelling: i) Change in production by sector and region, relative to change in production by sector in third countries (= Rest of the World ROW) $$\frac{\Delta GVA_{i,r}}{\Delta GVA_{i,ROW}} = \frac{GVA_{i,r,linked} - GVA_{i,r}}{GVA_{i,ROW,linked} - GVA_{i,ROW}}$$ ii) Change in economy-wide production by region, relative to change in production in third countries (ROW) $$\frac{\Delta GDP_r}{\Delta GDP_{ROW}} = \frac{GDP_{r,linked} - GDP_r}{GDP_{ROW,linked} - GDP_{ROW}}$$ iii) Change in investment by sector and region, relative to change in investment by sector in third countries (ROW) $$\frac{\Delta I_{i,r}}{\Delta I_{i,ROW}} = \frac{I_{i,r,linked} - I_{i,r}}{I_{i,ROW,linked} - I_{i,ROW}}$$
		4b.3 Expected change of permit price (before and after linking)	Economic Modelling: $$\Delta CP_i = CP_{linked} - CP_r$$
5. Increase market stability	**5. Market liquidity and market stability**	5.1 Number of market participants (before and after linking) relative to market size and number of	Economic Modelling Second-best Alternative: empirical quantitative data *Databases global coverage: Carbon Market Data (paid access), Thompson Reuters/Point Carbon EIKON (Covers global carbon markets: EU-ETS, US*

		trades	*markets (WCI and RGGI), China, South Korea, New Zealand and other emerging carbon market as well as CDM and other offset markets, paid access), Bloomberg New Energy Finance Carbon Market Analysis (paid access)* *Databases regional coverage: EUTL Dataset Project (EU ETS Phase I, free access)*
		5.2 Permit price stability (before linking)	Empirical quantitative data *Database global coverage: Thompson Reuters/Point Carbon EIKON (Covers global carbon markets: EU-ETS, US markets (WCI and RGGI), China, South Korea, New Zealand and other emerging carbon market as well as CDM and other offset markets, paid access), Bloomberg New Energy Finance Carbon Market Analysis (paid access)* *Databases regional coverage: EEX (EU-ETS, paid access), California Carbon Dashboard (California ETS, free access), www.szets.com, www.cbeex.com.cn, www.cneeex.com, www.cnemission.com, www.chinatcx.com.cn/tcxweb/, www.hbets.cn, http://222.178.87.205/index.html (Chinese regional markets)* *Data from private market analysts and carbon traders: Argus (paid access), ICIS (paid access), Climate Connect (paid access), Intercontinental Exchange ICE (paid access)* *No data from ETS that do not exist to date (Mexico, Turkey, country-level China)* *Issue with data from China (and to smaller extend from other ETS): no data on exchange market-distorting OTC-trading*
		5.3 Availability and compatibility of safeguards against oversupply	Empirical qualitative data

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Variables:

$Region\ r \in R\ (all\ regions\ in\ the\ model)$

$ROW = Rest\ of\ the\ World\ (third\ countries)$

$CP_r\ Permit\ price\ in\ region\ r\ before\ linking$

$CP_{linked}\ Permit\ price\ in\ both\ linked\ regions\ after\ linking$

$TE_{i,r} = Trade\ Exposure\ of\ sector\ i\ in\ region\ r$

$EX_{i,r} = Exports\ of\ sector\ i\ in\ region\ r$

$GVA_{i,r} = Gross\ Value\ Added\ of\ sector\ i\ in\ region\ r\ before\ linking$

$GVA_{i,r,linked} = Gross\ Value\ Added\ of\ sector\ i\ in\ region\ r\ after\ linking$

$GDP_r = Gross\ Domestic\ Product\ in\ region\ r\ before\ linking$

$GDP_{r,linked} = Gross\ Domestic\ Product\ in\ region\ r\ after\ linking$

$I_{i,r} = Investments\ of\ sector\ i\ in\ region\ r\ before\ linking$

$I_{i,r,linked} = Investments\ of\ sector\ i\ in\ region\ r\ after\ linking$

$NCF = Net\ Capital\ Flows\ from\ seller\ s\ to\ buyer\ b$

$E_{s,linked} = Emissions\ of\ ETS - sectors\ i\ in\ seller\ s\ after\ linking$

$CAP_s = Emission\ cap\ for\ ETS - sectors\ in\ seller\ s\ (same\ before\ and\ after\ linking)$

$E_{b,linked} = Emissions\ of\ ETS - sectors\ i\ in\ buyer\ b\ after\ linking$

$CAP_b = Emission\ cap\ for\ ETS - sectors\ in\ buyer\ b\ (same\ before\ and\ after\ linking)$

Economic objective: Static efficiency/ Reduce mitigation costs

There are two operationalised assessment criteria to evaluate the impact of a link on static efficiency/ reducing mitigation costs (economic objective 3 and assessment criterion 3).

The **expected change of the permit price (price before linking compared to expected price after linking)** ΔCP_i (operationalised criterion 3.1) will be calculated with data gathered by economic modelling. The empirically observable or modelled carbon price in a region r before linking (CP_r) will be subtracted from the modelled joint carbon price in the linked permit market (CP_{linked}). Although there might be empirical data for the carbon price in a region before linking, it is preferable to use the modelled carbon price before linking.[28] The change and not the absolute value is important. Since the carbon price in the linked market has to be estimated in models, it makes more sense to estimate as well the carbon price before linking and use this to calculate the change. Because of the fact that estimated carbon prices might deviate from the real carbon prices, results about the change are likely more consistent with real changes when using the estimated values for both carbon prices, before and after linking, instead of one empirical value and one modelled estimate.

Due to the complex interdependencies between the ETS-sectors and the non-ETS sectors' production (see Footnote 27), the **expected change in economy-wide production (GDP) (before and after linking**) ΔGDP_r (operationalised criterion 3.2) is added in addition to the assessment criteria from AP2. It will be calculated with data from economic modelling, too. The regional GDP before linking (GDP_r) will be subtracted from the regional GDP after linking ($GDP_{r,linked}$).

Economic objective: Reduce competitive distortions

The economic objective to reduce competitive distortions (objective 4) is divided into two distinct assessment criteria, relating to the linking partner (assessment criterion 4a) and to the rest of the world (assessment criterion 4b).

There are four operationalised criteria for the assessment criterion "Competitiveness and Carbon Leakage risk in relation to Linking Partner" (assessment criterion 4a).

Trade exposure of ETS sectors in relation to the linking partner $TE(rel.to\ partner)_{i,r}$ (operationalised criterion 4a.1) can be quantified by either using empirical data or economic modelling. The trade exposure of a certain sector i in region r to the partner is the share of exports from the region to the partner ($EX(to\ partner)_{i,r}$) in total production of sector i in region r, measured in terms of gross value added ($GVA_{i,r}$). The imports from partner to home are not considered in this calculation, since for domestic jobs, only the share of exports in total production is important. When imports were included, they would increase the trade exposure. However, on the one hand, imports from partner that are a necessary input for domestic production in a certain sector (complements) might even increase GVA and hence provide an opportunity for more domestic jobs. On the other hand, imports that are substitutes to domestic production de-

[28] Using modelling to answer the present question hinges on general trust that models have realistic assumptions in key parameters and provide realistic results, and on qualitative deliberations about to the impact of economic shocks. On the one hand, general, a modelled permit price that is close to the observed permit price indicates a good model fit. Yet, such corresponding prices might be as well the product of coincidence, i.e. when a variety of unrealistic assumptions lead by coincidence still to the observed permit price. On the other hand, the modelled permit price might deviate significantly from the observed permit price. Still, this does not necessarily mean that the model provides unrealistic results. The model might be perfectly well fitted, yet since optimisation models cannot account for unforeseen economic shocks, an observed permit price in an economy that just has been hit by an economic shock differs quite likely from the modelled permit price.

crease the GVA and hence might cause job losses. Therefore, implicitly accounting for the complexity of imports as substitutes vs. inputs as complements via the GVA in the denominator should be appropriate for this figure. As an alternative to using empirical data, estimates from economic modelling for the *expected future* trade exposure of the ETS sectors after linking can be used.

A **significant difference in free allocation methods** (operationalised criterion 4a.2) can be observed in qualitative empirical data for allocation methods before linking. Qualitative reasoning about the changes in the differences in free allocation methods with linking should provide an idea about the situation after linking. The larger the share of sectoral free allocation, relative to the partner ETS-secor, the larger the potential competitive advantage of the respective ETS-sector towards the corresponding partner ETS-sector.

A **significant difference of the permit price level before linking** between the linking partners (operationalised criterion 4a.3) can be identified by using empirical data for regional permit prices before linking from home and partner. The difference can be obtained by subtracting the partner permit price before linking from the home permit price before linking, or vice-versa.

The **expected net capital flows (from buyer to seller)** NCF (operationalised criterion 4a.4) have to be calculated with estimates from economic modelling, via two equivalent ways. Either one subtracts the real emissions after linking in the seller region s ($E_{s,linked}$) from the cap in the seller region s (CAP_s) to obtain the amount of permits that are unused and could be sold, and multiplies this amount by the linked permit price (CP_{linked}), to obtain the capital value and hence the capital flow of the permits being traded between the regions. Alternatively, one uses data from the buying region b, and calculates the capital flows by first subtracting the buyer's regional cap (CAP_b) from the buyers' real emissions after linking ($E_{b,linked}$) to obtain the amount of permits demanded by the buyer, and then multiplying the resulting number again with the linked permit price (CP_{linked}). Obviously, both approaches rely on the market clearing condition to be useful.

The rest of the world-related assessment criterion for the economic objective 4, "Competitiveness and Carbon Leakage risk in relation to third countries" (assessment criterion 4b) will be evaluated by aid of three different operationalised criteria.

A **high trade exposure of ETS sectors in relation to similar sectors in all third countries together** $TE_{i,r}$ (operationalised criterion 4b.1) can be calculated with empirical quantitative data. The calculation is similar to how it is conducted for trade exposure in relation to the partner, only with data for all third countries, hence it will not be repeated here. Again, as an alternative to using empirical data, estimates from economic modelling for the *expected future* trade exposure of the ETS sectors after linking can be used.

The **expected relocation of production and investment (after linking)** (operationalised assessment criterion 4b.2) has to be calculated by three different ways, since the criterion covers production and investments for sectors and the entire economy. All variants rely on data from economic modelling. First, the change in sectoral production in home (region r), relative to the change in production by sector in third countries (ROW) ($\frac{\Delta GVA_{i,r}}{\Delta GVA_{i,ROW}}$), can be calculated by subtracting the sectoral gross value added in home (region r) before linking ($GVA_{i,r}$) from the sectoral gross value added in home after linking ($GVA_{i,r,linked}$) for the nominator. The same approach holds for calculating the denominator, just with data for the rest of the world instead of home ($GVA_{i,ROW,linked} - GVA_{i,ROW}$). Second, the change in overall production in home (region r), relative to the change in production in third countries ($\frac{\Delta GDP_r}{\Delta GDP_{ROW}}$) will be calculated by subtracting the GDP in home before linking (GDP_r) from the GDP in home after linking ($GDP_{r,linked}$) for the nominator. Again, for calculating the nominator, the same principle applies, just with data for the rest of the world instead of home ($GDP_{ROW,linked} - GDP_{ROW}$). Third, to calculate changes of investment by sector and region, relative to change in investment by sector in third countries ($\frac{\Delta I_{i,r}}{\Delta I_{i,ROW}}$), the investments by sector in home before linking ($I_{i,r}$) are subtracted from the investments by sector in home after linking ($I_{i,r,linked}$) for the nominator. For the denominator, as before, the same principle holds like for the nominator, just with data for the rest of the world ($I_{i,ROW,linked} - I_{i,ROW}$).

The **expected change of the permit price (before and after linking)** ΔCP_i (operationalised criterion 4b.3) is calculated exactly the same way like operationalised criterion 3.1.

Economic objective: Increase market stability

The assessment criterion for the economic objective 5, increase market stability, is **market liquidity** (assessment criterion 5). Three operationalised criteria were identified for the assessment criterion.

The number of market participants (before and after linking) relative to market size and number of trades (operationalised criterion 5.1) has to be determined by aid of empirical data (number of market participants before linking) and with economic modelling (number of market participants after linking). In economic modelling, is no formula to obtain a value for this criterion, since it very much depends on the modelling approaches whether at all, and if so, how they provide estimates for this operationalised criterion.

The permit price stability (before linking) (operationalised criterion 5.2) can be evaluated by using empirical quantitative data, the availability and compatibility of safeguards against oversupply (operationalised criterion 5.3) with empirical qualitative data.

3.2.2 Interdependence of the selected economic assessment criteria

The selected operationalised economic assessment criteria (in red and bold font in the following description and in Figure 7 are interdependent and directly related to several other economic variables (in grey and bold font in the description and in Figure 7. Further economic, political or other variables might influence the relationships between the economic variables and the assessment criteria (in grey and normal font, with dashed frame in Figure 7).

Figure 7 shows these interdependencies graphically. As commonly used in economic equations, the upper-case delta ("Δ") means "change".

Linking ETS first of all leads to changes of the permit price (**3.1/4b.3 (Δ) Permit price**). The permit price is often used as a proxy to determine firms' costs of compliance with the (linked) ETS. The compliance costs result from using (opportunity costs of not selling), buying (permit costs) or selling/not buying (abatement costs) the permits.

There are some assessment criteria, which affect the level and direction of change of the permit price after linking, and there are some assessment criteria, on which changes of the permit price have an effect. The following sections will first describe the most important variables and operationalised assessment criteria that have an impact on the permit price level, and afterwards describe the relationship between the permit price level and other most important variables and operationalised assessment criteria.

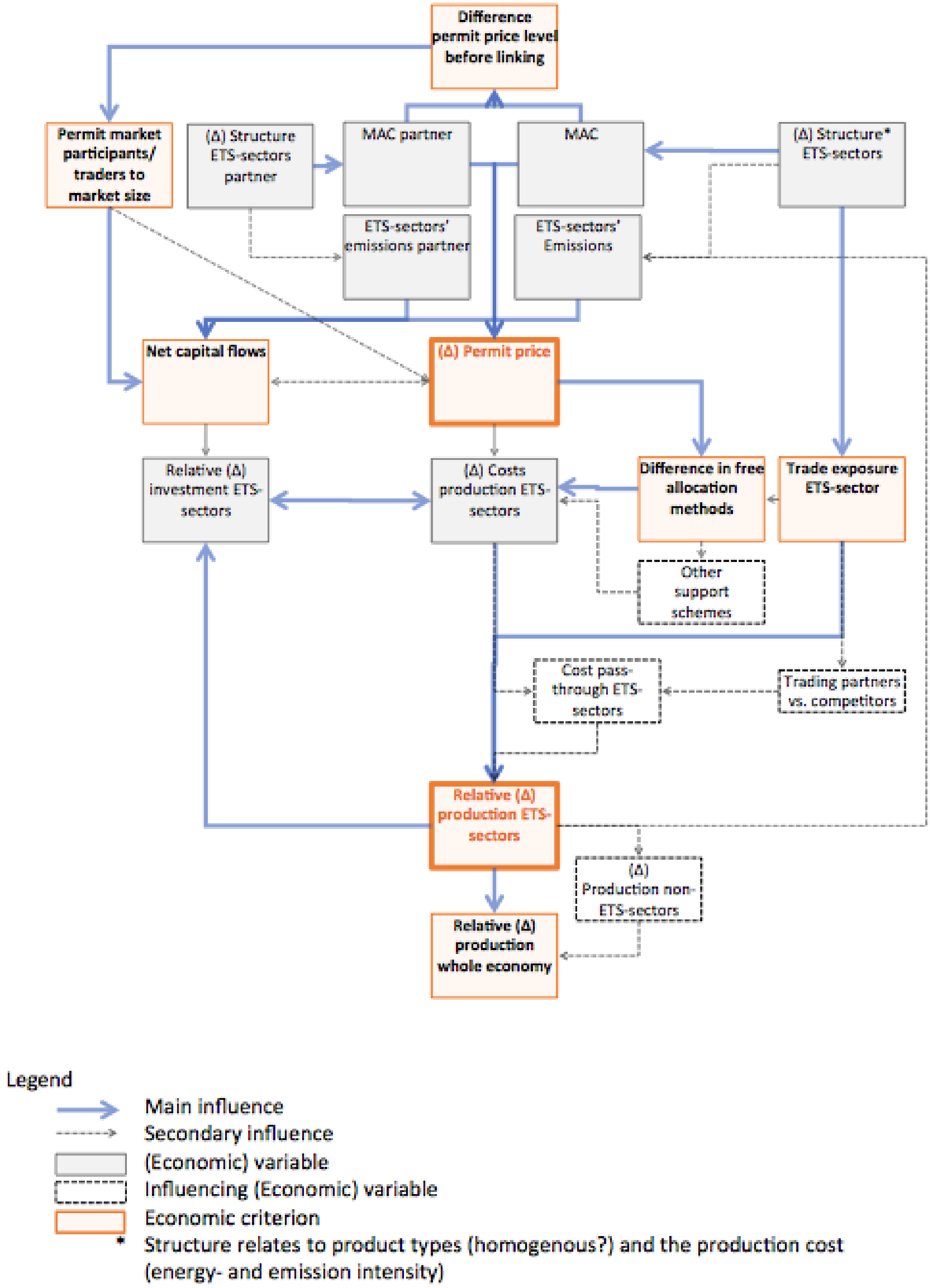
Most important variables and operationalised assessment criteria that affect the permit price

An important factor that determines the level of the permit price is the structure of the regional economy, especially of the ETS-covered sectors (**(Δ) Structure ETS-sectors** and **(Δ) Structure ETS-sectors partner**)[29]. The more carbon-intensive the production in the ETS-sectors, the higher is, ceteris paribus, the permit price, since the ETS-sectors' marginal abatement costs for different emission caps are higher for carbon-intensive firms (**MAC** and **MAC partner**).

The marginal abatement costs are assumed to increase with the level of emission abatement, which can be seen in the marginal abatement cost curve (MACC). Carbon-intensive ETS-sectors tend to have a relatively higher MACC. Yet, it needs to be differentiated between the relative position of the MACC and the actual MAC for a sector or firm. A very carbon-intensive, yet very energy inefficient firm might have relatively lower actual MAC than a firm with few carbon needs for production, which however produces already at a very efficient level of carbon consumption. This effect occurs due to "low hanging fruits", i.e. that the first investments in emission abatement tend to be cheaper than the following investments. Especially efficiency improvements tend to pay for themselves after a relatively short period of time. However, for the specific level of the equilibrium permit price, the MAC are relevant. Using a market-based instrument like an ETS yields, in equilibrium under perfectly functioning markets, to an equalisation of the MAC of ETS-firms. Ceteris paribus, the regional permit price will correspond to the marginal abatement costs for the specific ETS-wide level of the emission cap, because firms would otherwise still have potential for cost savings.

[29] The economic structure in this context relates primarily to the carbon intensity of the economy. The carbon intensity is mainly determined by the overall sectoral composition (many energy-intensive industries?), the technology-based emission intensity of the individual sectors' production processes (do the sectors use very carbon-efficient best available technologies or does the production rely on a rather old capital stock?) and the utilised energy mix (relatively large share of renewable energies for all ETS-sectors together and in the individual ETS-sectors?).

Figure 6: Interdependence of economic assessment criteria



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Based on the above line of argument, the difference in the pre-linking permit price between both regions (**4a.3 Difference permit price level before linking**) is positively related to the difference of the MAC (MAC and MAC partner). It is further positively related to the difference in the regional level of abatement ambition (Pre-linking cap and Partner pre-linking cap), which is a politically chosen variable.

After Linking, the country with the relatively higher MAC will face a decrease in the permit price, and the country with the relatively lower MAC will face an increase in the permit price (**3.1/4b.3 (Δ) Permit price**). Hence, the MAC in both regions at the post-linking cap (**MAC** and **MAC partner**) are the most important determinants of the change of the permit price for each region.

Yet, MAC and MAC partner are only the most important determinants for changes in the permit price after linking under the assumption of perfectly functioning markets. Yet, with market distortions, i.e. when the markets are not liquid or suffer from an oligopolistic structure, the post-linking permit price might be different. Further, barriers to capital flows might hinder arbitrage movements. Hence, the number of participants in the permit market and the number of trades relative to the permit market size (**5.1 # Permit market participants/ trade to market size**), as well as the net capital flows (**4a.4 Net capital flows**) have an impact on the permit price, too. The level of the permit prices is affected by the MAC, but the change in the level of the permit price due to linking is, besides the difference in MAC between the partners, as well determined by net capital flows (**3.1/4b.3 (Δ) Permit price**). Where there exist only few capital flows, i.e. due to market barriers or financial risk, there is likely not enough financial arbitrage movements. This means that the linked prices in both countries might not equalise, and the change in price for each individual ETS is lower than with full arbitrage movements. With more market participants and more trades to market size, the permit market should be more liquid, and capital flows should be larger, which leads in theory and all else equal, to a more stable and potentially lower permit price. Yet, the positive impact of the number of permit market participants and trade relative to markets size and net capital flows is not necessarily very strong, as indicated by the dashed line. First, many market participants does not necessarily mean that trade large sums are traded, which means that net capital flows might be small albeit there are many market participants. Second, few (large) market participants could trade large amounts of permits, which yields large net capital flows.

At this point, the interdependence between different operationalised assessment criteria becomes very clear. The number of trades relative to the permit market size (**5.1 # Permit market participants/ trade to market size**) determines, together with the ETS sectors' real emissions in each region (**ETS-sectors' emissions** and **ETS-sectors' emissions partner**) the net capital flows between the linked ETS (**4a.4 Net capital flows**). The higher the real emissions in one region, and the more trades between the regions, the more capital likely flows out of the region to the low-real-emission-region.

The ETS-sectors' real emissions (**ETS-sectors' emissions** and **ETS-sectors' emissions partner**) in turn are determined as well by the economic structure of the regions' ETS-sectors (**(Δ) Structure ETS-sectors** and **(Δ) Structure ETS-sectors partner**). The more carbon-intensive the production in the ETS-sectors, the higher are real emissions.

Most important variables and operationalised assessment criteria that are affected by the permit price

The permit price is part of the ETS-firms' production cost function. Ceteris paribus, when the permit price increases (**3.1/4b.3 (Δ) Permit price**), the production costs increase (**(Δ) Costs production ETS-sectors**). This might have several implications for the firms' production and competitiveness.

In the short-run, changes in the production costs have an impact on the production of the ETS-sectors. Depending on the degree to which a production costs increase (**(Δ) Costs production**

ETS-sectors) is passed-through to the consumer (Cost pass-through ETS-sectors), the relative production of ETS-sectors, compared to the partner and the rest of the world, decreases due to a loss in market shares with the worsening of the price-competitiveness (**4b.2i Relative (Δ) production ETS-sectors**). Vice-versa, the ETS-sectors in the pre-linking high-permit-price-country experiencing a permit price decrease, might end-up with an improvement of their competitiveness relative to the linking partner.

The relative changes in production (**4b.2i Relative (Δ) production ETS-sectors**) are further directly affected by the trade exposure of the ETS-sectors (**4a.1/4b.1 Trade exposure ETS-sectors**), which in turn is determined by the structure of the economy (**(Δ)Structure ETS-sectors**). Depending on the type of products, a very export-oriented firm might face a strong price-competition in international markets. Without additional measures, the export-oriented firm might, when it is carbon-intensive, lose some market shares and hence reduce its production. Yet, trade exposure is mediated again by the degree to which costs can be passed-through to the end-consumer (Cost pass-through ETS-sectors), and whether the other country is a trading partner or a competitor for the respective sector (Trading partner vs. competitor).

The production of the ETS-sectors has an impact on the changes in the structure of the ETS-sectors (**(Δ)Structure ETS-sectors**). When, for example, carbon-intensive firms lose market shares and produce less, the structure of the ETS-sectors might become less carbon-intensive, if a firm that produces at a lower level of carbon intensity gains the respective lost market share. The structure of the ETS sectors and the level of production directly and indirectly determine real emissions of the ETS-sectors in a positive correlation, which affect, as mentioned above, net capital flows (**4a.4 Net capital flows**) between the linking partners. Capital flows might affect the amount of available capital in the region, which can be used for investments, relative to the partner and the rest of the world (**4b.2iii Relative (Δ) investment ETS-sectors**). This is an important fact, since with capital from permit trade flowing between the partners, a region's capital gain is the partner's capital loss, which has direct implications for the long-run competitiveness in relation to the partner: With large capital outflows, there is less capital available for investments in more (carbon-) efficient production.

Besides net capital flows, changes in the production costs of ETS-sectors might have an impact on the amount of available capital for investments. Higher production costs imply ceteris paribus less available capital, given that firms cannot pass-through the production cost increase to the end-consumer (Cost pass-through ETS-sectors). Yet, a permit-price induced increase of production costs might as well lead to more investments in low-carbon technologies, which, in the long-run, might lower production costs. Again, the costs for investments might be passed-through to the consumer. Therefore, changes in production costs (**(Δ) Costs production ETS-sectors**) and changes of investments in the ETS-sectors relative to the partner and the rest of the world (**4b.2iii Relative (Δ) investment ETS-sectors**) are interdependent, and both relate to the long-run competitiveness-dimension.

The above-mentioned long- and short-run competitiveness-dimensions of relative investments is again reflected in a self-reinforcing circle of changes in investments in the ETS-sectors (**4b.2iii Relative (Δ) investment ETS-sectors**) and changes in the production of the ETS-sectors (**4b.2i Relative (Δ) production ETS-sectors**), both relative to the partner and to the rest of the world. If chosen wisely, more investments in a region lead, ceteris paribus, to more production; and more production might in the long-run enable further investments.

Policy-makers might want to control for adverse competitiveness-effects of price-changes. An increase of the permit price after linking might increase the extent to which the price increase-facing region tries to mediate the impact of the permit price increase on its regional ETS-sectors, to ensure economic competitiveness and political support for the link. Free allocation could be a method to mediate price increase concerns (although the method of allocation has no influence on the marginal cost increase). Therefore, changes in the permit price (**3.1/4b.3 (Δ) Permit price**) together with the ETS-sectors' trade exposure (**4a.1/4b.1 Trade exposure ETS-sectors**) might have a direct impact on the difference in both regions' free allocation methods (**4a.2 Difference in free allocation methods**). The higher the price increase and the higher the trade exposure compared to the partner, the larger the political pressure for free allocation and hence the potential difference in free allocation between both regions.

Alternatively, to mediate the adverse effects of the permit price on competitiveness, policy makers might provide free allocation of permits based on production cost increases instead of permit price increases. Therefore, there exists a two-way relationship between permit price-induced changes of the production costs (**(Δ) Costs production ETS-sectors**) and the difference in free allocation methods between both ETS regions (**4a.2 Difference in free allocation methods**). One way is politically determined and goes from costs to the allocation method, the other way is of economic nature and goes from free allocation to changes in (absolute) production costs. In both cases, further support schemes (Other support schemes) like a renewable energy standard or tax exemptions for carbon-intense production might reinforce or mediate the relationship between the cost-variable and the allocation-criterion.

Overall, changes in the production of the ETS-sectors (**4b.2i Relative (Δ) production ETS-sectors**) affect the production of the entire economy (**3.2/4b.2ii (Relative) (Δ) production whole economy**), compared to the partner and the rest of the world, which has implications for the economy-wide welfare and competitiveness. Changes in the production of the non-ETS sectors further influence changes in non-ETS-sectors' production, yet depicting or even modelling these changes is a very complex task, since many different relative aspects between the regions, the sectors and individual firms matter. To limit the extent and complexity of the analysis, this part will be left for further research.

3.3 Description of model families, modelling approaches and model types

As has been shown in chapter 3.2, Table 7, most of the economic assessment criteria cannot be measured empirically, but need to be modelled by aid of economic modelling, especially for an ex-ante ("pre-linking") assessment. The various models that are available in the market have been developed over the past years and decades, with partly very different economic foci and level of detail. This chapter examines these different modelling approaches to quantify the impact of linking Emission Trading Schemes (ETS) on those selected economic assessment criteria that cannot be measured with empirical data.

Chapter 3.4 highlights the main differences between existing economic model families and discusses their differences in light of the present requirements. Chapter 3.4.6 outlines the overall model requirements and how the existing models match these requirements. To this end, eleven economic models that were principally deemed suitable for analysing the economic effects of linking have been investigated: The analysis comprised six CGE models (Aim-CGE, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE), one macro-econometric model (E3ME) and four PE models (POLES, PRIMES, REMIND-R, TIMES-M.). A special focus of the analysis was the question to which extent the models could be used to quantify the economic linking criteria and indicators (see table 7).

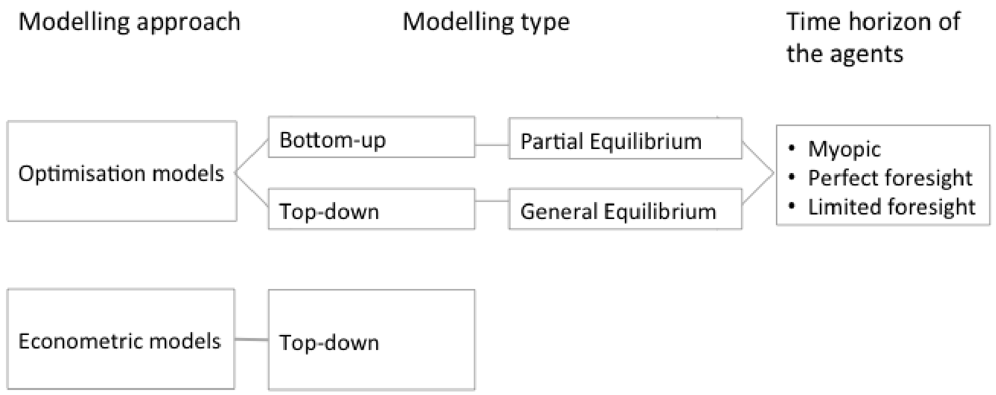
An ex-ante assessment of the impacts of linking ETS on selected economic indicators is a challenging task. Besides concrete specification requirements (see Chapter 3.4.6), useful models should be based on a consistent macroeconomic framework, evaluate short- and long-run effects, reflect technological constraints and allow for technological progress.

Regardless of how well a model is designed and set-up, modelling never replicates reality and always has shortcomings that have to be kept in mind when working with modelling output. To ensure computability, global models usually use highly aggregated data, which limits the validity and meaningfulness of results. Assumptions about learning curves, especially in low-carbon technologies, are very important in the context of linking, since they influence the permit price via the marginal abatement costs. These assumptions often lag behind the real figures, since updating and re-calibrating the models takes time and is costly. Therefore, modelled costs for low-carbon technologies (i.e. renewable energies and energy efficiency technologies) tend to be higher in models than in reality. Further, some models assume a widespread employment of technologies like Carbon Capture and Storage (CCS), nuclear energy and the large-scale use of biomass, which, due to their relatively high (perceived) risks and societal opposition, are in reality highly debated.

Models are designed to answer different questions, therefore model characteristics vary largely. There is a broad range of questions different energy system models and economic models can be applied to (Hedenus et al. 2012, p.2).

In general, there are two main approaches to economic modelling: Optimisation models and econometric models (section 3.3.1). They can either be of bottom-up or top-down type (section 3.3.2). Within the group of optimisation models, these two main types correspond to the two main classes: Partial equilibrium (PE) models and General equilibrium (CGE) models. Further, the optimisation models differ in their underlying optimisation principle which represents the time horizons of the agents (section 3.3.3). Figure 8 shows the differentiation in modelling approaches, modelling types and driving solution principle.

Figure 7: Model families – main differences



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3.3.1 Modelling approaches

There are two main economic modelling approaches, which can principally be used for assessing the economic impacts of linking ETS: Optimisation- and econometric models. They differ in economic backgrounds, and especially in their treatment of behavioural relationships. Whilst optimisation models assume behaviour in line with economic optimisation theory, i.e. perfect knowledge or that markets are completely cleared, econometric models allow for the possibility of unused resources and sub-optimal behaviour (Cambridge Econometrics 2014, p.26).

a) Optimisation models

These models are based on the equilibrium principles of neoclassical economic theory. In order to find the equilibrium solution, theory-based models need to make assumptions about agents' behaviour and the basic driving principles of the economy (see section 3.3). Given these assumptions and general theoretical reasoning, the models' functions are defined. The modellers then calibrate the parameters of these functions to reflect empirical cases. Depending on the aim of the analysis, this calibration either reflects convenience (easily solvable functions), different values (to show the importance of parameters or to analyse differences of changes in parameters' values) or empirical estimates. Based on the functions, the system of equations is mathematically solved, finding the optimal solution under certain constraints.

The advantage of these models are the limited data requirements. Yet, some of these models' crucial assumptions to reduce complexity and data requirements[30] are considered as not being realistic, for example the assumption of perfect competition. They might reduce complexity and reduce the required computational power to solve the model. Nevertheless, these assumptions might as well yield economically optimal, yet unrealistic results.

[30] Crucial assumptions are assumptions where the model outcome changes with changes in the assumption.

b) Macro-econometric models

These models are based on empirical data about past relationships between the variables of interest. When modelling macro-economic behaviour of a system, these models are usually based on input-output accounting. Instead of computing equilibrium solutions, they simulate flows of capital and other monetised quantities between different sectors. By aid of econometrically derived input-output coefficients, the model then shows the impact of these flows on different variables of interest, like economic output or investments. National indicators like Gross Domestic Product (GDP), labour markets and wages can be derived by aggregating sectoral values (Loulou et al. 2005, p.23).

The advantage of econometric models is that they do not rely on restrictive assumptions like rational agents and self-interested behaviour. Yet, a major disadvantage is the extensive need for comparable data across time and space. The more disaggregated the model, the more difficult it is to collect the necessary data.

Conclusion

Since it is quite difficult to collect internationally comparable input-output data that go far enough in the past to obtain meaningful coefficients and still have a rather high level of sectoral disaggregation, a suitable model for the present research purpose is a CGE model where at least some coefficients are econometrically estimated with time-series data, rather than just calibrated to a single base year (Capros et al. 2013, p.80f.).[31] These models are sometimes referred to as hybrid models, when the share of estimated parameters is relatively high, compared to the calibrated parameters.

3.3.2 Model types: Top-down vs. bottom-up

Models differ between top-down versus technology-specific bottom-up approaches, which roughly corresponds to the dichotomy between partial- versus full market coverage. Macro-econometric models belong to the type of top-down models. Within the group of optimisation models, both approaches can be found (Hedenus et al. 2012, p.5f.):

a) Partial equilibrium models (PE): Technology-specific bottom-up approach

These models estimate the effects of changes, i.e. in energy prices, on changes in partial areas of the economy, i.e. the energy system. The limited sectoral scope of these models allows for a detailed coverage of e.g. different energy-consuming technologies. The representative agent chooses amongst a set of represented technologies the profit- or utility-maximising production technology[32]. Linking inputs and outputs of the bottom-up technology-choices yields the overall market outcome. Thus, in contrast to pre-defined production functions in the top-down approach, production functions and marginal abatement cost curves are implicitly constructed in

[31] Capros et al. 2013, p.80f. provide a useful overview over the pros and cons regarding parameter calibration versus estimation.

[32] Besides PE models, simulation models represent another type of technology-specific models. Here, agents do not only focus on profit-maximisation when taking decisions. As such, investments in technologies with higher life-cycle costs than other technologies become possible (Loulou et al. 2005, p.23). However, the present report focuses on PE and CGE models, since simulation models are not as well developed as the other types, yet. They do not consider the complex interactions of economic variables, which are required for quantifying the economic assessment criteria for the present analysis.

the bottom-up approach (Loulou et al. 2005, p.21). A major limitation of using these models for the present research purpose (i.e. to assess mitigation costs) is that overall economic indicators like Gross Domestic Product (GDP) are usually exogenous model inputs.

b) (Computable) General equilibrium models (CGE): Top-down approach

These models estimate the effects of changes in some parts of the economy (e.g. in energy prices) on all sectors and general welfare, by aid of aggregated functions and values. Instead of a detailed technological representation, the top-down approach uses pre-defined production functions and marginal abatement cost curves. The production function simulates the potential substitutability between the production factors, which are themselves usually highly aggregated (such as "labour", "energy", "capital"). Function parameters are calibrated either with bottom-up model results, or using empirical data (Hedenus et al. 2012, p.5; Loulou et al. 2005, p.20f.). A disadvantage to use these models for the present purpose is the usage of pre-defined production functions and the resulting lack of a detailed and empirically grounded technology representation in each sector, which might yield significantly different results regarding competitiveness and leakage effects (Alexeeva-Talebi et al. 2012).

Conclusion

Albeit both, CGE and PE models, use optimisation techniques, PE models usually pursue a welfare-maximising approach, and CGE models a cost-minimising strategy. This is due to the fact that PE models usually calculate the production, consumption and prices of commodities simultaneously (Loulou et al. 2005, p.20). In order to limit complexity, most CGE models use exogenously given demand in commodities to determine the respective prices; or vice-versa.

Recently, modellers increasingly combine the advantages of PE and CGE approaches in so-called hybrid models. Several top-down models represent an increasingly differentiated energy sector, which is very useful to get a broad and realistic impression of the effects of linking on economic assessment criteria. Some bottom-up models start to include effects of energy system changes on the entire economy, like changes in end-use demand, or are linked to macroeconomic models (for example linking TIMES with MACRO, cf. Remme & Blesl 2006).

3.3.3 Time horizon of the agents in optimisation models

The following section applies only to optimisation models and is not relevant for econometric approaches. By solving a set of pre-defined equations under certain constraints, optimisation models try to find either the welfare maximising solution (usually in partial equilibrium models), or the cost minimising solution (usually in CGE models). There are three main time-dynamic approaches to do the optimisation which represent the time horizons of the agents (Hedenus et al. 2012, p.4f.):

a) Myopic optimisation

The optimisation is done at each point in time without knowing or by ignoring the state of the future system. It is mostly suitable to analyse reactions to certain policy measures by myopic agents, i.e. in the financial sector when short-term profits guide agents' decisions.

b) Perfect foresight (rational expectations)

The optimisation is done under full consideration of all future states of the system (prices, constraints etc.). This approach is mostly used to find the optimal solution from the policy planner's point of view, i.e. to find the cost-efficient technology mix to reach a certain emission reduction goal.

c) Limited/imperfect foresight

The optimisation is done under perfect foresight for a limited period of time without knowing the state of the future system beyond the considered period. This approach is used to model a rather realistic behaviour of economic agents and impacts of non-optimal decisions in a rather inflexible world due to behavioural routines or inertias in the capital stock in the short-run (Waisman et al. 2010, p.2f.). For example, the assumption is useful when modelling production- and investment decisions to a newly introduced policy, which are based on medium-run considerations that go beyond myopic decisions but where knowledge about the future states of the world is limited.

Conclusion

For the present purpose, limited foresight seems to be the most appropriate approach. Perfect foresight would probably yield results of limited reliability, since with market-based instruments like ETS, decisions of many decentralised and heterogeneous market participants add up to a certain outcome. These individually optimal decisions do usually not correspond to the welfare-maximising solution of the farsighted social planner (especially not when dynamic efficiency is taken into account, see excursus 2 in chapter 3.7). At the same time, these market participants usually remain in the market over a longer period, implying that they do not take decisions in a completely myopic way. It is rather likely that market participants take the near future into consideration when making decisions, which means that limited foresight should be favoured when choosing amongst different suitable models.

3.4 General model requirements

3.4.1 Coverage and level of detail

Models differ in the coverage and level of detail in different aspects. For the present analysis, the coverage of spheres of the economy (economic fields), sectors, regions, time horizons and greenhouse gases (GHG) is relevant for the model selection. This section describes briefly the general requirements suitable models should fulfil for the present purpose. A more detailed discussion of the requirements by assessment criterion and region can be found in section 3.5.

3.4.2 Economic fields

For this report, models have been assessed with regard to their capability to quantify linking-induced changes of mitigation costs in the ETS-sectors and the entire economy, competitiveness and carbon leakage in relation to the linking partner and third countries, and market liquidity, compared to a baseline scenario where already existing ETS are not linked. Therefore, a models' scope should cover the relevant fields of the economy, i.e. the domestic economy (in order to analyse mitigation costs), international trade (in order to analyse carbon leakage and competitiveness) and the permit market (in order to analyse market liquidity).

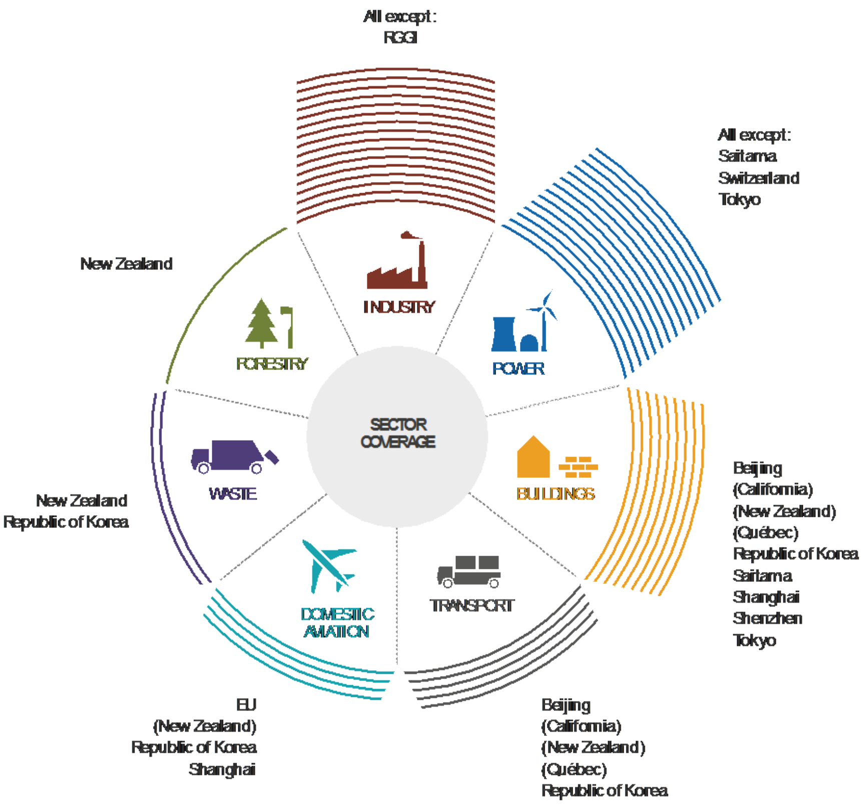
3.4.2.1 Economic sectors

Every model quantifying the effects of a symmetric linking ETS on different economic indicators needs to cover at least all sectors that are covered by the ETS. For the EU-ETS, this means that the industrial sector, the energy sector and aviation need to be included. For asymmetric linking, all sectors of the partner ETS need to be included, too. For an overview over which sectors are recently covered by ETS respectively, see Figure 9. For the models considered in the report, it is assumed that the EU-ETS pursues a symmetric link, focussing on the energy- and industry sector, as well as aviation. With regard to the linking partners, most ETS schemes cover more sectors than the EU-ETS or do not cover both, electricity and industry. However, for simplicity, it will be assumed in the following assessment and selection of suitable models that a symmetric link between the EU-ETS and the potential linking partner can be established.

Further, since changes in one sector might affect other sectors as well, a complete sectoral coverage or at least endogenous overall economic production is necessary for assessing economy-wide abatement costs.

The required level of sectoral disaggregation depends on the specific assessment criterion. If for example the change in sectoral abatement costs due to linking ETS is to be analysed, the level of sectoral disaggregation does not have to be as detailed as when analysing competitiveness and carbon leakage, which varies highly with specific sub-sectors (Alexeeva-Talebi et al. 2012)

Figure 8: Regional, national, and sub-national ETS: Coverage of aggregated sectors



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3.4.3 Regions

Obviously, a suitable model has to cover the jurisdictional boundaries of the different ETS whose linkage is to be simulated. For the EU-ETS, these are the EU-28 + Liechtenstein, Iceland and Norway. Further, it should cover potential linking partners. For the present analysis, c **China, South Korea, Mexico and Turkey** have been selected for illustration purposes as they are major economies having established already or considering implementing an ETS and could therefore be potential candidates for linking in the future.

To analyse carbon leakage with respect to third countries or the rest of the world, it is necessary that the respective countries should be included, too. Further, when changes in domestic abatement due to linked ETS affect trade patterns, trade with the rest of the world needs to be included in order to assess 2nd round effects of changes in mitigation costs.

3.4.4 Time horizon of the model

The definition of a suitable time horizon of the analysis is important for selecting a suitable model. ETS usually define a short- and long-term emission cap. The model should cover at least the clearly defined trading periods (which is the year 2020 for the EU-ETS). From the current perspective, this is a short-run time horizon (less than 5 years). Short-term economic effects of linking will have an impact on the political acceptability of the policy measure and are hence an important aspect in the linking decision. At the same time, in order to estimate overall policy costs, the performance of the system needs to be evaluated over a longer period (more than 10 years). It is useful to evaluate a time frame that goes significantly beyond 10 years, since the capital turnover cycle in the energy market is around 35 years. As such, replacement investments in low-carbon technology at the end of the "natural" replacement cycle would significantly reduce overall compliance costs (Hedenus et al. 2012, p.3).

The existing energy system is likely to remain largely the same in the short run due to long time frames of investment planning and operation. This means that technological change takes its time to translate into changes in the carbon price. Facing a trade-off between technological level of detail (mostly PE models) and broad coverage of sectors at a level disaggregated enough for a meaningful analysis with endogenous GDP (mostly CGE and econometric models), one should favour a disaggregated sectoral coverage. The latter models have the further advantages that they take interactiond and interdependences between all sectors into account (i.e. interdependences in production and MACC between ETS- and non-ETS-sectors) CGE models and econometric models are hence very useful to analyse short-term effects of linking when technologies do not change significantly (Hedenus et al. 2012, p.2).However, if partial effects or technological details are of interest, CGE modelling might be complemented with PE models.

Yet, in the long-run, the foundations of the energy system will likely change due to replacement investments, introduction of new technologies etc. Further, a policy measure might induce changes in the entire economic structure. Here, technology-specific PE models are less useful, since they rely on pre-selected specific technologies and focus only on one sector. CGE models in contrast simulate the influence of changes in one sector on the performance of other sectors, which drives changes in the overall economic structure. Further, they allow for abstract technological change, which induces changes in the economic structure, too, without having to specify parameters for technologies that are not invented, yet and might be beyond the modellers' imagination.

Hence, both model types might be useful for the present purpose. Alternatively, hybrid models can be used to capture both, the short- and the long-run (Hedenus et al. 2012, p.3).

3.4.5 Coverage of ETS-gases

The model should include all greenhouse-gases (GHG) covered by the respective ETS. This can become quite complex in practice. The following questions need to be answered before assessing the fitness of a model to cover all GHG gases included in the ETS:

1) Are all ETS-gases covered?

2) Are all sources of these ETS-gases covered (e.g. fossil fuel combustion, process emissions, waste, land use and land use change etc.)?

3) Are these emissions reported at a sufficiently disaggregated level (e.g. not only at the regional level, better ETS vs. non-ETS or by sector)?

The EU-ETS covers CO_2, N_2O (from the production of certain acids) and PFC (from aluminium production) emissions. This means that these emissions from burning fossil-fuels in energy generation, industry processes and aviation need to be reported. However, it might be difficult to obtain the specific N_2O emissions from the production of certain acids and the specific PFC emissions from aluminium production, since models usually do not report these emissions in such a level of disaggregation (the aluminium sector for example is in most models not reported explicitly, hence its emissions are not disaggregated, either). As economic models have to reduce complexity, different GHG gases and their specific sources and characteristics can only be covered to some extent. In the present analysis, the emission coverage requirement is already adequately fulfilled if at least CO_2 emissions from fossil fuel combustion and production processes are reported at the sectoral level.

When analysing asymmetric links of the EU-ETS, the required coverage of GHG emissions might include as well GHG emissions from other sources, for example LULUCF (land use land use change and forestry). This means that the CO2 emissions should reflect these emissions, too. Further, GHG emissions other than CO_2, N_2O and PFCs, such as CH_4, have to be simulated as well, if they are covered in the linked ETS.

Table 8 summarises the general model requirements. It will be used for the general description of models in the Annex to this report.

Table 8: Summary of general model requirements for assessing economic effects of linking ETS

Model	Requirement
Type	Ideally CGE with bottom-up PE-elements in the energy sector + ideally in the industry sector; and ideally many econometrically estimated parameters
Time horizon of the agents	Ideally limited foresight optimisation
Economic fields	Domestic economy, international trade, linked permit market
Sectors	All ETS-sectors (energy, industry, domestic and partly international aviation for EU-ETS) + rest of the economy
Sectoral disaggregation	Disaggregation should be detailed enough to provide meaningful results, depending on the selected assessment criteria. When, for example, sectoral competitiveness-effects are to be assessed, a single-industry-sector model does not provide the information required (cf. Alexeeva-Talebi et al. 2012).
Regions	EU-ETS31 + potential linking partners (e.g. China, South Korea, Mexico, Turkey) + Rest of the world (ROW)
Time horizon of the model	Short- (less than 5 years) and long term (more than 10 years, ideally more than 35 years) (until 2020 annual steps, end date around 2050)
Emissions	All ETS-gases from all ETS-sectors at disaggregated level (CO_2, N_2O, PFCs; from fossil fuel combustion and processes for a symmetric link of the EU-ETS)

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3.4.6 Required model outputs

An assessment of the economic effects of linking ETS requires that some relevant economic indicators are quantified by aid of economic modelling (as listed in Table 7). Thus, models have to provide the following (endogenous) output data:

- **Endogenous permit price for all ETS-sectors in linked markets**
  - One should favour an endogenous permit market price to a shadow-value carbon price because the latter is only determined by the emission constraint (shadow value of carbon), and not by the permit market's demand-supply equilibrium. Market distortions, which likely have a significant effect on the permit price, are hence not reflected.
- **Endogenous production (i.e. GVA) by ETS-sector by region**

  - First determine ETS-design: All domestic ETS-sectors and all sectors covered by the link (these might differ from the domestic ETS sectors in the case of asymmetric linking) need to be explicitly reported at a level of high disaggregation
- **Endogenous overall production (i.e. GDP) by region**
- **Endogenous investments by ETS-sector by region**
  - First determine ETS-design: All domestic ETS-sectors and all sectors covered by the link (these might differ from the domestic ETS sectors in the case of asymmetric linking) need to be explicitly reported at a level of high disaggregation
- **Endogenous exports by ETS-sector by region**
  - First determine ETS-design: All domestic ETS-sectors and alll sectors covered by the link (these might differ from the domestic ETS sectors in the case of asymmetric linking) need to be explicitly reported at a level of high disaggregation
- **Endogenous real emissions from ETS-sectors by linked region**
  - First determine ETS-design: For asymmetric links of the EU-ETS one might need to cover as well CO2- or GHG-emissions other than from fossil fuel combustion, industry processes and aviation, e.g. from LULUC
- **Endogenous number of transactions in the linked permit market (ideally)**
- **Endogenous number of market participants in linked permit market**
- **Endogenous volume of permit trade in linked permit market**
- **(Endogenous) volume of linked permit market**

The requirements outlined above form the basis for assessing whether the models are suitable or not to address linking effects.

3.5 Preliminary evaluation of economic models with regard to their suitability to assess economic effects of linking ETS

Models have been evaluated in a consecutive way: checking the coverage of sectors and emissions (section 3.5.1) is followed by checking the regional coverage (section 3.5.2). Based on both assessments, section 3.5.3 concludes on the general suitability of the eleven reviewed models. Since a symmetric link between the EU-ETS and the potential linking partner is assumed, all models that are analysed in this report cover the industry and the energy sector, as well as fossil fuel combustion and process emissions.

Requirements on the sectoral disaggregation may differ depending on the indicators to be analysed. The following preliminary evaluation will therefore first analyse to which extent the model outputs match to the economic assessment criteria and then, in a second step, if the sectoral disaggregation is sufficient for analysing the criterion. Eventually, the results of the evaluation provide, in combination, a first recommendation towards a preliminary shortlist of suitable models.

In order to reduce complexity, the impact of linking ETS on the non-ETS sectors is not covered in this analysis.

3.5.1 Coverage of relevant linking assessment criteria in economic models

Economic models can be used to quantify the operationalised assessment criteria from table 1 primarily for those criteria where no empirical data is available, i.e. when a post-linking state of the world needs to be assessed with an ex-ante analysis (cf. Table 1 for a general overview over the considered economic criteria and a description of how the criteria are calculated). The following sections discuss the ability of the pre-selected models to quantify the operationalised assessment criteria.

3.5.1.1 Coverage of criteria for objective 3: Reduce mitigation costs (static efficiency)

The operationalised criterion 3.1, expected change of the permit price for the ETS sectors, measures the reduction in mitigation costs for the ETS sectors. It is covered in all models, apart from IMACLIM-R and REMIND-R.

The majority of the models (Aim-CGE, EPPA, G-cubed, POLES, PRIMES, REMIND-R) model the permit price via the shadow value of carbon. The disadvantage of such an approach is that it does not consider market distortions, which are, however, anyways by definition usually not or only to minor extend represented in optimisation models. The other models considered in the present analysis determine the permit price alternatively: E3ME uses a macroeconometric energy consumption equation as basis. GEM-E3 uses the supply-demand equilibrium in the permit market. In PACE, permits are connected directly to the fossil fuel inputs with zero elasticity of substitution (Leontief). Hence, the permit price is computed directly as a consequence of increased or decreased demand for fossil fuel inputs. PRIMES uses the Hotelling-rule. TIMES uses an objective function where all energy system costs are included. The carbon price is then modelled via the emission caps and therefore similar to the shadow value of carbon approach. The permit price is the undiscounted dual value of the emission balance equation, which reflects the cost impact of one unit of additional emission abatement on the objective function.

The operationalised criterion 3.2, expected change in economy-wide production (GDP), serves as a proxy for changes in economy-wide changes in mitigation costs. It is covered in all general equilibrium models (Aim-CGE, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE) as well as the macro-econometric model E3ME.[33]

The partial equilibrium models do not endogenously determine the GDP.

➔ From the general equilibrium models, Aim-CGE, EPPA, GEM-E3, G-cubed and PACE can be used to compute both, the expected change of the permit price for sectoral mitigation costs and changes in economy-wide production for overall mitigation costs. The macro-econometric model E3ME can be used as well. From the partial equilibrium models, POLES, PRIMES, REMIND-R and TIMES are suitable to calculate changes in prices, but they do not report on endogenous changes in GDP.

3.5.1.2 Coverage of criteria for objective 4a: Reduce competitive distortions - Competitiveness and Carbon Leakage risk in relation to linking partner

If expected trade exposure after linking is of interest (operationalised criterion 4a.1), all considered general equilibrium models (Aim-CGE, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE) as well as the macroeconometric model E3ME provide bilateral trade matrices by sector and hence the necessary output to calculate the trade exposure of the ETS-covered sectors in relation to the linking partner[34]. From these models, E3ME provides the most detailed sectoral disaggregation, followed by PACE, Aim-CGE and GEM-E3. Since EPPA(-EU) and IMACLIM-R cover only two (industry) sectors, they are not as well suited to provide the necessary disaggregated sectoral information as the other general equilibrium models (for a discussion about the necessity for detailed sectoral disaggregation when analysing competitiveness-effects cf. Alexeeva-Talebi et al. 2012).

Partial equilibrium models do in general not endogenously determine the required bilateral trade matrices by ETS-sector. Non-energy sectors are not covered at a level of detail sufficient to differentiate between different ETS-sectors, and the non-energy sectors' production is usually exogenous. The energy sector's output is barely traded internationally, PEM usually only cover international fuel markets. The REMIND-R model has a hybrid nature, yet the production output for the single macro-economic aggregated sector does not provide any useful information for this criterion. [35]

The operationalised criterion 4a.4 expected net capital flows, can be assessed with every model apart from IMACLIM-R.

[33] Alternative operationalised criteria for objective 3 might be the endogenous emission reduction caused by the GHG emission price (in Aim-CGE), total policy (abatement) costs or changes in welfare (in EPPA, GEM-E3, IMACLIM-R, PACE, POLES, REMIND-R) and gains from trade for permit buyers and sellers (in POLES).

[34] Note again that this analysis focuses on symmetric linking (cf. Marschinski et al. 2012), i.e. the linking of similar sectors. From the EU-perspective, this primarily means the coverage of energy- and industrial sectors and the resulting CO2-emissions from fossil fuel combustion and industrial processes.

[35] Alternative operationalised criteria for objective 4a might be first endogenous competitiveness-effects (E3ME, IMACLIM-R, PACE), second relative export-prices (IMACLIM-R, PACE), third the carbon leakage rate (PACE) and fourth changes in relative production costs (TIMES). Yet, they are only second-best alternatives. The carbon leakage rate is not a useful means to assess competitiveness-effects (there might be output-leakage without observable carbon-leakage), it should only be used as an additional hint to competitiveness-effects and to assess the environmental integrity of the system. Relative export-prices and changes in relative production costs are only a second-best proxy to changes in overall production. Relative export prices do not differentiate enough between different products (a company might be a niche-producer within a broader product class, which might justify higher prices that do not lead to losses in competitiveness). Changes in relative production costs do not account for cost pass-through to the consumer.

- ➔ The partial equilibrium models POLES, PRIMES, REMIND-R and TIMES could be used to quantify expected net capital flows. However, general equilibrium models cover as well net capital flows and are better suited to analyse the (sectoral) competitiveness effects in relation to the linking partner since they cover the entire economy. The macro-econometric E3ME model has the most detailed sectoral disaggregation, and provides hence the most useful information. PACE, Aim-CGE and GEM-E3 have as well a quite detailed sectoral disaggregation.

3.5.1.3 Coverage of criteria for objective 4b: Reduce competitive distortions - Competitiveness and Carbon Leakage risk in relation to third countries

For evaluation of models the operationalised criterion 4b.1, trade exposure of the ETS sectors in relation to third countries, corresponds largely to the evaluation for the criterion 4a.1 (see description above).

The operationalised criterion 4b.3 expected change of the permit price, can be modelled by all models except IMACLIM-R.

The operationalised criteria 4b.3i-ii, change in production by ETS-sector (4b.3i) and in the whole economy (4b.3ii) relative to third countries or the rest of the world after linking, can be assessed by all general equilibrium models (Aim-CGE, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE) as well as the macroeconometric model E3ME. Yet, the same sectoral aggregation issue arises like for criterion 4a.1/4b.1, hence EPPA(-EU) and IMACLIM-R are not so well suited for the analysis of 4b.3i. Again, E3ME performs best in terms of sectoral disaggregation , followed by PACE, Aim-CGE and GEM-E3.

In partial equilibrium models, sectoral (GVA) and economy-wide production (GDP) is usually an exogenous input. However, POLES provides sectoral GVA as an output, whilst GDP is exogenous. Further, PRIMES and TIMES can be linked with general equilibrium models like GEM-E3 for an "endogenisation" of GVA and GDP. REMIND-R is not useful, albeit its hybrid nature, since it has only one macro-economic aggregated production sector.

The operationalised criterion 4b.2iii, change in investments by sector relative to investments by sector in third countries or the rest of the world after linking, is covered in all general equilibrium models (Aim-CGE,, EPPA(-EU), GEM-E3, G-cubed, IMACLIM-R and PACE) as well as the macrieconometric model E3ME. Yet, again, the level of sectoral aggregation in EPPA(-EU) and IMACLIM-R is too high for meaningful results. Further, the PACE model only gives overall investments as an output, it does not differentiate investment by sector. Again, E3ME provides results on the most detailed level of sectoral disaggregation, followed by PACE, Aim-CGE and GEM-E3.

The partial equilibrium models only provide investments in the energy sector and are hence not useful for the assessment of this criterion. The hybrid model REMIND-R provides investments as an output, yet its single macro-economic sector is far too aggregated for any meaningful results.[36]

[36] Alternative operationalised criteria for objective 4b can be world export (import) prices relative to regions' export (import) prices (in Aim-CGE, IMACLIM-R, PACE), the regional carbon price relative to the third country's carbon price (in Aim-CGE), competitiveness-effects (in E3ME, IMACLIM-R, PACE), the carbon leakage rate (in PACE) and changes in relative production costs (in TIMES).

➔ The partial equilibrium models POLES, PRIMES, REMIND-R and TIMES can be used to calculate the change in the permit price, and POLES might even quantify sectoral competitiveness effects. However, general equilibrium models are better suited to analyse (sectoral) competitiveness effects on the economy in relation to third countries, since they cover the whole economy. The E3ME model has the most detailed sectoral disaggregation, and provides hence the most useful information. Yet, PACE, Aim-CGE and GEM-E3 have as well a useful level of sectoral disaggregation.

3.5.1.4 Coverage of criteria for objective 5: Increase market stability – Market liquidity

The operationalised criterion 5, the number of market participants relative to the market size and the number of trades, consists de-facto of two criteria. Especially the first part of the criterion has some shortcomings. It stems from the assumption that more market participants means more *active* market participants, which is not necessarily true. Further, the size of firms in the market matters as well for market liquidity. It would be better to adjust the number of firms by their size, i.e. by calculating the Herfindahl-concentration-index[37] if adequate data is available.

This very complex double-criterion is not covered explicitly in any of the considered models. The number of trades is not covered in any model, but GEM-E3, POLES with the ASPEN-model-extension, PRIMES and TIMES provide the permit market trade volume as output. The volume itself, however, provides rather limited information as long as the number of market participants is not known. It might be more informative to assess the trade volume in relation to the overall permit market volume (approximated by the difference between the joint current emissions and the joint cap) in the linked ETS, compared to the pre-linking relation in the individual countries. A relatively higher share in the linked ETS indicates more liquidity. PACE provides the size of market participants in terms of market share in the permit market.

➔ When using an alternative criterion by comparing the trade volume relative to the market volume of the linked market with the not linked markets, the models GEM-E3, POLES, PRIMES and TIMES can be used.

3.5.2 Coverage of regions in economic models

The regional coverage accompanied with a meaningful sectoral disaggregation is a central criterion for the selection of an appropriate model to assess the effects of linking ETS. If the regions of interest are not covered or not treated on a level that is disaggregated enough, the modelling results will not provide adequate information.

Given that the focus of the project is to assess impacts of linking the EU-ETS to a selected partner-ETS, the economic modelling approach should cover the EU-28 (or ideally the ETS-31, i.e. EU-28 + Liechtenstein, Iceland, Norway). Further, the model has to treat the potential linking partner as individual region. For this review, the following potential linking partners are considered in detail: China, South Korea, Mexico and Turkey. However, since an earlier version of this review looked as well at other linking partners, these are still included in brackets in Figure 7, which shows each model's regional coverage.

[37] The Herfindahl concentration index (or Herfindahl–Hirschman Index HHI) measures the size of firms in relation to the industry, which indicates the amount of competition among firms. It is defined as the sum of squares of the market shares (as fractions of the total market) of the firms within the industry. The index ranges from 0 (huge number of very small firms) to 1.0 (single monopolistic producer).

Table 9 provides an overview over the default-specification from each models' regional coverage. All pre-selected models do somehow cover the EU and the rest of the world (apart from PRIMES). However, this coverage might be adaptable: Table 2 is based on readily-available model descriptions. It might well be the case that databases are more up-to date in the meantime (e.g. reflecting EU-28 and not EU-25) and the level of aggregation can be tailored to the special needs of the project (especially when the regional coverage is flexible as in the TIMES model). Further, different models might well be combined, for example PRIMES with GEM-E3. This might overcome some shortcomings of regional aggregation.

Table 9: Coverage of regions in the models

			Models										
			Aim-CGE	E3ME	EPPA	GEM-E3	G-cubed	IMACLIM-R	PACE	POLES	PRIMES	REMIND-R	TIMES-M.
EU-ETS countries	European Union	AT	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	Flexible, depending on the databases available or the chosen existing TIMES modelling approach
		BE	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		BG	Rest EUR	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		CY	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		CZ	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		HR	Rest EUR	X	EU+	X	EE+FSU	EUR	X if have data		X	ROW	
		DK	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		EE	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		FI	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		FR	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		DE	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		GR	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		HU	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		IE	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		IT	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		LV	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		LT	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		LU	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		MT	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		NL	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		PL	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		PT	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		RO	Rest EUR	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		SK	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		SI	EU	X	EU+	X	EE+FSU	EUR	X if have data	EU	X	EU	
		ES	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		SE	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
		UK	EU	X	EU+	X	WE	EUR	X if have data	EU	X	EU	
	+EU-ETS-31	LI	Rest EUR	Rest Annex I	EU+	Rest Annex I	WE	EUR	X if have data	EUR		ROW	
		IS	Rest EUR	X	EU+	Rest Annex I	WE	EUR	X if have data	EUR		ROW	
		NO	Rest EUR	X	EU+	Rest Annex I	WE	EUR	X if have data	EUR	X	ROW	
Potential linking partners: Countries		CN	X	X	X	X	X	X	X	X		X	
		KR	Rest Asia	X	X	ROW	Rest OECD	Rest Asia	X	X		Other Asia	
		MX	Rest SA?	X	X	ROW	Rest OECD	Rest LA	X	X		LA	
		TR	X	X	EE+CA	Rest Annex I	Rest OECD	EUR	X	X	X	ROW	
		(CH)	Rest EUR	X	EU+	Rest Annex I	WE	EUR	EUR	EUR	X	ROW	
		(KZ)	FSU	ROW	EE+CA	ROW	EE+FSU	FSU	EUR	CIS		Other Asia	
		(NZ)	Oceania	X	Oceania	Oceania	Rest OECD	OECD Pacific	AU+NZ	AU+NZ		ROW	
Potential linking partners: Sub-country regions		(California)	US	US	US	US	US	US	US	US		US	
		(RGGI)	US/CA	US/CA	US/CA	US/CA	US/Rest OECD	US/CA	US/CA	US/CA		US/ROW	
		(Alberta)	CA	CA	CA	CA	Rest OECD	CA	CA	CA		ROW	
		(Quebec)	CA	CA	CA	CA	Rest OECD	CA	CA	CA		ROW	
		(Regions in JP)	JP	JP	JP	JP	JP	OECD Pacific	OECD Pacific	JPN		JP	
		(Regions in CN)	CN	CN	CN	CN	CN	CN	CN	CN		CN	
Rest Global		*Variable, e.g. ROW*											
Total Regions			17	53	18	38	9	12	12	57	36 (only Europe)	11	Flexible, up to 30

Country codes: ISO 3166 Alpha-2

Regions:

EUR = Europe; EU = European Union; WE = Western Europe; EE = Eastern Europe;

FSU = Former Soviet Union; CA = Central Asia; CIS = Commonwealth of Independent States; SA = South America; LA = Latin America; ROW = Rest of the World

Potential linking partners in brackets: Potential linking partners considered in an earlier version of this review, selected from the World Bank, Ecofys 2014 review.

Blue = Countries aggregated in the EU/EU-ETS region

Green = Individual country included in the model

Light grey = Country included within a more aggregated region

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3.5.2.1 Coverage of the EU-ETS

Based on the information in table 2, within the general equilibrium models, the ETS-31 countries are covered only by EPPA. Yet, EPPA includes Switzerland, a potential linking partner, into the same group. ETS-31 except Liechtenstein is covered by E3ME. Aim-CGE treats the EU-25 as one region. The countries of the EU-28 are covered individually in GEM-E3. The other general equilibrium models (G-cubed, IMACLIM-R) use a different regional aggregation scheme regarding Europe and are therefore not useful for the purposes of this project in their default-specification.

From the partial equilibrium models, POLES and REMIND-R cover the EU-27. PRIMES features the EU-28 member states individually. The TIMES model family allows for a user-determined flexible regional coverage, as long as data are available. Several TIMES-models do include the EU. The PACE default-specification includes the EU-ETS-31 countries in the larger "OECD-Europe incl. EFTA and Central and Eastern Associates" aggregate. Yet, the model can be flexibly adapted, and using the EXIPOL database, the individual EU-ETS-31 countries can be aggregated to a single EU-ETS-31 region.

➔ This shows that, when taking the readily available model specifications, Aim-CGE, E3ME, EPPA, GEM-E3, POLES, PRIMES, REMIND-R and TIMES fulfil the most important requirement, to cover the EU-ETS. Yet, the regional aggregation differs. E3ME comes the closest to an exact coverage of the EU-ETS, followed by GEM-E3 and PACE. For the other models, the level and extend of acceptable aggregation needs to be discussed.

3.5.2.2 Coverage of potential linking partners

A meaningful model should not only cover the ETS of interest, which is the EU-ETS in the present analysis. It has to cover as well potential linking partners at a meaningful disaggregation, i.e. as individual regions and not within a regional aggregate. For the present analysis, China, South Korea, Mexico and Turkey are taken into account as potential linking partners. Table 2 provides an overview over each model's coverage of these regions. In addition it includes also consideration on further potential linking-partners.

The general equilibrium model PACE, the econometric model E3ME, and the partial equilibrium models POLES and TIMES (with the very flexible coverage) provide a very good coverage: They enable the analysis of all four potential linking partners, China, South Korea, Mexico and Turkey, at the individual country-level. This broad coverage of all partners allows as well for a comparison of results between the four potential links, since this requires using the same modelling framework for the countries.

The general equilibrium model EPPA covers China, South Korea and Mexico at the country level. Turkey is only included in the country-aggregate "Eastern Europe and Central Asia".

Aim-CGE, another general equilibrium model, covers only China and Turkey at the individual country-level. South Korea is included in the "Rest of Asia" aggregate. Mexico seems to enter the "Rest of South America"-group, yet this is not the correct group in geographical terms (Mexico belongs to North America).

The remaining models cover only China as an individual region, and put all other potential linking partners into aggregates: The general equilibrium model GEM-E3 includes South Korea and Mexico into the "Rest of the World" group, and Turkey enters the "Rest of Annex I" aggregate. G-Cubed, another general equilibrium model, includes South Korea, Mexico and Turkey all together in the "Rest of OECD". In the remaining general equilibrium model, IMACLIM-R, South Korea enters the "Rest of Asia", Mexico enters the "Rest of Latin America" and Turkey enters "Europe", which means that it is included in the same group as the EU-ETS countries, which makes an analysis of this link with this model meaningless. The partial equilibrium model REMIND-R puts

South Korea into the “Other Asia” group, Mexico into the “Latin America” aggregate and Turkey to the “Rest of the World”.

➔ This shows that, with regard to a complete coverage of the potential linking partners, to analyse not only the effects of a potential link, but to compare as well the effects of linking between different potential linking-partners, E3ME (econometric model), PACE (general equilibrium), POLES (partial equilibrium) and TIMES (partial equilibrium) are the best suited models.

3.5.2.3 Coverage of regions and model selection

When combining the most suitable models from 4.1 and 4.2, E3ME, GEM-E3 (for the link with China only), PACE and TIMES fulfil the regional coverage requirements for a meaningful analysis of the impact of linking the EU-ETS with selected potential linking partners. Since regional coverage differs with the models, there is no single most suitable model for every case. Instead, the most suitable coverage of the potential linking partner and the acceptable regional EU aggregation depend on the specific linking plan and the regional focus.

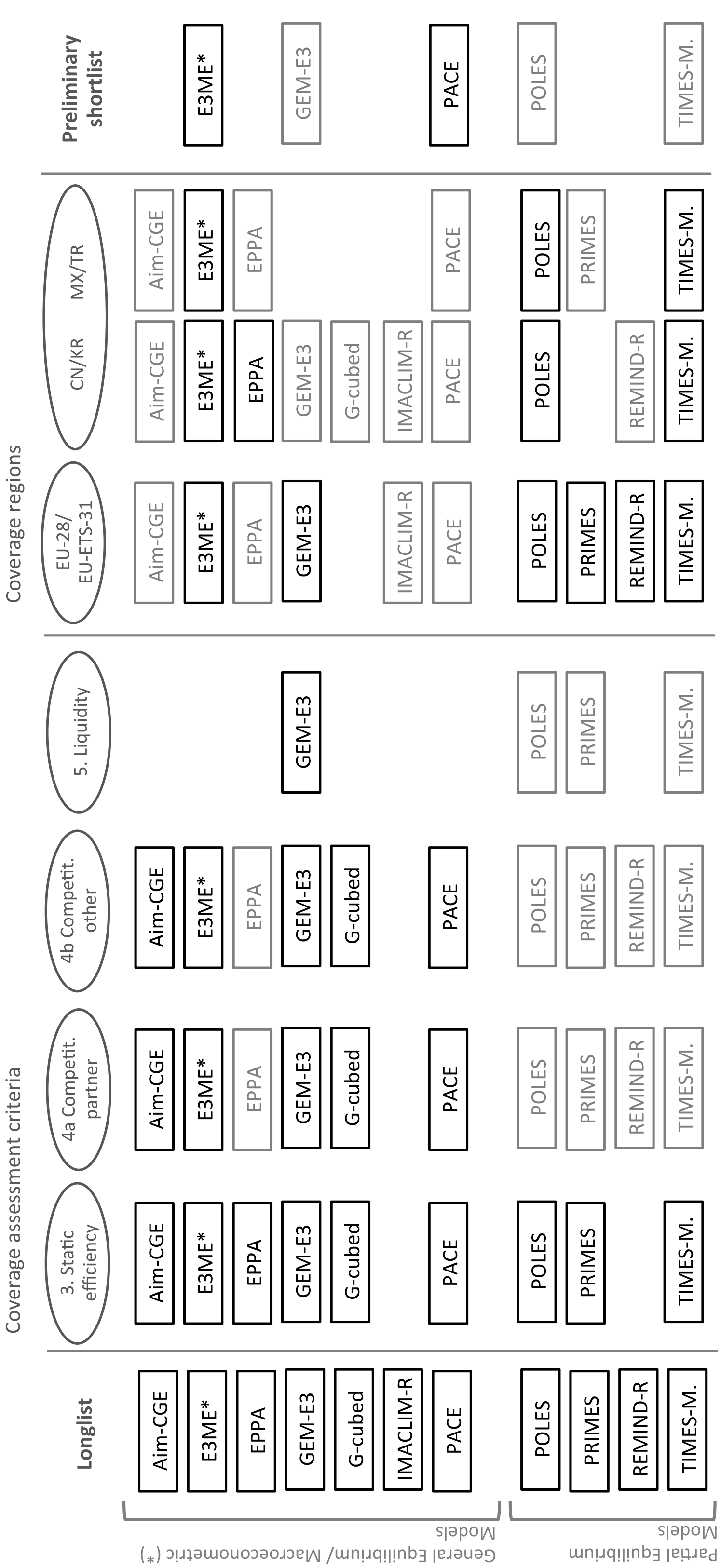
3.5.3 Selection of most suitable models

Overall, the CGE models seem to be more suitable than the PE models when all linking assessment criteria are to be covered, since they provide output for the whole economy and disaggregated for all ETS-sectors. Amongst the general equilibrium models, GEM-E3 has the best fit and covers all operationalised assessment criteria almost completely. E3ME and PACE have as well a relatively very good coverage of the operationalised assessment criteria. EPPA seems to be the least suitable in terms of operationalised assessment criteria coverage among the general equilibrium models.

For the PE models, REMIND-R covers the least criteria. Yet, all other PE models have major shortcomings, too. They suffer from the lack of detail and necessary output with regard to ETS-sectors other than the energy sector. Some PE models that cover the industry sector as well like POLES do not differentiate enough between different industry sectors. PRIMES, which has with 18 sectors the most detailed industry sector coverage amongst the PEM, does not cover non-CO2-emissions. However, these models (POLES, PRIMES, TIMES) are still able to deliver quantitative results for at least one operationalised assessment criterion for each assessment criterion.

The requirements need to be fulfilled consecutively.Taking into account the results for regional coverage (section 3.5.2) the list of potentially useful models is reconsidered. When combining the most suitable models regading coverage of asessment criteria (E3ME, GEM-E3 for the link with China only), PACE and TIMES fulfil the regional coverage requirements for a meaningful analysis of the impact of linking the EU-ETS with selected potential linking partners. Since regional coverage differs with the models, there is no single most suitable model for every case. Instead, the most suitable coverage of the potential linking partner and the acceptable regional EU aggregation depend on the specific linking plan and the regional focus.

Figure 9: Overview on how assessment criteria for linking ETS and regions are covered in existing models



Light grey means that the model covers parts of the requirements, but not entirely or with some shortcomings (see descriptions for more details).

The shortlist is preliminary since the final selection very much depends on the adaptability of regional aggregation of the models for the purposes of this analysis. // Light grey means that the model provides some very useful features, yet it does not fulfil all requirements. Interviews should clarify the extend to which these models can be adapted to the present analysis' needs.

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3.6 Excursus 1: A note on marginal abatement cost curves

A central factor related to the impacts of linking on the (expected change of the) permit price and hence the mitigation costs are marginal abatement cost curves in the ETS-sectors (Förster & Schumacher 2015, p.7). Marginal abatement cost curves (MACC) visualise the marginal abatement costs (MAC) associated with different levels of emission abatement. They can in theory be constructed for all possible levels of aggregation, as long as data is available, from products and individual firms or sectors, up to the entire economy (Cludius et al. 2016, p.12).

The MACC are influenced by several factors: Amongst others, the economic structure and the sectoral composition, the emission intensity of the production process and the utilised energy mix, the availability and costs of low-carbon substitutes (products or available and future (not yet available) technologies) and transaction costs play the most important role. The MACC are a composite of different cost differences, all compared to the business as usual case: The investment cost difference, the operating and maintenance cost difference, the social transfer difference and the difference in interest rates and returns to investment (Förster & Schumacher 2015, p.18f.). Closely related to the last element is the time period until when the investment costs need to be paid back, since this influences annuity (Förster & Schumacher 2015, p.19).

Obtaining MACC from the models

When deriving the MACCs, it is rather impossible to take all influencing factors into account. The shape of the MACC therefore is as well a result of the researcher's decisions, which factors to include, which technologies to account for (only market-ready existing technologies or as well technologies at other stages of technology development and diffusion process, static or dynamic approach (Förster & Schumacher 2015, p.15)), or which time horizon to apply, which depends as well on the overall research objective.

There are different ways of how to derive the MACC, from bottom-up MACCs using real data for an individual sector (or production process or product) without taking interdependencies with other sectors into account, to energy system (partial equilibrium) model-based MACC that do consider interdependencies between the fuel mix, energy generation and consumption, up to MACC from macroeconomic (general equilibrium) models that reflect interdependencies regarding the entire economy (cf. the reports from Förster & Schumacher 2015 and Cludius et al. 2016, where approaches and the respective limitations and problems are discussed in detail). The appropriate way depends again on the overall research objective.

When using modeling, as is the case for the present analysis, the general approach is to feed the model with different exogenously determined emission caps. The model will use this information to find, based on the pre-specified model equations and assumptions on optimal decision-making, the emission shadow price. With perfect markets, the shadow price corresponds to the permit price, which in turn corresponds to the MAC for the specific cap. After running the model for different caps, the (macro-economic) MACC is obtained by plotting the resulting permit prices to the corresponding caps. Albeit the overall approach to obtain MACCs in general and partial equilibrium modelling is the same, results differ since both models differ in terms of system boundary (interactions and sectors taken into consideration), level of technological detail and input substitutability, coverage of future technologies, assumptions about technology diffusion, etc. (Förster & Schumacher 2015, p.21).

3.6.1 Using general equilibrium models for deriving the MACC

The advantage of using general equilibrium models (GEM) to derive MACCs is that they take sectoral interactions into account and are able to provide information for the entire economy or the ETS-sectors as a whole. Yet, the broad coverage comes at the cost of a limited level of detail regarding production technologies, technological change and technology diffusion in the system of equations that needs to be solved to find the equilibrium solution. However, technology-related aspects significantly influence the MACC over time. Further, the models' system boundaries sometimes do not correspond to the required level for the analysis, i.e. ETS- and non-ETS sectors would have to be reported separately. Therefore, general equilibrium models with bottom-up MACC specifications in some sectors like the GEM-E3 model might be better suited for analysis, although the data requirements for such approaches increase again significantly.

General equilibrium models – Example GEM-E3

The MACC for the non-energy sectors are explicitly estimated in GEM-E3 by IIASA and EPA data and take the costs from abatement by input substitution and by investments in efficiency improvements, both induced by changes of the user-costs of energy, into account (Capros et al. 2013, p.115f. + 119ff.). The model assumes that firms behave in a profit-maximising way, i.e. that they abate emissions until the permit price equals the MAC.

The change in the user-costs of energy is determined in the energy sector and consists of the permit price and abatement costs. Therefore, for the energy-sector, which is represented in a bottom-up approach, the model uses bottom-up derived MACC that distinguishes sectors, durable goods, pollutants and countries for end-of-the-pipe abatement (Capros et al. 2013, p.115). However, these MACC refer only to non-CO_2 emissions, since it is assumed that CO_2-emissions are directly related to fuel combustion and can only be abated through fuel substitution, shifting power generation to low-carbon technologies like renewable power, reducing production or improving energy efficiency (Capros et al. 2013, p.118).

GEM-E3 provides as well estimates of the total abatement costs (cf. Capros et al. 2013, p.121f. for the total abatement cost equations). Production prices reflect the costs of technologies for process-related emission reductions and expenditures for permit purchases. The unit costs of production are reduced by the amount of free permit endowments when grandfathering is the allocation method (Capros et al. 2013, p.122).

3.6.2 Using partial equilibrium models for deriving the MACC

In contrast to general equilibrium models, partial equilibrium models (PEM) differentiate between varieties of existing (and future) technologies, could account for different reinvestment cycles, learning curves and technology diffusion rates, which are all very important determinants of the MACC. Yet, partial equilibrium models do not take interactions between different sectors into account. Further, technologies for the very heterogeneous industry sector are in most models not as well covered as for the more homogenous energy sector. Although the technological differentiation for the industry sector is not necessarily more detailed in GEM, and always less detailed for the energy sector than in PEM, GEM might be better suited than PEM for assessing the impacts of linking on efficiency in the ETS-sectors apart from energy, since GEM models take the interactions between the sectors into account, which influences the MACC, too.

Partial equilibrium models – Example POLES

In POLES, MACC for each of the sectors with fossil fuel use, and for the entire economy, are simulated by introducing a "shadow carbon tax" (the shadow value of carbon for a specific emission constraint) to each module where fossil fuels are burnt, proportionally to the carbon content of the fuel (Criqui & Mima 2001, p.2). The shadow carbon tax leads to adjustments in final energy demand via behavioural- or technological change, or replacement of investments in the energy conversion systems. By increasing the carbon value stepwise, the model provides the resulting emission reductions, which allows for plotting the shadow-value of carbon against the corresponding emissions (Criqui & Mima 2001, p.2). This is in principle the same approach as plotting different levels of exogenously given emission constraints against the endogenous carbon price from multiple simulations with stepwise changes in emission caps, it only changes the shadow carbon tax exogenously and not the emission cap.

The production functions in the energy conversion system are reported at a high level of detail, which makes the MACC relatively technology-specific. The extensive use of the TECHPOL (to capture future technology costs and performances) and the TRANSMAT (to capture the intensity of material use in production) databases allows for a detailed treatment of technologies over time: Since the model is recursive-dynamic, technologies employed for energy production might change over time, which results in changes of the MAC over time.

The resulting MACC are used as input for the POLES-ASPEN Module, where they serve as an input to calculate total abatement costs and gains from trade (Criqui & Mima 2001, p.2).

3.6.3 Using MACC for assessing the impacts of linking on compliance costs

In an ex-post evaluation of the impact of linking on static efficiency and the permit price, analysing the MACC is quite interesting: When the MAC for a given cap differ significantly from the permit price, the permit market does not function perfectly. An imperfect permit market reduces the static efficiency of the entire ETS significantly. However, in an ex-ante evaluation where no empirical data is available so far, the value-added of using these MACC for the assessment of linking on economic objectives is limited, since the permit prices and the MACC result both from the same modelling framework with the same assumptions regarding permit, product and financial market characteristics, the underlying economic structure and firms' production functions and mostly under the assumption of a perfect market (with permit prices = MAC). Therefore, the operationalised assessment criteria focus solely on the permit price as a proxy for the MAC and the underlying MACC, which are both determined by the model-specific assumptions regarding the factors that influence marginal abatement costs (see above & report on work package 1).

However, for a first ex-ante assessment of possible efficiency improvements, knowing the MACC is not necessary. The impacts of linking on economic efficiency can be approximated by the permit prices (operationalised assessment criterion 3.1) for the following reason:

In two ETS with perfectly functioning permit markets, the respective permit prices resulting from individual permit trades is equal to the aggregate MAC (and, due to the equimarginal principle, to the individual MAC) at the point where the respective emission caps cross the ETS-sectors' aggregate MACC. With perfectly functioning markets, linking does always (by definition) come with an efficiency improvement in terms of reduced total net costs for both partners, taking the change in the permit price together with changes in real emissions in the respective region into account (Although linked permit market will reach the cap all together, real emissions by region likely deviate from the autonomous emission cap, since the relocation of emission abatement is the main reason for linking ETS). In reality, perfectly functioning markets barely exist. Yet, due to its ex-ante nature, the present analysis relies on models to estimate the impact of linking on efficiency. Based on economic theory, these models usually assume as well perfectly functioning markets. Therefore, for the present ex-ante analysis with the modelling approaches considered, linking will always come with an efficiency improvement.

Yet, since it is rather difficult to obtain the MACC, and it is assumed that the permit price is equal to the MACC at the point of intersection with the cap, it is possible to use the distance between the endogenously determined regional pre-linking and the joint post-linking permit prices as proxies to get an idea about the efficiency improvements. Knowing the entire MACC itself is not important at this point, it is sufficient to know the local cap-specific MAC via the permit price. The larger the difference between the regional pre-linking and the common post-linking price, the larger the efficiency improvement to be expected from a linking of the individual regions. Even without knowing the post-linking permit price, it can be reasonably assumed that the larger the difference between the MAC between both countries, i.e. the larger the difference between both regions' pre-linking permit prices, the larger the difference between the regional pre-linking permit price and the joint post-linking permit price. Therefore, it is sufficient to look at the permit prices (operationalised criterion 3.1) for assessing whether linking implies rather large or small efficiency improvements for the linking partners. Therefore, the present analysis will focus on the permit prices for a first *approximation and rough assessment* of static efficiency gains. Deriving the MACC is a more complex task that provides only real value-added when the gains in static efficiency are to be *quantified explicitly, i.e. with concrete values*.

Only if the exact amount of net cost changes for the ETS-sectors[38] is of interest to the policy-maker, the regional MACC are needed as an input for quantifying the efficiency improvement. Net cost savings from linking-induced static efficiency improvements consist of a) changes in the costs for buying/not selling emission permits in the production process, and b) changes in total abatement costs due to changes in the level of real emissions. Yet, since the exact quantification will still rely on the very specific modelling assumptions, quantifying the net cost savings might in reality not provide any additional information than using the permit prices as a proxy. The steps for quantifying the net savings, illustrated in the following, show that using the MACC for assessing the impact of linking on static efficiency requires more work than just using the permit prices:

1) The pre-linking permit prices of each region need to be modelled (by aid of a specified cap for each region separately) or taken from empirical data.

2) The linked permit market price has to be estimated by treating the partners together as a single region in the model, with a joint cap.

3) For obtaining each region's ETS-sector's MACC, one needs to run a model several times for different levels of exogenously determined emission abatement (different cap) to obtain the corresponding regional permit price, which is assumed to be equal to the MAC for the specified cap. At this stage, the regions are again treated as separate regions, not as a combined region with one common cap (in contrast to step 2). By plotting the different caps to the corresponding prices, one obtains the MACC for the ETS-sectors by region. Ideally, the MACC can then be described or at least approximated with a MACC-function f(x).

4) Real emissions of the ETS-sectors under the linked scheme in each region need to be quantified, since, for efficiency, linking usually leads to a relocation of emissions from the low-abatement-cost region to the high-cost region. Real emissions in the high-cost-region will therefore exceed the pre-linking regional cap, and vice versa in the low-cost

[38] For assessing the change in costs for the entire economy (operationalised criterion 3.2), the GDP is an appropriate proxy, since it ideally (depending on the model) incorporates the interdependences between the linking-induces production changes between ETS- and non-ETS sectors.

region. The real emissions from the ETS-sectors by region can be taken from the point where the post-linking joint permit price crosses each region's ETS-sector's MACC.

5) Linking-induced net change in emissions in the regional ETS-sectors has to be calculated for each region by subtracting from the real emissions as obtained in step 4 the region's individual cap (not the joint market's cap), which indicates the level of emissions that would have been realised without linking (assuming that the linked cap equals the sum of the individual caps). A negative term implies net emission savings (permit seller), a positive term means that emissions are higher after linking than with an autonomous cap (permit buyer).

6) $\Delta e = e_{real} - e_{cap}$ (1)

7) The linking-induced change in net costs can be calculated by adding up the change in the total expenditures for permits and the change in the total emission abatement costs.[39] In concrete, this means that for a permit seller, i.e. when the regional emissions decrease with linking, one needs to first integrate the MACC from the real emissions (from step 4) to the individual emission cap that would have been realised without linking to obtain the increase in total abatement costs. Further, the linked permit price has to be multiplied with the net change in emissions (equation (1)). For a seller, the net change in emissions is a negative term, which means that this part will be in fact subtracted from the cost increase to obtain the monetary value for the permits that can be sold (negative costs imply revenues). Finally, the total permit revenues have to be subtracted from the increase in total abatement costs, which will, in theory, always give a negative value. This means that the change in net costs from linking implies a net cost saving. For the permit buyer, it will be the other way around: The integral will become negative when integrating the MACC from the real emissions to the emission cap, since the cap is lower than the real emissions. This implies less abatement costs. However, since the net change in emissions is positive for a permit buyer, adding the cost increase from permit expenditures to the cost abatement savings. The sum of the two terms, however, will according to theory still be negative, implying a reduction of net total costs through linking.

$$\Delta\, total\ costs\ = \int_{e_{real}}^{e_{cap}} f(x) + p_{linked} * \Delta e \qquad (2)$$

$$with\ f(x) = MACC_{ETS}$$

3.7 Excursus 2: Linking ETS and Dynamic Efficiency

A main rationale for linking ETS is economic efficiency. Whilst static efficiency can be relatively easily approximated, i.e. via changes in firms' marginal abatement costs or, respectively, changes in the permit price, dynamic efficiency, i.e. inter-temporal efficiency, is more difficult to capture. Yet, it plays a very important role in assessing a policy measure, more specifically when thinking of long-term effects of the policy measure on incentives for firms to invest in technological pro-

[39] It would be interesting for further research to assess as well the distribution of efficiency gains amongst the sectors (ETS and non-ETS). Such distributional effects have as well important implications for the political support of linking.

gress (Nicklisch & Zucchini 2005).[40] Without inducing technological change, or when technological change is delayed, the costs of carbon abatement policies are significantly higher, as shown in several modelling analyses (Edenhofer et al. 2007; Edenhofer et al. 2010). Overall, the long-term benefits from technological change are likely to outweigh the social and firm-level costs of the policy measure by far (Fischer et al. 1998; Stern 2007).

In the long-run, there seems to be a clear link between dynamic efficiency of a policy measure and competitiveness. Or, to put it another way, innovation is one of the most important dimensions of competitiveness (Dechezleprêtre & Sato 2014).[41]

After an introduction to dynamic efficiency in theory with a focus on technological change, elements of dynamic efficiency in the context of linking will be presented in theory, most important questions of design to counteract negative effects on dynamic efficiency will be identified and discussed, and issues surrounding the modelling of linking ETS with respect to dynamic efficiency will be described. By summarising the previous findings, and by pointing on aspects that will not be part of this paper, it will be concluded that dynamic efficiency effects of linking ETS remain a large research field of high relevance and a challenging task to modellers evaluating the linking of ETS.

3.7.1 Dynamic efficiency in theory

Generally speaking, economic theory defines dynamic efficiency as inter-temporal efficiency, i.e. as a situation where the inter-generational welfare is maximised. A dynamically inefficient situation exists when the current generation holds too much capital, i.e. when the capital stock exceeds the golden rule level (Abel et al. 1989). A trade-off between today and the future exists, when the present generation consumes too much and does not invest enough in the consumption of future generations.

This trade-off between today and the future occurs especially in the timing of investments in existing technology (technology diffusion) and in R&D (technology innovation). There are three main dimensions of this trade-off:

- Investment in technology is usually done to reduce the long-run production costs. Yet, for the present generation, investment in technology means at first stance bearing more costs and less consumption for financing the expenditures (Grubb 2004; Stern 2007; Dawnay & Shah 2011).
- Technology investment is special in the sense that more investments in one generation decrease not only future production costs, but reduce as well investment costs per unit for future generations. This effect occurs due to economies of scale and learning by doing (Fischer et al. 1998; Parry 1998) which can also described as learning by investing or technology learning. Empirical studies suggest that reducing the installation cost of a certain technology has a larger impact on adopting this technology than reducing its relative user

[40] Note that this chapter does not discuss the performance of ETS in terms of dynamic efficiency, compared to alternative policy measures. It rather focuses, after general considerations about ETS and dynamic efficiency, on some likely impacts of linking ETS on dynamic efficiency. Anyways, when taking different aspects into consideration, there is not the one and only most dynamically efficient policy instrument (Downing & White 1986; Jaffe & Stavins 1995; Fischer et al. 1998; Parry 1998; Denicolo 1999; Montero 2002).

[41] Innovation in “green” technologies seem to be more beneficial for an economy than in “dirty” (i.e. fossil-fuel based) technologies (Dechezleprêtre & Sato 2014). Yet, an ETS induces both, investments in “green” and “dirty “technologies and R&D, as long as they are less carbon-intensive than existing technology.

costs (Jaffe & Stavins 1995), which makes sense when considering that installation costs have to be borne at once, whilst user costs spread over the time of use.

- Investment in R&D enables technological progress, which is in standard neoclassical models a major source of future economic growth (Abel et al. 1989).

In this sense, dynamic efficiency relates to the inter-temporally optimal amount of investments in existing technology and in technology innovation in each period. To put it different, the technology-aspect of dynamic efficiency can be interpreted as making the production *progressively* more statically efficient.

Inter-temporal efficiency can be considered at different levels (i.e. firm-level, national, international). Regional policy makers, who decide about linking regional ETS, usually take the regional level of efficiency into account. Yet, inter-generational trade-offs at the domestic level might differ from the inter-generational trade-offs at the international level, depending on which parameters are taken into account. Hence, a decision that might increase domestic dynamic efficiency does not necessarily increase international dynamic efficiency.

However, the public good character of technological progress mediates this aspect: Technological progress in one country likely spills over to other countries that do not bear the investment costs, but benefit as well from reduced investment costs and improved technologies.[42] Yet, at the same time, the public good character introduces as well a domestic-foreign trade-off regarding investments in technology. This trade-off can be characterised by a game-theoretic strategic momentum in the decision about which amount of investment in technological progress is regionally optimal. Policy-makers and firms may count on other countries to invest in technological change, and benefit from the change at a later stage, without bearing the investment costs. Or they may consider it as unfair and adverse to economic competitiveness to bear the investment costs and being an “early mover”, whilst the rest of the world just benefits from the cheaper investments at a later stage (without even having to solve the present-future trade-off for the same results).[43] Both lines of argument change the conception of domestic dynamic efficiency: They add a strategic element to the domestic inter-temporal payoff of the investment. This strategic element might in game theory be represented by a payoff-matrix with values depending on technological investments the rest of the world in answer to domestic investments, and vice-versa.

Summary Box 1 – Most important trade-offs regarding investments in technology

a) Present-future trade-offs:

- Bear investment costs at present – reduce production costs for the future
- Bear investment costs at present – reduce investment costs for the future
- Bear investment costs at present (less consumption) – long-run economic growth for the future (more consumption)

b) Domestic-foreign trade-offs:

- Bear investment costs in domestic – reduce technology costs in domestic and foreign (technological progress as a public good)

[42] At least when one assumes that other regions would benefit from investments in the respective technologies, too. For example, if policy-makers, people or firms in a region did not care about climate change or were even in favour of it, this region would not benefit from low-carbon technological change.

[43] Yet, it is controversely debated whether being an early mover is adverse or beneficial to competitiveness. Eventually, this question depends amongst others on the structure of the economy, the ways of production of domestic firms, the economic strategy for the future, etc. (Dechezleprêtre & Sato 2014)

The trade-off between future and present would require for an optimal solution either perfectly forward-looking agents, which take future generations into account when making decisions, or a forward-looking social planner, who uses policy instruments to incentivise investments over time in the preferred technology and/or R&D.

With an ETS, given that the cap is optimally set for each period, and there are no further market failures or investment barriers, the carbon price equals the resulting emission permit price in each period, which should trigger an optimal investment path over time.[44] The incentive for agents to invest in low-carbon technology and low-carbon R&D consists of the reduced need for buying additional permits and/or the possibility to sell unused permits (Baker & Shittu 2006).

However, two very important concepts determine to which extend the permit price-incentive to invest in technological progress translates into dynamic efficiency: Network effects and learning effects/ economies of scale.

Network effects mean that the benefits of using a certain technology increase with an increasing number of users of the respective technology. A smart grid for example is a technology that gets more beneficial to each agent with an increasing number of users. In a broader sense, network effects might also apply to R&D: For example, it is often stated that the amount of innovations in Silicon Valley is so high because there is a large number of people with very different, yet complementary skills, at very close distance. This is assumed to be highly fruitful for the early stages in the innovation chain.

Learning effects and economies of scale describe two empirical observation: First, the investment costs of a technology decrease significantly with more investments in the technology (economies of scale). Second, the user-costs of a technology decrease over time when more agents use the technology and gain experience in how to optimise its usage (learning effects).

3.7.2 Dynamic efficiency and linking ETS

Neoclassical theory assumes that investment decisions solely depend on the (relative) technology or R&D costs, including the capital costs for financing the investment over time. Regarding the latter aspect, investments in technology diffusion and innovation are getting more expensive with increasing risks and uncertainty around the point in time when the investment pays off (Baker & Shittu 2006). With increasing risk, the investing agent needs to pay for example a higher interest rate if the investment is financed via the capital market.

Obviously, reality is more complex than models. Thinking about innovation and investment responses to an ETS-setup in general becomes already a challenging task when accounting for at least some of these complexities (Baker & Shittu 2006). Thinking about the reactions in the context of linking ETS is even more difficult. Yet, there are some important aspects and complexities that are captured in the literature, which directly relate to linking and dynamic efficiency.

Linking ETS influences main elements of the (relative) technology costs, which has an impact on the amount of investments in the respective technology. First, linking has an impact on the relative user-costs of alternative technologies via changes in the level of the permit price. User cost are relevant as changing permit prices not necessarily reduce investment costs but reduce the cost of applying the respective technology Second, it might have an impact on the volatility and

[44] This optimal investment path is a theoretical concept, which depends heavily on the chosen discount rate, over which there still exists a lot of disagreement, especially in the very long-run context of climate change (cf. for example Arrow et al. 2013).

uncertainty about the expected long-run level of the permit price, which translates into changes in uncertainty about the point in time when the investment pays off. Third, closely related to the second point, it might have an impact on the perceived policy risk.

Since the direction of influence of linking on each element is not straightforward, the following section will elaborate on each element in more detail.

Summary Box 2 – Most important variables regarding the impact of linking on dynamic efficiency:

1. Permit price level changing relative user-costs
2. Permit price volatility and permit price uncertainty
3. Policy risk

3.7.2.1 Dynamic efficiency, linking and the permit price level

The permit price itself has no direct impact on relative investment costs. However, it influences the relative user-costs of technologies. The influence on the relative user-costs first changes static efficiency in a first round effect. Yet, considering second-round effects, it influences as well dynamic efficiency: When relative user-costs of low-carbon technologies decrease, firms have more incentives to invest in these technologies.45 More such investments trigger technological progress via economies of scale and learning by doing.

The linking-induced direction of change of the permit price level differs between the linking partners. For the high-permit-price region, the reduction in the permit price due to arbitrage movements when linking the markets means that the relative user-costs of low-carbon technologies change to the disadvantage of low-carbon technologies. Buying permits for carbon-intensive production becomes less expensive.

When increasing investment in low-carbon technology at present is desirable in terms of dynamic efficiency, as stated by Stern 2007 and Dechezlepretre & Sato 2014, linking worsens dynamic efficiency for the region with the relatively higher pre-linking permit price. Made investments in the past have now a negative impact on the high-price country and investments in the future might be hindered. This might, in the long-run, worsen the competitiveness of the region, the covered sectors and the firms with regard to the linking partner.

For the low-price region, one can expect the opposite. The increasing permit price translates into an incentive to sell more permits, which should encourage more investments in low-carbon technologies. Or, to put it different, the user-costs of carbon-intensive technology increase, which results in a reduction of the relative user costs for low-carbon technologies.

When increasing investments in low-carbon technology in the respective economy at present is desirable in terms of dynamic efficiency, as stated by Stern 2007 and Dechezlepretre & Sato 2014, linking improves dynamic efficiency for the region with the lower pre-linking permit price. This might, in the long-run, improve the competitiveness of the region, the sector and the firms with regard to the relative low- price linking partner.

[45] This argument hinges on equal interest rates for investments for the set of available technologies, and equal payoff-periods. There might be the case that investment costs for a low-carbon technology are relatively so much higher than for a conventional technology, that the lower user-costs over time do not outweigh the larger sum of interests that a firm has to pay over the entire payoff-period for having borrowed the money for the investment at first stage in the capital market (or, equivalent, the opportunity costs for foregone interests when the investment is not financed by the capital market, but by using own profits).

Overall, in theory, investments only relocate between the regions. This relocation of investments is a key factor for improving static efficiency of the ETS for both linking partners. Yet, dynamic efficiency is different, since it depends on the amount of total investments in a region. It hinges on regional levels of network effects, on regional economies of scale and regional learning by doing. To put it simple, when there exist no technological exchange between both linking partners, linking may help to improve dynamic efficiency in the low-price-country, and hinder it in the high-price country, all else equal. Yet, there might exist as well interdependencies in the development of new technologies and overall technological progress between both regions, which might alleviate the issue of less concentrated regional activity in technological diffusion and R&D.

For the entire linked market, however, improving dynamic efficiency by linking depends on whether technological innovation, network effects, economies of scale and learning by doing (before linking) are higher in the low-price region (where more investments are expected with linking, hence the dynamic efficiency in the linked ETS would be higher then in both ETS separately) or in the high-price region (which would reduce the short-run costs of the entire system since "low-hanging fruits" can be exploited, but would be detrimental to improving dynamic efficiency of both ETS together by linking in the long-run).

3.7.2.2 Dynamic efficiency, linking, and permit price volatility and uncertainty

The larger the permit price volatility and the long-run permit price uncertainty, the more costly the investment, when agents price-in the risk surrounding the point in time when the investment pays off (Baker & Shittu 2006). It is almost impossible to assess ex-ante whether linking increases or decreases the volatility of the permit price and the uncertainty about the long-run level of the permit price. Yet, some relevant factors can be identified that cause more or less permit price volatility and permit price uncertainty in the context of linking.

Regarding volatility, linking implies on the one hand side a risk of importing macro-economic shocks that occur in the partner country. If this is the case, market-induced permit price volatility may increase, which can have negative impacts on technology investments. When the two partners are of very different size in relative terms (relating to the magnitude and size of covered economic sectors), importing macroeconomic shocks is on the one side likely a serious issue for the smaller economy. The risk of importing a macro-economic shock is rather low for the bigger country.

On the other side, linking increases the size of the permit market, which means that the impact of macroeconomic shocks on the permit price may be more easily buffered by the market itself. This is especially true for macroeconomic shocks that occur in the economy of the smaller linking partner. For example, an economic recession in the smaller linking partner likely translates immediately and 1:1 into a permit price drop, when markets are not linked. Although this permit price drop may make the recession less painful for the economy in the short-run, it adversely affects long-run investments in low-carbon technologies, and hence long-run competitiveness. However, when the smaller market is linked with a larger ETS, the recession in the smaller linking partner does not translate 1:1 into a permit price drop, since the larger partner has relatively more influence on the permit price.

However, if regions do not solely want to rely on market forces, but favour policy-instruments to buffer the impact of macroeconomic shocks on the permit price in a discretionary way, linking may make such discretionary policies more complicated. Since a regional policy to influence the permit price has an impact on the entire market, it is likely only uncontroversial when business cycles of both countries are symmetric. However, if one country faces a recession, but the other country faces an economic boom, it is very unlikely that both agree on the same discretionary policy, because such a policy would reinforce the situation for one of the two partners.

Depending on the market form, linking can further reduce permit price volatility thanks to increased liquidity in the linked permit market, given that there are more active market participants. However, liking could as well enable or reinforce certain large firms to behave in an oligopolistic way, and to control the amount of permits in the market. Whether this increases or reduces volatility then depends on the decisions of the oligopolies.

3.7.2.3 Dynamic efficiency, linking and policy risk

The expected long-run level of the permit price after linking is closely related to the observed volatility, but as well the credibility of maintaining the link (and/or the individual ETS), as has been empirically shown by Koch et al. 2014. It is debated whether linking increases or decreases the policy risk, i.e. the credibility of maintaining a certain minimum permit (or carbon) price level over the long-run.

Authors like Flachsland et al. 2009 argue that linking ETS reduces the policy risk, compared to national ETS. Aiming at an effectively high permit price in the long-run creates a time-inconsistency problem for a government with limited commitment power. Firms might suspect the government to abandon the ambitious climate policy, either due to high costs, changes in policy priorities with changing governments, or when sufficient investments in low-carbon technologies have materialised. All of these aspects significantly reduce the incentives of the ETS for firms to invest in long-run technological change.

Flachsland et al. 2009 state that linked ETS are less prone to discretionary policy changes, since there will be mutual pressure amongst the linking partners not to relax the cap, for example. Apart from the political pressure, which may also exist in a national ETS when there was already sufficient investment in low-carbon technology that there is a sufficiently large and powerful interest group that benefits from and lobbies for maintaining an ambitious emission cap, there exist sanctioning mechanisms in the international context, like trade restrictions or complete de-linking. National policymakers may blame the international pressure which "ties their hands" (Flachsland et al. 2009, p.361) when justifying the national targets. In the EU-ETS, blaming the EU Commission for the stringent emission caps apparently enabled some national constituencies to uphold the ambitious targets (Ellerman et al. 2010). As a consequence, Flachsland et al. 2009 argue, that linked ETS are able to provide a more credible and stable long-run permit price level, which improves the dynamic efficiency of the policy measure.

Yet, it remains questionable why the threat of complete de-linking should increase the credibility of maintaining the link and the ambitious policy over the long-run. Further, when autonomous policy answers to macroeconomic shocks become an issue in linked markets, national authorities might have to abandon the link to avoid serious economic damages. Recent crises in other policy areas like the European monetary union show: When questions about national autonomy and the degree to which discretionary policies might be justified in certain circumstances do not translate into commonly agreed rules when designing the link, a linked ETS might as well reduce the stability of the long-run carbon price, and increase the policy risk.

In addition, the whole Flachsland et al. (2009) argument may be inversely interpreted. Shifting responsibilities to achieve policy targets to higher governance levels (from local to national, continental, intercontinental, global) has several important implications:

1) While in many cases a certain control over national targets is retained, due to the link with other regions, full control over the total system is lost and shifted to a higher governance level.

2) Typically, at a higher governance level, agreements and negotiations become much more complex and lengthy. Due to diverging interests of covered partners, the system becomes more rigid, not only regarding future developments, but especially when dealing with more short-term adjustments which renders short-term discretionary policies responding to shocks or unexpected market developments ever less possible. For example, despite a wide-spread agreement in science and many governments that due to a significant amount of excess EUA permits in the EU-ETS, it was impossible to adjust it adequately in the running period due to divergent interests and the lengthy procedure of changes to the legal framework.
3) National governments may judge market developments (e.g. when permit prices are lower than expected) as detrimental to their domestic dynamic efficiency. If the supranational system (and the argument hold even more for an ETS linked to outside-Europe systems) exhibits rigidities that inhibit adequate discretionary interventions, national governments will recur on complementary domestic policies such as the introduction of national carbon taxes. As a consequence, the ETS loses its position as "primary climate policy instrument". Exactly this development can be observed in some ETS countries (e.g. DK, SE, FR, IE, NO).

Following these arguments, linking the ETS to other regions implying a further shift to higher governance levels would be counterproductive to the functioning of the system. In consequence, the price signal would not be as strong as expected to induce the optimal amount of investments in technologies.

3.7.3 Dynamic efficiency and linking design

As has been mentioned in the previous sections, some aspects of the ETS design influence the impact of the policy on dynamic efficiency. Yet, some issues with dynamic efficiency when linking ETS might be mediated through wise linking design choices. Further, since linking requires at least some harmonisation of the ETS design features between the linking partners, it opens as well a window of opportunity for policy-makers to change the system rules to induce more dynamic efficiency. In such circumstances, linking ETS might improve the dynamic efficiency, compared to autonomous ETS.

Five design aspects seem to be most important to mediate adverse impacts of linking on the permit price level, permit price volatility and uncertainty and policy risk: The initial allocation method, possibilities for ratcheting[46], the length of the trading period, the scope for (discretionary) market stability polices, and the contract design of the linking agreement.

In general, the design options influence several dimension of the policy outcome or assessment criteria at the same time. All of the following observations and resulting conclusions solely focus on dynamic efficiency. Yet, a trade-off between different dimensions of the policy outcome (i.e. for selected assessment criteria) is likely for several design-options, and policy-makers would have to make a deliberative design choice, which takes different design-options and their impact on selected assessment criteria into account.

[46] Ratcheting = the ability of policy-makers to react flexibly to permit price drops due to technological progress, by for example reducing the amount of permits in the next trading period to keep a permit price level that sustains incentives for technology innovation and investment (Downing & White 1986; Parry 1998).

Summary Box 3 – Most important design elements regarding the impact of linking on dynamic efficiency:

- Initial allocation method
- Ratcheting
- Length of the trading period
- Market stability policies
- Linking contract design

3.7.3.1 Dynamic efficiency of linking and the initial allocation method

Linking partners might re-consider the initial allocation method when linking their ETS, i.e. due to competitiveness-concerns. The initial allocation method influences dynamic efficiency from different points of view. Free allocation extends the scope of profit for firms, which might enlarge the scope for financing innovation and investment in low-carbon technology (Ellerman et al. 2010). Combined with grandfathering however, it provides as well a disincentive to invest in new technologies, since permits are given for free, based on historic carbon emissions (Stern 2007). When free allocation is based on best available technology criteria, the incentive for firms to invest in existing technologies is uphold. However, it might be difficult for policy-makers to identify the best available technology and update the requirement regularly (Fischer et al. 1998). Auctioning or selling the permits at a fixed price is a remedy to the issues with free allocation, yet it reduces the firms' profits, which might reduce their investments in existing low-carbon technology and R&D.

3.7.3.2 Dynamic efficiency of linking and ratcheting

Closely related to free allocation based on best available technology is the possibility of the policy-makers to adapt to long-term low-carbon technological change, which reduces the compliance costs and hence the permit price.

When small firms invest in technology in a perfectly competitive market, their decisions should not have an impact on the permit price. However, if a firm makes a very large (non-marginal) investment in low-carbon technology, or if it invents in a new very low-carbon technology at first place, the resulting decrease in the demand of permits (and respectively the increase in permit supply) might result in a steady permit price decline over the long-run (Nicklisch & Zucchini 2005). This distorts incentives to innovate and to invest further in low-carbon technologies. The reduced permit price reduces the benefits of selling more permits or buying less permits, and it extends the period until which the large-scale investment pays off, which increases the investment risks (Fischer et al. 1998). Further, if other agents adapt a very low-carbon technology innovation, the demand and hence the price for permits further decrease, which provides disincentives for the diffusion of the new non-marginal technology and the innovation for the innovating firm at first place (Parry 1998).

Therefore, to sustain incentives for technology innovation and investment, policy-makers should be able to react flexibly to permit price drops due to technological progress, for example by reducing the amount of available permits in the next trading period (Downing & White 1986; Parry 1998). Enabling for ratcheting is a very important design question that has to be taken into account when negotiating the linking-policy-framework (decision on the allocation method). A market stability reserve, which is primarily designed to alleviate the impact of economic shocks to the permit price, might as well be designed to account for technological change when deciding to limit the amount of permits in the market.

3.7.3.3 Dynamic efficiency of linking and the length of the trading period

Each end of a trading period poses a certain policy-risk whether the ETS will be maintained after, and if so, in which form and with which caps. For large-scale investments, or innovation processes where the outcome and the point in time of its materialisation is uncertain, the investment, pay-back periods and innovation process likely takes longer than the trading period. In such circumstances, the ETS may not encourage large low-carbon investments since the unused permits cannot be sold in the existing trading period, but only in the future, which bears a certain risk. Longer trading periods may thus encourage large-scale investments.

However, at the same time, longer trading periods limit as well the scope for policy intervention at the end of a trading period to stabilise the permit price (see Section 3.7.2.3) (Taschini et al. 2014). In the absence of within-period adjustments (which may on the other side introduce another policy risk for investments), longer trading periods may imply as well more uncertainty regarding the permit price, since a fixed permit supply meets the volatile permit demand. Hence, there is no clear-cut tendency regarding the direction of influence regarding this design element; and it has to be analysed in the context of the surrounding design choices and the behaviour of agents in the context of large-scale investments.

3.7.3.4 Dynamic efficiency of linking and market stability policies

There is an entire strand of literature on policies aiming at reducing the permit price volatility, which is important for inducing investments in low-carbon technology and R&D (consider for example Taschini et al. 2014). Discussing the details of the different instruments goes far beyond the scope and the core topic of this section, yet the general purpose of such policies is very relevant when discussing dynamic efficiency in the context of linking ETS.

In order to reduce the short-run volatility of the permit price, linking partners should agree on a certain set of quantitative and qualitative criteria justifying discretionary policy interventions to stabilize the permit price, for example in the response to macroeconomic shocks. It is very important that such interventions are, albeit discretional, triggered if (and only if) certain criteria are fulfilled (i.e. *rule-based* discretionary policy), to ensure that they do not pose another dimension of policy risk and uncertainty to the market (Taschini et al. 2014). Especially in an international context, it is very important that these criteria are agreed-upon in advance, since starting the negotiation about the criteria likely worsens when the shock is already there, as has been shown in the context of the EU-ETS (Koch et al. 2014).

Yet, especially when the linking contract is of rather informal nature and it does not foresee formal institutions to supervise the markets (see Section 3.7.3.5), the linking partners should as well hold regular market screenings and consultations to ensure that criteria are up to date and that detrimental permit market developments are discovered at an early stage.

3.7.3.5 Dynamic efficiency of linking and the linking contract design

The jurisdictional nature of the agreement between the linking partners may have an important influence on the perceived policy risk of unilateral or bilateral withdrawals from the link (Flachsland et al. 2009). This section will not go into detail about the discussion of the strength of international law and treaties[47]. Yet, some considerations may be interesting in the context of providing a credible policy signal to maintain the link with implications for the long-run permit price, and hence might change the incentives to invest in R&D and low-carbon technologies.

[47] For further reading: Görlach, Benjamin; Michael Mehling und Ennid Roberts (2015): Designing institutions, structures and mechanisms to facilitate the linking of Emissions Trading Systems, DEHSt.

Although no international treaty is, due to the sovereignty of nations, proof to unilateral withdrawal, parties may be more reluctant to abandon a link when the legal force of the agreement is "stronger". Further, choosing a "stronger" legal force when designing an international treaty, may signal a deeper wish for sustaining the link over time than for example a memorandum of understanding would.

However, having a legally strong document does not mean that all details of the linking design should be pre-defined in this document. It may be more beneficial for the long-run credibility and stability of the link to have a legally strong framework document, which at the same time enables the parties to react to shocks in a pre-defined, yet flexible manner (cf. Section 3.7.3.4).

3.7.4 Modelling the dynamic efficiency of linking ETS

Modelling the dynamic efficiency of linking is quite complex, and it is almost impossible to capture every element of dynamic efficiency in a single modelling approach. Furthermore, none of the considered modelling approaches provides a single measure that takes into account the most important elements for assessing endogenous dynamic efficiency with a simplified proxy to reduce complexity, and the modellers usually do not refer to dynamic efficiency at all in the modelling descriptions. However, there are several modelling decisions and variables that influence technological change, which might be used as a set of proxies to assess the impact of linking on dynamic efficiency in the context of technological progress. Some of these variables and related modelling problems are very well described in a critical assessment of energy-economy-climate models by Hedenus et al. 2012. Yet, the authors focus on technological progress in general, and do not refer to the broader concept of dynamic efficiency. Therefore, their paper has been used as a starting point for the following analysis (the choice about the time-horizon of decision making, assumptions about technological change, the modelling of the evolution of the capital stock), and has been extended by further aspects that are specific to the modelling of dynamic efficiency in permit markets (the exogenous choice of the permit market design) and the modelling of circumstances that affect firms' decisions when investing in technologies (the choice about available technology options and their modelling, the resource availability, and the financial capital costs).

It is important to note that, by definition, optimisation models are not able to model the deviation of the entire economic system from the hypothetical optimal growth path. Such deviations might occur for example due to macroeconomic shocks that cannot be mediated by adequate discretionary policies, since the (full) control over the cap and the (full) control over discretionary measures has been shifted to either a higher level of governance, or need to be agreed upon again and again with the linking partner (see arguments in Section 3.7.2.3). Therefore, one very important objection to linking cannot be modelled at all. This shows that it is very important to complement the modelling analyses with qualitative reasoning and empirical evidence, based on past experiences and broader theoretical understanding.

Summary Box 4 – Most important modelling elements regarding the impact of linking on dynamic efficiency:

1. Permit market design, especially allocation method (exogenous)
2. Time-horizon of the model and for agents in decision-making (exogenous)
3. Technological change (exogenous or endogenous)
    - If endogenous influenced by:
    a) Economies of scale (regional?)
    b) Learning by doing (regional?)
    c) Network-effects (region?)

   d) Investments in technology innovation (how financed? revenue recycling?)
   e) Investments in technology diffusion (how financed? revenue recycling?)
4. Available technology options (exogenous):
   a) Input substitution?
   b) Production efficiency?
   c) Change of entire production process?
5. Evolution of the capital stock (endogenous):
   a) Diffusion constraints?
   b) Vintage rate?
   c) Resource availability (exogenous or endogenous)
6. Financial capital costs (endogenous)

3.7.4.1 Permit market design (exogenous)

The permit market design influences dynamic efficiency in several ways. The relevant market design elements for assessing the impact of linking ETS on dynamic efficiency are outlined in Section 3.7.3 and are not repeated here. Obviously, how these design features enter, for example, the profit function of firms (revenue recycling, allocation method) or the capital cost function in the financial market (market stability provisions), influences the outcome of the model in terms of dynamic efficiency/technological change.

A major issue for assessing the impact of linking on dynamic efficiency is the fact that most modelling approaches assume that the permit price behaves identically to a carbon tax, i.e. that there is no volatility and uncertainty surrounding the permit price. As a consequence, any impact of linking on volatility and uncertainty, and the respective effect on investments in low-carbon technology diffusion and R&D, cannot be estimated by most of the existing models.

3.7.4.2 Technological change (exogenous or endogenous)

It is important whether technological change is modelled endogenously or exogenously. If exogenous, this dimension of the impact of linking on dynamic efficiency cannot be analysed by the respective modelling approach. In such a case, costs and technology performance change with a pre-specified parameter in a pre-specified schedule, which is usually estimated with historical data (Hedenus et al. 2012).

If endogenous, the impact of linking on technological change can be analysed – yet depends on how technological change is modelled. Usually, technological change is induced via investments. Yet, it is important to consider how investments translate improved technology costs and performance, i.e. which factors do have an influence on these aspects. There are three main factors surrounding investments, which are related to technological change. Depending on which of these factors are included in the model and how, the impact of linking on technological change might differ significantly (Hedenus et al. 2012).

- First, when thinking of technology diffusion and reducing the costs of existing technology, it is important that a model considers **learning effects and economies of scale** of cumulative investments in a certain technology over time. How these translate into lower technology costs depends on the structure and the parametisation of the model – very different results may come up with different approaches to economies of scale. However, decisions in an ETS about which technology to invest in do not depend on the absolute costs of a certain technology, but on the relative costs. Hence, in order to account for substitution effects, the model needs to cover the technology costs for technologies that may be a substitute in the production process. A very interesting aspect in the context of linking ETS occurs if economies of scale relate to regional and not global installation of a certain technology. In this case, it matters for regional technology costs where the technology is installed, and hence shifting investment patterns due to linking likely influences the dynamic efficiency of the ETS.

- Second, **network effects** are important for technology diffusion and innovation. However, these are rarely covered by models. Here again, absolute and relative technology costs matter, and regional boundaries have an important influence when analysing the effects of linking ETS on the dynamic efficiency of the ETS.
- Third, the way how **investments in R&D** are modelled has a major impact on technological change that goes beyond the diffusion of existing low-carbon technologies via reduced relative costs. In this context, it is as well interesting how the investments in R&D are financed in the model – most models use savings, which implies that there needs to be a certain surplus in the economy for a firm to either use the own savings beyond what is needed for the replacement of depreciated capital assets (which is not really possible in a zero-profit-condition-framework) or to get a credit from private households for financing the investment. When using own profits for financing investments in R&D, the choice of the initial allocation method in the model plays an important role for determining the amount of profits for a firm. Yet, most models assume that firms make decisions at the margin, hence the effects of the allocation method on profits and thus on investment in R&D are usually not modelled. In some models, when auctioning is the chosen permit allocation method, the government either redistributes the auction revenues in a lump-sum fashion back to the firms, or invests the revenues directly into R&D programs. Both ways of modelling revenue recycling will have an impact on technological change: The first via the available capital at the firm level, the second as some sort of endogenised exogenous technological change, where the amount of available capital at the governmental level determines the rate of technological change (Edenhofer et al. 2010).

One additional aspect regarding incentives to innovate and the diffusion of new technologies is whether the model assumes innovation being specific to one firm, or whether it can be transferred to another firm or across the economy (Downing & White 1986; Fischer et al. 1998). Further, modelling asymmetric firms, where past experiences or size do have an impact on investments due to economies of scale or learning by doing (Montero 2002), would be interesting. However, none of the considered models goes into sufficient detail, since such a modelling exercise would significantly increase the complexity of the model.

3.7.4.3 Time horizon of the model and for agents in decision-making (exogenous)

Several basic modelling decisions, i.e. about the model's driving principles, have an influence on technological progress. As such, especially the time horizon of the entire model and of agents in decision-making is important. Perfectly forward-looking agents tend to invest much more in existing technology (and thus technological change, if this is an endogenous factor) than myopic (short-sighted) agents. When modelling the optimal solution from a social planner's point of view, the modeller would rather use perfect foresight; yet for modelling the impacts of linking on decentrally induced technological progress, limited foresight is appropriate. A model that calculates an optimal solution over a very long time-horizon likely allows for more technological change than a model that takes only a very short period of time into consideration, due to the process of maturation of entirely new technologies and more scope for replacement investments (Hedenus et al. 2012).

3.7.4.4 Available technology options (exogenous)

Modelling approaches always face a trade-off between complexity and the level of detail. This relates especially to modelling different technologies. For assessing the impacts of linking on technological change, the modellers' choice about which technologies and development options to include in the model plays an important role. For example, when the model only allows for technological progress in terms of efficiency, substantial innovations regarding completely new production technologies, that strongly influence dynamic efficiency since they might change the entire way of production, cannot be modelled. Further, if there are no constraints to efficiency, a model might overstate dynamic efficiency, and the issue that some firms close down since in reality, there are financial constraints to efficiency, will not be covered. Alternatively, when a model allows as well for input substitution in the production process, the degree of substitutability strongly affects static (high degree of substitutability – more static efficiency) and dynamic efficiency (higher degree of substitutability – less investments in new technologies – less dynamic efficiency). Last, dynamic efficiency can only be reasonably analysed if the model is capable of simulating as well the introduction of entirely new technologies; yet this is a very challenging task since some fundamental hypothetical future technologies are by definition still unknown to the present modellers. (Baker & Shittu 2006).

In sum, more technologies per se do not necessarily mean that the respective model provides more realistic results regarding dynamic efficiency. More important than it's specific technological *shape* is the *dynamics* behind the technological change, i.e. the set of potential reactions to the change in the permit price (efficiency improvements? substitutability of input factors? entirely new technologies?), their parameters' values and their constraints.

3.7.4.5 Evolution of the capital stock (endogenous) and resource availability (exogenous or endogenous)

The way of modelling the evolution of the capital stock is especially important for the diffusion of alternative technologies. For example, a high vintage rate of the existing capital stock allows for more frequent replacement investments, which likely increases the diffusion of alternative cost-competitive technologies (Edenhofer et al. 2010; Hedenus et al. 2012).

A model might as well include diffusion constraints to prevent unrealistically high diffusion rates (Hedenus et al. 2012). Unrealistically high diffusion rates usually emerge in the context of perfect foresight in combination with economies of scale and learning by doing. In such a context, investment in one technology in period 0 favours investments in this technology in all subsequent periods since its absolute costs decrease with the level of installed technology. In consequence, it has a relative cost advantage that increases exponentially, which is rather unrealistic, given that in reality, there are constraints to technological diffusion other than relative costs. The diffusion constraints could significantly alter the model results, yet they are seldom public, since they require extensive expert knowledge. This is a serious issue for the transparency of the model results (Hedenus et al. 2012).

As an alternative to diffusion constraints, some models use technology distribution functions, where investments in one technology depend on relative technology and input prices (Hedenus et al. 2012).

Related to technological possibilities, resource availability plays another role. It might be the case that a model allows in principle for a certain technology, but that this technology requires a resource that is globally rare or regionally not available. A realistic estimate of technological change in a model needs to take this into account, since resource availability has an influence on the relative user costs of technology, and not only the relative costs of installation at first place.

3.7.4.6 Financial capital costs (endogenous)

If a model is to cover all aspects relevant to dynamic efficiency, the impact of linking ETS on the costs of capital in the financial capital market is important, too. As outlined in the previous chapters, uncertainty and risk surrounding the carbon price and the point in time when the investment pays off increase capital costs. However, since there are multiple options how a link may be established, with each having different implications for uncertainty and risk, and that all these implications again depend on the specific circumstances, there is no clear tendency whether linking increases or decreases uncertainty and risk. As such, there needs to be first more research about the expected direction of influence of linking ETS on uncertainty and risk surrounding the permit price and its translation into increased capital costs, before this aspect of linking can be meaningfully modelled.

Further, to reduce complexities, most modelling approaches assume that the permit price behaves like a carbon tax, i.e. that there is no price uncertainty and volatility (cf. Section 3.7.4.1). Hence, any influence of linking on uncertainty and volatility, and consequently on capital costs and technology investments cannot be estimated with most modelling approaches.

3.7.5 Final thoughts about dynamic efficiency of linking in theory and modelling

In the previous sections elements of dynamic efficiency in the context of linking were presented, most important questions of design to counteract negative effects on dynamic efficiency identified and discussed, and issues surrounding the modelling of linking ETS with respect to dynamic efficiency described.

It has been shown that analysing the impact of linking ETS on dynamic efficiency is a very complex and highly challenging task. So far, the implicit focus of the lines of argument were on the ETS-sectors. Things get, however, even more complicated when trying to analyse the impact of linking ETS on the dynamic efficiency in the NETS-sectors, which has not been considered in this working paper.

Further, the arguments so far primarily focused on standard neoclassical arguments regarding the (cost-) incentives to invest in technology and innovation. However, there is a wide range of aspects beyond the standard market failure perspective that influence why, how and when agents invest in technological change (Grubb 2004; Dawnay & Shah 2011). Things like behavioural and organisational factors have not been taken into account. Yet, since the analysis focused on the impact of linking ETS on dynamic efficiency, and linking ETS unlikely changes these other factors (Stern 2007), it is necessary to keep in mind that technological change itself is a very broad topic that extends beyond standard models.

Most importantly, the present analysis has shown, that dynamic efficiency is a field of high relevance for the evaluation of linking ETS but at the same time very difficult to model. Existing models can rarely cover a substantial fraction of the sub-effects in a satisfactory manner yet (e.g. issues around uncertainty/volatility of market developments and resulting investment behaviour) or can almost by definition not be modelled (e.g. external shocks and the loss of domestic control when shifting policymaking to a higher governance level and the effect on domestic and global dynamic efficiency).

As a consequence, dynamic efficiency effects of linking ETS remain a large research field of high relevance and a challenging task to modellers evaluating the linking of ETS.

3.8 Towards a quantification approach: Preliminary conclusions

Results of chapter 2 show that the majority of operationalised criteria has to be modelled to provide a comprehensive picture of the economic effects when linking ETS, based on the selected criteria. Only few (4, perhaps 5) operationalised criteria can be quantified based on available empirical data. Hence, only four to five operationalised criteria might be used in WP5. Data availability for quantifying indicators appears sufficient at this stage of analysis, but will be further investigated. Two operationalised economic criteria have to be addressed qualitatively.

Table 10: Data sources for quantification of assessment criteria

Economic Modelling	Empirical quantitative data	Empirical qualitative data (no quantification possible)
3.1 Expected change [decrease] of permit price (before and after linking)	4a.1 [High] trade exposure of ETS sectors in relation to linking partner ← might also be modelled	4a.2 [Significant] differences in free allocation methods
3.2 Expected change [increase] in economy-wide production (GDP) (before and after linking)	4a.3 [Significant] difference of permit price level before linking	5.3 Availability and compatibility of safeguards against oversupply
4a.4 Expected net capital flows (from seller to buyer)	4b.1 [High] trade exposure of ETS sectors in relation to similar sectors in all third countries together ← might also be modelled	
4b.2 Expected relocation of production and investment (after linking)	5.2 Permit price stability (before linking)	
4b.3 Expected change of permit price (before and after linking)		
5.1 Number of market participants (before and after linking) relative to market size and number of trades second best: empirical quantification →		

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Only few operationalised criteria are empirically quantifiable. At this point, the compilation of a basic database therefore appeared not useful. Moreover, for some indicators a database covering all relevant countries/ETS regions is not available (e.g. permit price).

The analysis of interdependencies of linking effects demonstrates the central role of the change in the permit price. There are some assessment criteria, which affect the level and direction of change of the permit price after linking, and there are some assessment criteria, on which changes of the permit price have an effect. Together with the analysis on the MACCs, a conclusion is that the permit price could be used for a first *rough estimation* of static efficiency gains from linking. The underlying MAC curves are not necessarily to be made explicit and used explicitly as they are central influencing part of the economic models' output. However, if efficiency gains are about to be *quantified exactly*, knowing the MACC is necessary.

A main rationale for linking ETS is economic efficiency. This is covered by the operationalised criteria as static efficiency. It has been shown that analysing the impact of linking ETS on dynamic efficiency is a very complex and highly challenging task. So far, the implicit focus of the lines of argument was on the ETS-sectors. Things get, however, even more complicated when trying to analyse the impact of linking ETS on the dynamic efficiency in the NETS-sectors, which has not been considered in this working paper. Most importantly, the present analysis has shown, that dynamic efficiency is a field of high relevance for the evaluation of linking ETS but at the same time very difficult to model. Existing models can rarely cover a substantial fraction of the sub-effects in a satisfactory manner yet (e.g. issues around uncertainty/volatility of market developments and resulting investment behaviour) or can almost by definition not be modelled (e.g. external shocks and the loss of domestic control when shifting policymaking to a higher governance level and the effect on domestic and global dynamic efficiency). As a consequence, dynamic efficiency effects of linking ETS remain a large research field of high relevance and a challenging task to modellers evaluating the linking of ETS.

Central part of the report is a description of available economic models and their suitability to assess bilateral direct ETS linking effects. The analysis of whether the selected criteria and indicators are covered in these models confirmed the results of the first screening. Generally, none of the available economic models covered all criteria but a number of models shows a "good" coverage. This held also true after the analysis was expanded to the regional coverage of the exemplary countries South Korea, China, Mexico and Turkey. There does not exist the one and only perfect model. Some models perform better in terms of regional coverage, some perform better in terms of criteria coverage (usually the general equilibrium models), some provide a compromise with good but not best regional and criteria coverage at the same time. In general, modelling never replicates the entire reality, and even crucial aspects might in reality differ from what is assumed in the models. Therefore, any modelling data needs to be interpreted with caution. Still, there is however no reasonable alternative when ex-ante assessments rely on the quantification of certain variables.

Based on the research, a model selection to assess linking effects will be conducted in the following (see as well Figure 8).

The best compromise seems to be the macro-econometric model E3ME. It is the most useful model in terms of combined regional (EU-ETS and linking partners)- and criteria coverage, apart from assessing market liquidity (see Figure 7). It further provides a meaningful, detailed sectoral disaggregation.

PACE seems to be a well-suited model, too: It provides output for all relevant assessment criteria, apart from permit market liquidity (see Figure 7). The regional coverage seems to be quite flexible, which means that, given that data is available, its regional specification might perfectly fit the present needs.

A good alternative, or a model that might be useful to complement an analysis with E3ME or PACE, is the partial equilibrium model POLES. Apart from the fact that it has a good regional coverage (EU-ETS and potential linking partners), this model has an explicit **permit trade module** (ASPEN), which might provide interesting detailed insights in the permit market, which is rare for general equilibrium models. It further covers all assessment criteria. Yet, since it is a partial equilibrium model, the assessment criteria are not as well covered as in the general equilibrium models.

Another good compromise in the partial equilibrium context is TIMES. The model family is supposed to be quite flexible and provides a useful regional coverage in line with a broad coverage of assessment criteria. However, again, since it is a partial equilibrium model, the assessment criteria are not as well covered as in the general equilibrium models.

In terms of criteria coverage, the general equilibrium model GEM-E3 stands out of the other models. In addition, it has a good coverage of the EU-ETS. However, its major shortcoming is that it covers only China as the potential linking partner. Therefore, it might be a useful complementary model to assess the permit market liquidity, since this criterion is not covered in the other general equilibrium models.

Based on the information available so far, the shortlist of this model selection is as follows (in alphabetical order):

- E3ME (macro-econometric model)
- GEM-E3 (general equilibrium model)
- PACE (general equilibrium model)
- POLES (partial equilibrium model)
- TIMES (partial equilibrium model)

From the result that different models cover different criteria, we conclude that a future quantification should be based on a number of choices of decision-makers.

- specifying the countries to be linked
- prioritising domestic effect to be looked at and the scope of assessment (e.g. impacts on NETS sectors)

Depending on the political priority that ETS linking has or might receive in the future, one could also think of

- agreeing on a common framework with modellers on which basis models analysing particular cases of linking can be adapted accordingly
- or building a modeller task force (think tank)

It is important to note that, by definition, optimisation models are not able to model the deviation of the entire economic system from the hypothetical optimal growth path. Therefore, it is very important to complement the modelling analyses with qualitative reasoning and empirical evidence, based on past experiences and broader theoretical understanding.

For further tasks of this project, a major conclusion from WP3 is that it appears difficult to develop a simple tool that assesses the economic linking effects quantitatively, as only a limited number of criteria can be quantified on the basis of existing empirical data. The assessment of many of the economic criteria would remain a qualitative description. Moreover, environmental and political criteria would additionally have to be considered. We suggest to rather develop a guidance for decision makers on how to proceed in the still “rough” assessment of economic linking effects together with requirements that more complex modelling will have to satisfy in order to execute a quantitative ex-ante (“pre-linking”) assessment of linking ETS.

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4 ETS design - Qualitative analysis of the potential impacts of linking

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4.1 Introduction

In 2016, emissions trading systems (ETS) can be found across four continents covering approx. 9 % of global emissions (ICAP, 2016). . This number continues to grow, with many policymakers preparing to introduce an ETS in the coming years. Most notably, in 2017, the Chinese national system will be launched, forming the world's largest carbon market at almost twice the size of the European carbon market. Linking two or more ETS can deliver many potential benefits, such as increasing mitigation, cost-efficiency, market liquidity or provide a strong political signalling effect. Technically, two systems could immediately link without negotiating or amending any design features, however, this would likely not lead to a robust carbon market.

Certain design features need to be aligned in order to create a functioning joint market in which allowances can be traded across jurisdictions and that a 'tonne is a tonne' of emissions reduced across the whole system. Additionally, policymakers must also pay close attention to design features that would be automatically imported into the other system as a result of linking. Such automatic propagation may come with significant environmental, political and economic implications that could undermine the goals and policy preferences of the respective linking partners.

This chapter looks at the degree of ETS design harmonisation necessary for linking to take place. It analyses the compatibility and harmonisation requirements of key ETS design features and discusses the respective environmental, political and economic implications. The pachapterper builds on the previous chapters, which have described the potential reasons policymakers may have for linking their ETS with another system. In order to realise the expected benefits of linking, it is crucial for policymakers to carefully consider and understand the various design features that characterise an ETS, and how the linked systems would interact.

Policymakers must also bear in mind that the design features of an ETS are the result of many different influences at play and may have been implemented for a number of reasons:

- they may be a means of delivering policy goals, such as driving a certain level of domestic emissions reductions or generating sufficient funding for other government programmes;
- they may have been implemented to appease or gain support from key stakeholders, such as businesses, NGOs or address policy concerns of other ministries;
- they reflect the local conditions in which the ETS operates, for instance, in some jurisdictions a certain sector might be excluded from the ETS due to its high marginal abatement costs or indirect emissions may be included in cases where there are price controls in the electricity sector.

Thus, any amendments to the ETS will also affect these underlying policy goals and political compromises. Policymakers must bear this trade-off in mind when entering into linking negotiations.

The chapter is organised as follows. After a brief outline of the analytical approach, ETS design features are grouped into ten categories discussed with a view to their harmonisation requirements and implications for linking: (1) system type; (2) caps and targets; (3) scope and coverage; (4) allocation; (5) price and supply management measures; (6) offsets; (7) temporal flexibility; (8) monitoring, reporting and verification (MRV) and registry design; (9) enforcement and penalties; (10) other links (e.g. links with a third system or indirect links with international crediting systems). The order in which these design elements are reviewed within each risk category does not imply a sequential ranking as to which issues should be dealt with first, nor does it imply a hierarchy as to which issues are most important. In cases when full harmonisation may not be possible but is nevertheless crucial, we briefly discuss options for restricted linking or linking by degrees.

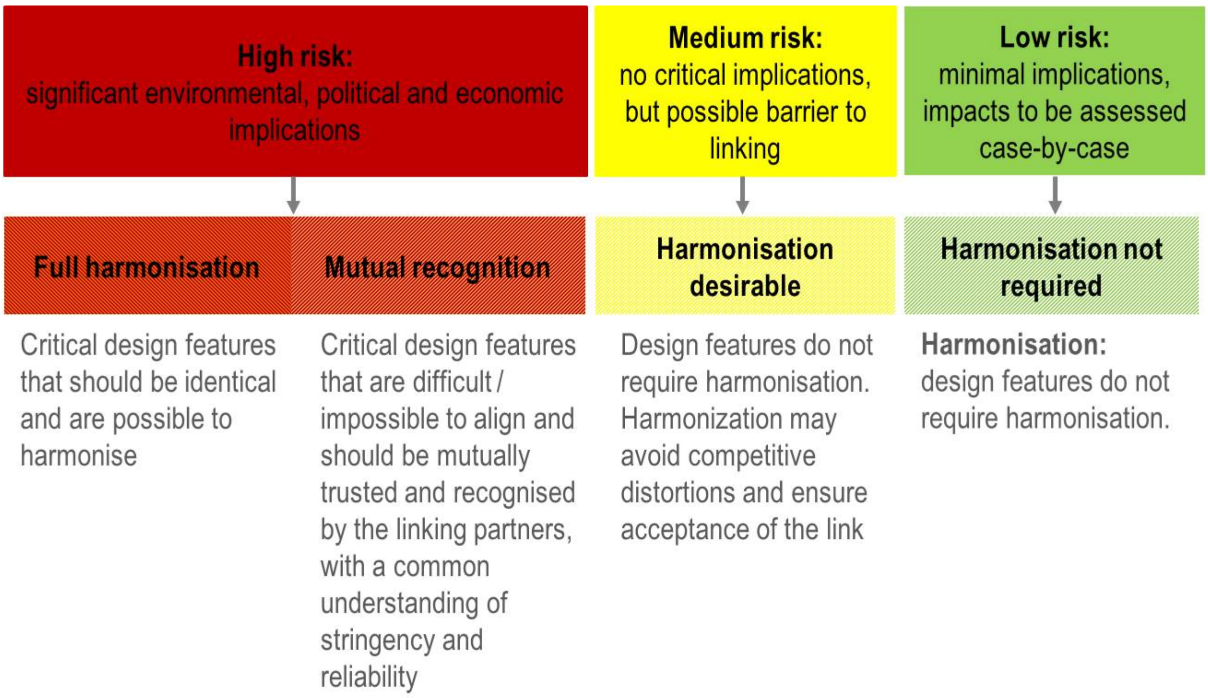
4.2 Analytical approach

Figure 12 describes the analytical approach of this chapter. Based on the linking objectives and the assessment criteria to measure the achievement of these objectives, which are outlined in chapter two, we identified key ETS design features which need to be considered with respect to their potential effects on linking and harmonisation requirements.

For a linking process and agreement to happen, mutual trust in and transparency of the ETS design between the linking partners is a necessary precondition. Furthermore, if there is no mutual trust and credibility before and throughout the linking process than there will be no further consideration and agreement on harmonising specific ETS design features.

First, the paper analyses the main ETS design features with regard to their potential political, economic and environmental implications for the linked market and also for each linking partner. Based on the risks these design features could pose if unaligned, they are grouped into three categories: high, medium and low risk (see below). Based on the potential implications, the paper examines the extent to which each design feature needs to be aligned in order to achieve a functioning joint carbon market, as well as the linking objectives and system objectives of each partner.

Figure 10: Analytical framework



adelphi, 2017

1. High risk. Critical design elements of an ETS that have significant environmental, political and / or economic implications might pose a potential barrier to linking if not aligned. These critical elements can jeopardise environmental targets, undermine political goals of the linking partners or disrupt the functioning of the common market. Ideally, these design features should be identical. Linking partners need to agree on which level of alignment is necessary and possible:

1. **Full harmonisation necessary.** These are critical design features that should be (more or less) identical and are possible to harmonise. Some design features must be harmonised for technical reasons or because a different design would lead to significant environmental, economic and political drawbacks. If not aligned, they will undermine the environmental integrity or effectiveness of the linked system. For example, if participation in one system is mandatory and voluntary in the other, or if the cap is an absolute figure in one system and intensity-based in the other. These features must be identical to ensure a functioning joint carbon market.
2. **Mutual recognition necessary.** Where the full harmonisation of such critical design features is not possible, policymakers must be able to accept the differing design feature in the linking partner's system and trust that it is sufficiently stringent and reliable. For example, a robust MRV framework is crucial to the functioning of linked ETS, but full harmonisation of two different MRV systems is not possible because the detailed provisions usually reflect the jurisdiction's emissions profile, legal system, administrative procedures and cultural background etc. As long as the MRV systems are comparable in their stringency and mutually recognised by the linking partners, they can remain different and the environmental integrity of the linked system will not be undermined.

2. Medium risk. This group includes design elements that do not have critical implications, i.e. they will not undermine the environmental integrity and / or achievement of long-term abatement targets. However, they can still pose a barrier to linking and the differences should be carefully investigated by the linking partners.

1. **Harmonisation desirable.** Medium risk design features do not require (full) harmonisation but their alignment may be desirable for other reasons, such as reducing competitive distortions, ensuring political acceptance of the link, facilitating the linking process or reducing the administrative burden of operating a joint carbon market. For example, allocation mechanism and rules are not necessary to harmonise for the linked market to function. At the same time, if one system allocates its allowances for free, and the other system uses auctioning, compliance entities in the second system will be more sensitive to price changes resulting from linking. This will raise fairness and competitiveness concerns

3. Low risk. Design elements in this group normally have little or no environmental, political or economic implications. Linking partners should assess potential impacts and whether there is a need for alignment on a case-by case basis.

2. **Harmonisation not necessary.** Aligning and adjusting these design elements is not necessary in order to establish a functioning joint carbon market, i.e. there would be no significant impact if they were not aligned. An example for this group is ETS inclusion thresholds for companies. Unless the differences are large, the inclusion thresholds do not form a barrier to linking. They are formed based on domestic considerations of the linking jurisdictions. Lowering the threshold to include smaller emitters may impose high transaction costs on these entities or increase the administrative burden on the regulator.

This categorisation may also change depending on, among other things; the jurisdiction's linking goals and the size of the linking partners. The motivation for linking would elevate or reduce the importance of certain design elements to ensure that policy priorities are met. Multiple linking goals also imply trade-offs and compromises. For instance, while a government may be focused on having an environmentally ambitious system, it may also offer its regulated entities more (and potentially cheaper) means of emissions reductions. Another example would be linking with a system that has a significantly lower carbon price. Such a link would deliver the greatest cost efficiency gains but at the same time it also risks undermining the environmental effectiveness of a joint carbon market.

Secondly, the degree of harmonisation also depends on the relative sizes of the carbon markets considering linking. A system that links to a significantly smaller ETS may not be as concerned about the impact of some unaligned design features. Developments and design elements in the smaller system will still affect the larger system but not to the same degree as developments in the larger carbon market will determine conditions in the smaller ETS. Finally, other issues, such as the history of cooperation between the linking partners, the acceptability and availability of compromise options, institutional structures and wider climate change framework will also all have a bearing on the relative importance of these issues.

4.3 High Risk (Full Harmonisation)

4.3.1 System type (voluntary vs. mandatory)

While linking is theoretically possible between a voluntary and mandatory ETS, in practice, all currently existing ETS are mandatory systems and linking has only occurred between mandatory ETS. Although linking negotiations between the EU and Switzerland started when the Swiss ETS was a voluntary system, Switzerland subsequently amended their program to be a mandatory system and bring it closer in line with the EU ETS.

Environmental issues. Voluntary programs generally have a lower coverage than mandatory programs and it is unlikely voluntary participants would accept a stringent target (Haites & Mullins, 2001; Sterk et al., 2006). Thus, a jurisdiction with a mandatory ETS that has a more ambitious target than the voluntary system may raise concerns if they were to enter into linking negotiations. Specifically, two environmental issues must be addressed: (1) the total level of emissions reductions across the linked ETS; and (2) the issue of circumventing the ETS.

Given the voluntary nature of the system, there is no guarantee that a certain level of emissions reduction would be reached, threatening the environmental integrity of the mandatory system (Sterk et al., 2006). Furthermore, it is likely participants would only accept a relatively weak target. Secondly, given the price will likely rise in the voluntary system following the link, this also strengthens the incentive for covered entities to shift production outside of the ETS in order to generate excess units to sell (ibid). More broadly, rising prices in the voluntary system would be an additional incentive for entities to not participate in the system. Although both these risks are present without linking, if linking increases the price in the voluntary system, these risks would be heightened.

Economic issues. Given the relatively weak nature of a voluntary ETS (i.e. weak target, no mandatory compliance), there are unlikely to be any significant economic issues as a result of linking. However, a voluntary system also does not bring significant economic advantages as a linking partner. For instance, a jurisdiction looking to improve its market liquidity or strengthen the carbon price signal may not opt for linking with a voluntary program given its relatively weak targets, coverage and liquidity. This is further undermined if the voluntary system has generous opt-out provisions.

Political issues. Equity issues may arise as regulated entities in the mandatory system would be subject to a carbon price, whereas this would be optional for entities in the voluntary system. Entities in the mandatory system, particularly if they are in direct competition with entities in the voluntary system, may resent the imposition of a higher reduction target and mandatory surrender obligations.

4.3.2 Absolute or intensity-based cap

A system with an absolute cap imposes a clear limit on the number of emissions allowed under its ETS. Conversely, in an intensity-based system, the focus is on the number of allowances per unit of GDP (or other metrics such as energy consumption). With an intensity-based cap, the amount of emissions reduced under the ETS can only be known ex post. The total amount of emissions that have to be reduced will fluctuate depending on the performance of that jurisdiction's economy. This fluctuation would then be imported into the linked system with an absolute cap.

Technically, it is possible to link a system with an absolute cap with one that employs an intensity-based cap (Ellis & Tirpark, 2006). However, this raises a number of issues, such as cap integrity, competitiveness and liquidity shocks. Ultimately though, in practice, differences in the cap design may not be as important given that currently no operational ETS uses an intensity-based cap.

Environmental issues. Linking a system with an absolute cap with one that has an intensity-based cap could result in a higher level of total emissions within the linked ETS. There would be no guarantee that the target of the system with an absolute cap will be met. Whether the target is met depends on the economic conditions in the intensity-based system as this will determine whether emissions will grow or shrink in that jurisdiction. Linking could lead to higher emissions overall if output increases in the intensity-based system (Sterk & Schüle, 2009).

The risk to the environmental integrity of the linked market also increases if the system with an absolute cap becomes a net buyer. By importing allowances from the intensity-based system, which provides no guarantee on its total level of emissions reductions, there is also no guarantee that there would be a certain level of emissions reduced across the linked market (Tuerk et al., 2009b; Marschinski, 2008). On the other hand, if a system with an intensity-based cap were a net buyer from an absolute cap system, its effectiveness would be compromised as it would allow for more production than otherwise possible (Tuerk et al., 2009b).

Economic issues. With an intensity-based cap, allocation takes place based on projected production levels and is then adjusted once the actual figures are known. This adjustment can lead to liquidity shocks, which would affect the linked ETS (Sterk et al., 2006). Additionally, intensity-based systems provide less of an incentive for regulated companies to factor in a carbon cost, which may raise competitiveness concerns from companies under a system with an absolute cap.

Political issues. Concerns about environmental integrity can also become political issues, particularly if an emissions increase in the absolute cap system due to linking undermines broader climate change policy targets.

Some of the environmental and economic issues can be addressed by introducing exchange rates (see section on restricted linking options for more information) whereby allowances from the system with an intensity-based cap would be discounted against allowances from the system with absolute cap. However, this may raise issues of political acceptability and will increase the technical complexity of the linked systems (Tuerk et al., 2009b).

4.3.3 Supply management measures

The treatment of supply management measures in a linked carbon market is controversial and challenging as these measures reflect the political preferences and compromises of the policy-maker. There are also a number of ways in which such measures can be implemented, further increasing the complexity of linking. There are quantity-based instruments like the EU ETS' Market Stability Reserve (MSR) and price-based instruments (price collars, floors and ceilings).

As these measures are automatically propagated from one linking partner to another, agreement on these design features is crucial to the functioning of the joint carbon market. Namely, if one of the systems uses a price ceiling, the allowance price on the linked market will not grow beyond this value. Similarly, in the case of a minimum price, if the allowance price on the linked market is below the price floor applied in one of the linked systems, the allowances will be bought in the system without a price floor until its level has been reached.

In practice, linked jurisdictions have chosen to adopt identical price management measures, such as the Allowance Price Containment Reserve[48] and minimum auction (reserve) prices in both Québec and California. During linking negotiations with the EU, Australia also agreed to abolish its AUD 23 (EUR 15.61) fixed price.

Finally, as Ranson and Stavins outline, price-based supply management measures also reflect policymakers' broader notions of an 'acceptable' carbon price, which is also related to approaches to cap stringency and the ambition of its ETS (2014). If these approaches differ significantly, this likely prevents a system from being seen as an 'acceptable' linking partner. However, the existence of price-based supply management measures could make the jurisdiction a more attractive linking partner, as it safeguards (to some extent) against significant fluctuations in the carbon price and / or the number of allowances in circulation. Linking systems with different approaches to supply management (e.g. quantity-based vs. price-based supply management) may be difficult.

Price-based supply management: Price ceiling

If one system has a maximum allowance price (price ceiling), this feature will be automatically propagated into the linked partner's system, acting as a price cap across the joint carbon market (Burtraw et al., 2013; Tuerk et al., 2009). Reconciling the use of price ceilings is not only challenging, as it reflects the political priorities of the jurisdiction, but there are also significant environmental implications. In practice, only the Korean ETS has provisions that would allow for the establishment of a temporary price ceiling, which would make it challenging should it opt to link with a system opposed to any upper limits on its carbon price.

Environmental issues: Depending on how high the price ceiling is set in one of the linked partner's system relative to the cost of the carbon price, this may not pose any environmental issues for the joint carbon market. However, an imported price ceiling would affect the environmental effectiveness of the linked systems because the cap would effectively cease to apply after a certain price has been reached (ICAP, 2014). Thus, linking with a system that has a price ceiling may not be appealing for policymakers that want to achieve a certain reduction target.

Economic issues: Price ceilings may also have been implemented to safeguard the competitiveness of their industries or to ensure that allowance price does not reach untenably high levels (Hepburn, 2006, Comendant & Taschini, 2014). If the price ceiling is removed during linking negotiations this may undermine market participants' confidence in the price stability.

[48] Although the Reserve annually removes a percentage of allowances from auction, these are only released if certain price levels are reached. Therefore, it is considered as a price-based mechanism.

Political issues: Price ceilings are challenging to harmonise as they represent the political preferences of policymakers on appropriate carbon price levels or are implemented to ease industry concerns regarding the compliance burden of the ETS. Any amendments to the price ceiling as a result from linking negotiations would risk undermining these political goals or key stakeholder support.

Price-based supply management: Price floor

Similar to the discussion on price ceilings, the treatment of a price floor in a linked carbon market also raises challenging issues and can be quite complex to resolve. A minimum price in only one of the linked systems is ineffective if the allowance price is below the price floor. The emission allowances would then be bought in the system without a minimum price until the minimum price has been reached. Furthermore, if there is sufficient supply of allowances at a price below the price floor, the new allowance price on the linked market may set below price floor levels.

Both Québec and California have the same auction price floor and the Ontario ETS, which will come into operation in 2017, has also set its price floor to match the Québec and Californian carbon market. RGGI also has a minimum auction price and there is also the possibility of setting up a temporary price floor in the Korean ETS. In practice, even though there is no price floor in the secondary market, the auction price floors operate as a de facto price floor.

Environmental issues: A price floor may have been implemented in order to secure a minimum price on pollution and maintain a minimum level of incentives for abatement. A price floor can also correct against the possibility of oversupply (Purdon et al., 2014).

Economic issues: A price floor offers a certain degree of price certainty and provides a minimum return on investment in low-carbon technology (Fankhauser & Hepburn, 2009). It can also limit price volatility and reduces uncertainties for low-carbon innovation (Wood & Jotzo, 2009). If the price floor is circumvented (market participants buy allowances in the system without price floor), this redirects auction revenues from the jurisdiction with the floor price to the jurisdiction without floor price.

Political issues: Adjusting or abolishing the price floor, as outlined in environmental and economic issues, can undermine the policy objectives of the jurisdiction (Fankhauser & Hepburn, 2009). If a certain level of auction proceeds is an important source of revenue for a jurisdiction, it may oppose the abolishment or amendment of its price floor. For instance, Australia's decision to abolish its AUD 15 (EUR) price floor not only raised concerns about the loss in fiscal revenue (estimated at AUD 3-5 billion annually) but the resulting AUD 2.4 billion cut in funding to additional climate programs also undermined the credibility of Australia's larger climate policy (Drummond, 2012).

Quantity-based supply management

So far, only the EU has adopted a quantity-based approach to supply management. The MSR will come into effect at the beginning of 2019 and release or remove allowances circulating in the European carbon market to control situations of substantial oversupply or scarcity.

There has not been any research at this stage on the challenges of aligning quantity-based instruments when linking ETS. Linking partners should thoroughly assess the impact of the quantity-based instrument on the linked market and vice versa as such instruments will automatically propagate into the other system. At the same time, in order to remain effective, instruments like the MSR will have to be applied to the whole linked market and adjust to the new supply and demand after the link. If the MSR were to only apply to the EU market, this would limit the effectiveness of the reserve. In the case of the potential link between the EU ETS and the Swiss ETS, if the MSR were to only apply to the EU-ETS, not the linked Swiss ETS, this may not have such a dramatic impact on the joint system, as the Swiss carbon market is significantly smaller than the EU carbon market (1,939 $MtCO_2e$ compared to 5.2 $MtCO_2e$). However, it is unclear how the issue of the MSR will be treated in the EU-Swiss link.

As a first step, a preliminary impact assessment or modeling of the potential effects of the MSR for both linking partners could be done. However, considering the long negotiations on the adoption of the MSR, any changes to the mechanism would be challenging.

4.3.4 Banking

If one system allows banking and the other does not, the banking option will be propagated into the other system (Tuerk et al., 2009). With effective caps, banking will have a little effect on the linked market. It may, in fact, provide a positive incentive for early abatement (Sterk & Schüle, 2009; Jaffe & Stavins, 2007). However, the use of different banking provisions may complicate the accounting process (Ellis & Tirpak, 2006).

In considering the use of banking, two aspects have to be considered: the quantitative restrictions and the time period over which allowances can be banked (eg. within phases, between phases) (DEHSt, 2013). Quantitative restrictions not only include the proportion of allowances that can be banked but also holding limits that circumscribe the number of allowances that can be held by an entity (as is the case in California and Québec).

Environmental issues. Banking can encourage entities to reduce emissions below their annual target, as the excess reductions can then be banked and used in the future (Burtraw et al., 2013; Sterk & Schüle, 2009). Additionally, this element of temporal flexibility may also reduce the cost of abatement (PMR & ICAP, 2016). However, there may be some concern about the impact of these allowances returning to the carbon market (DEHSt, 2013). Broadly speaking, a return of allowances into the carbon market would weaken the carbon price signal and may make the transition to a low-carbon economy harder. The exact effect this will have on the joint market depends on the size of the banked surplus as well as the overall size of the jurisdiction. This issue would be even more pressing if banking transfers system failures, such as an oversupply of allowances, into future compliance periods.

Economic issues. Different economic issues arise depending on the type of banking. In the case where banking is limited by the type of allowance (e.g. allowances in system A can only be surrendered for compliance until a certain date) then it raises strategic purchasing issues. Namely, if a system that did not allow banking linked with a system that allows banking, this would affect strategic decisions as to which allowances to hold as allowances that cannot be banked would not be as valuable as those that can be used for future compliance. For instance, entities would be incentivised to hold allowances from the system that allows banking, undermining the banking regulations in the other jurisdiction. In the case where banking is limited to the type of entity (e.g. those in system A) this can incentivise participants in the system without banking to sell their allowances to the system that allows banking.

Political issues. With sufficiently stringent caps and if both systems have no significant oversupply problem, banking raises no serious political concerns.

4.3.5 Borrowing

Borrowing allowances from future compliance periods is a design element that is often criticised in the literature on ETS and linking as it might lead to delays in emissions reductions and investments in low-carbon technology. In turn, this increases the cost of abatement and may encourage governments to set less ambitious reduction targets (ICAP, 2014; Tuerk et al., 2009;

Boemore & Quirion, 2002). However, the exact impact of borrowing on a linked system also depends on the number of allowances that can be borrowed and for how long.

Environmental issues. As discussed in the previous paragraph, schemes that allow for a significant share of borrowing may reduce the environmental effectiveness of the system. This may also happen if the company goes bankrupt or dissolves before it pays back its “borrowed” emissions reductions (Sterk et al., 2006). There is also a risk that companies might borrow allowances to artificially increase their future compliance cost and pressure policymakers for adopting a weaker target (Boemore & Quirion, 2002).

Economic issues.

If companies can use a future share of allowances for compliance, this may weaken the carbon price signal and decrease incentives to invest in low-carbon technology.

Political issues. Policymakers that are concerned with the environmental integrity of their ETS or want to achieve a certain level of domestic investment in low-carbon technology may not want to link with a system that allows borrowing.

4.4 High Risk (Mutual Recognition)

4.4.1 Cap determination and annual reduction

In many cases it may not be appropriate to perfectly harmonise the approaches for setting the cap and the cap reduction trajectory; however, linking partners should aim for caps and annual reduction trajectories that reflect a similar level of ambition (Burtraw et al., 2013). Indeed, many studies and existing linking cases show that having comparably stringent caps, as well as sharing a joint vision of medium and long-term emission trends and reduction objectives, are likely to be preconditions for linking (Haites, 2013; Sterk & Schüle, 2009; Edenhofer et al., 2007).

Cap stringency represents the environmental target and is important to provide sufficient incentives for long-carbon investments and achieve short- and long-term abatement targets (see also chapter two). That being said it is challenging to define stringency or compare it across different systems. Generally speaking, the lower the number of allowances under the cap (compared to the baseline emissions), the more ambitious the cap is, and all things being equal, the higher the carbon price. On the other hand, the stringency of the cap will also be affected by, among other factors, the size and nature of the linking partner’s economies. In addition to that, it is necessary to differentiate between situations where ETS is the only (or main) climate policy instrument or where there are other interacting climate and energy policies for ETS sectors[49]. Thus, evaluating stringency becomes more complicated than simply assessing the number of emissions under the cap (Burtraw et al., 2013). Therefore, although the level of cap stringency cannot be fully harmonised, cap design, cap reduction factors and the overall ambition of the jurisdictions’ climate policies need to be discussed and mutually accepted by the partners before linking.

However, some aspects relating to the timeline and the main policy milestones of the systems, such as planned reviews, targets and reduction pathways should preferably be harmonised. The regularly scheduled United Nations (UN) reviews of countries’ climate targets, e.g. Nationally Determined Contributions (NDCs), provide a potential starting point for harmonising cap setting

[49] Whereas the allowance price may be a good indicator for stringency of the cap in the first case, it is more complex in the latter case, where interacting climate and energy policies lead to abatement, thus influencing (decreasing) the price.

and review periods. For instance, California and Québec conduct their system reviews separately within their respective jurisdictions, but harmonise the timing and focus of their reviews.

Environmental issues. Linking with a jurisdiction that has a cap that is comparatively less stringent will reduce the environmental performance of the linked systems by potentially introducing "hot air"[50] into the linked systems (ICAP 2014, Haites & Mullins 2010). In the system with a more stringent cap, the lower carbon price after linking may also reduce incentives for investments in domestic low-carbon innovation or domestic emissions reductions.

Economic issues. Three major economic issues arise when linking systems with differing caps and annual reduction trajectories. First, there is a trade-off between economic and environmental benefits: the greater the differences in carbon prices, the greater the efficiency gains, at the cost of less domestic emission reductions. Second, linking systems with significantly different allowance prices can lead to substantial financial outflows from the more stringent system and allowance transfers from the lower priced system until prices equalise. Finally, an additional concern when linking with less ambitious systems, raised by Flachsland (2008), is the incentive to relax the cap to generate additional revenues from selling the allowances into other system (Helm, 2003; Rehdanz & Tol, 2005). However, it can be minimised if both partners share a common vision on climate policy objectives (Flachsland, 2008).

Political issues. Jurisdictions with very different carbon prices may find it politically challenging to negotiate a link. A difference in carbon prices often reflects a differing level of ambition in terms of emissions targets, caps, the use of supply management measures and offsets. Given the importance of these features, such a wide array of differences makes it unlikely that these two jurisdictions would find it easy to link systems. Additionally, systems with a significantly higher price may be unwilling to link with systems that have a lower price as linking would drive down their price, reducing the incentive to mitigate and invest in low-carbon technology. Equally, the system with the significantly lower price may have concerns about the burden a higher carbon price would have on their economy.

That being said, the environmental, political and economic impact of the cap should also be considered in the context of a jurisdiction's broader environmental and climate policy portfolio and the relative role the ETS plays in this policy mix. If the ETS is small in scope and/or not the only/main climate policy instrument in both jurisdictions, then the impact of having unaligned caps on their broader climate policy targets also decreases (see chapter two). If such a system were to link with a jurisdiction that has an ETS as their main climate policy instrument, the issue of unaligned caps can become problematic.

4.4.2 Offset quotas

In most cases, ETS have limited the number of offsets they allow within their system. The use of offsets in an ETS may create a new upper limit of the cap if offset prices turn out to be lower than the allowance price, as was the case with offsets allowed in the New Zealand and the EU from the Kyoto mechanisms (CDM/JI). In a linked market, the quotas in both systems would then add up to a new upper limit for the joint carbon market (Tuerk et al., 2009b). In practice, some linking partners have chosen to harmonise their offset quotas, as is the case in California and Québec where the use of offsets is capped at 8% of an entity's compliance obligation. However, some

[50] Credits or allowances that do not actually result in real emissions reductions.

differences are also acceptable. For instance, during phase II of the EU ETS, member states could set their own offset limits (as outlined in their National Allocation Plan).[51]

Offset quotas need not be identical across systems, but given linking will create a common pool of offsets for both partners, both systems need to mutually accept the offset provisions of the other and fully understand the implications of linking differing offset provisions. Many authors have stated that differing offset provisions can be a significant barrier to linking (ICAP 2015; Burtraw et al., 2013; Flachsland et al., 2009; Sterk et al., 2009). This is because the use of offsets in one system will affect participants in the other system and can challenge the environmental integrity of the linked system. Not only will they be available for use by all regulated entities but it will also have an indirect effect on the joint carbon market. The use of offsets in one system “frees up” additional domestic allowances that would otherwise have been used for compliance. This increases the overall supply of allowances in the linked system. (Hawkins & Jegou, 2014; Burtraw et al., 2013; Zetterberg, 2012).

Additionally, the MRV provisions surrounding the use of offsets must be transparent, robust and credibly enforced. Significant differences in the number of offsets allowed in the respective systems would raise several concerns.

Environmental issues. For policymakers concerned with the environmental integrity of their system, linking with a system that allows a generous use of offsets may not be attractive as this would weaken the overall cap and increase the number of emissions within the joint market (Edenhofer et al., 2007).

Economic issues. Linking with a system that allows a significantly higher number of offsets would likely lower the carbon price in the joint system (Edenhofer et al., 2007) which could undermine the incentives for domestic low-carbon investment and innovation (Ranson & Stavins, 2012). Generous crediting rules can also result in competitive distortions if the offsets are cheaper than the market carbon price (DEHSt 2013; Edenhofer et al., 2007)

Political issues. Offset quotas reflect political objectives and compromises in each system. Also, given their potential effect on environmental integrity and market carbon price in the linked system, adjusting offset quotas may be challenging for political negotiations.

4.4.3 Offset standards

The decision as to which type of offsets to allow into a system is informed by a number of factors, including the marginal abatement cost for certain sectors, the jurisdiction’s emissions reduction target and the political preferences of the policymaker. Different offset standards can still exist in a linked carbon market if they are mutually recognised and accepted by the linking partners. For instance, the use of large-scale hydropower offset credits are completely banned in Norway but allowed in the EU (Hawkins & Jegou, 2014).

Linking partners do not need to fully harmonise their offset standards but should mutually agree upon the offset eligibility criteria, the relative stringency (e.g. setting of the baseline) or additionality of the projects and overall environmental integrity (Flachsland et al., 2008; Burtraw et al., 2013). They also need to make sure that accounting rules are credible and do not allow for double counting. Similarly, monitoring and verification procedures as well as registries and administrative systems can differ but should be comparable, transparent and mutually trusted by the partners (Pershing, 2007).

[51] Although the use of credits in the EU ETS was generally limited to 50% of the overall reduction under the ETS in that period.

Environmental issues. Offsets with low or questionable additionality will compromise the environmental integrity of the carbon market and lead to a higher total number of emissions in the linked system (Tuerk et al., 2008). If a jurisdiction has concerns about the environmental effectiveness of certain offset projects, this could cause problems prior to linking. Depending on the severity of their concern and the number of offsets allowed in the system, they may not be willing to even accept an indirect use of such offsets (Edenhofer et al., 2007). For instance, while some ETS linked to the Clean Development Mechanism (CDM), California chose not to as a result of their concerns about the environmental effectiveness of CDM credits (Taenzler et al., 2013). The widespread use of HFC-23 destruction projects in the CDM has also raised concerns about additionality and market distortions. Not only did the HFC-23 projects lead to over-crediting (Wara, 2008; Schneider, 2011) but the cheap cost of these projects also created perverse incentives to develop new refrigerator plants to get CDM credits (Wara, 2008). Additionally, the Western Climate Initiative (WCI) has also stated that any offset credits generated outside of North America must demonstrate its environmental effectiveness. The European Commission had also issued concerns about the environmental integrity of international REDD credits and domestic land-use credits, both of which are currently not allowed in the EU ETS (2008).

Economic issues. The stringency of the offsets, e.g. how stringent the baseline is set, may lead to low credit prices. If there is a significant amount of low-quality, low-cost offsets flowing into the linked system, not only would the environmental integrity of the joint carbon market be compromised, but the allowance price will also drop, decreasing investment incentives for low-carbon technologies (Flachsland, 2008).

Political issues. As Zetterberg outlines, the decision as to which offset projects to allow in an ETS is closely connected to the political objectives and compromises made between domestic policymakers and their stakeholders (2012). If a jurisdiction were to link with a system with differing offset types, the partners have to make sure that the agreed offset provisions for the linked system will not challenge their policy objectives and / or undermine the level of domestic stakeholder support for emissions trading.

As offset provisions are often shaped according to the unique circumstances of the jurisdiction (e.g. marginal abatement costs as discussed above), they can be difficult to align. As such, some authors suggest imposing a discount rate or quotas as intermediate solutions (see section on restricted linking options). Discount rates or quotas can be introduced for the use of certain project types or the partner's offset quota. However, such measures will affect the market value of these offsets and increase the complexity of the joint market, as well as increase the transaction costs.

4.4.4 MRV

Strong MRV provisions are essential to the functioning of any ETS, let alone a linked carbon market. MRV provisions in both systems should be comparable in terms of robustness, credibility and transparency in order to sustain a certain level of mutual trust in the linked market (Flachsland, 2008; Tuerk et al., 2009). For instance, using comparable methodologies and tracking provisions, ensuring 'a tonne is a tonne' and avoiding the double counting of allowances across the joint market will be key to creating a robust joint carbon market. Furthermore, credible enforcement (also see next section) of the relevant provisions in order to create confidence in the data will also be crucial. Additionally, MRV harmonisation may also represents a first step towards tackling other, more politically contentious design features (Burtraw et al., 2013).

However, full harmonisation of all these provisions may be quite complicated given they are often designed to cater for the economic and political circumstances of the jurisdiction, as well as reflecting certain institutional and legal traditions (e.g. environmental permitting procedures, national metrology, accreditation bodies, etc.). Thus, alignment may face considerable legal and technical issues. Nevertheless, a linked market could still function as long as the MRV provisions and registries of the linking partners are equally robust and use comparable designs such that both partners are confident in the data.

Environmental issues. If a system were to link with one that employs more lax MRV standards, this may raise concerns about the overall environmental integrity of the linked system. If the MRV system cannot guarantee the validity of the emissions represented by that system's allowances or offset credits, there is no guarantee that the environmental targets of both jurisdictions will be reached (Tuerk et al., 2008). For instance, a system might not have the necessary monitoring equipment, a history of under or over counting their emissions or there may be concerns about corruption. In such instances, the environmental integrity of their system may be in doubt. Additionally, even if systems have reliable MRV provisions, further coordination may be necessary if there are, for instance, differing points of regulation. If a system that covered emissions downstream (system A) were to link with a system that regulated emissions upstream (system B) there may be an increased risk of double or under counting emissions. Once linked, there is a risk that system B could import energy to entities under system A, which would then be counted twice unless additional MRV requirements were put in place that pay specific attention to the origin of energy products.

Economic issues. Although full harmonisation of the MRV provisions of both the linking partners is not necessary, identical MRV provisions would make the joint carbon market more stable and efficient (Edenhofer et al., 2007).

Political issues. As MRV provisions may not be as politically sensitive as other design elements, there may be some regulations that may be easier to align or connect via a relatively easy technical solution that can be a good starting point in building a linking relationship (Burtraw et al., 2013).

4.4.5 Penalties

In order for market participants to have faith in the carbon market, rigorous enforcement of the ETS in both jurisdictions is crucial (Burtraw et al., 2013). It is important to have similarly stringent compliance enforcement mechanisms as this is crucial to the functioning of a robust, linked carbon market as it builds mutual trust and credibility in the system. For instance, Switzerland amended its penalties to align itself with the EU ETS. Under the Swiss ETS, companies now face a EUR 100 penalty for each missing allowance and must also surrender the missing allowances in the following year. As it is difficult to measure rigorous supervision and enforcement in cases of non-compliance, the focus of this analysis is on the level of the non-compliance penalties (Haites, 2003).

Environmental issues. If a system links to a jurisdiction where a financial penalty is in place that is lower than the carbon price and non-compliant entities are not required to surrender the missing allowances on top of the fine, the financial penalty may become the default option. There is little incentive for participants to comply with the ETS and the financial penalty may act as a price cap. This would lead to lower emissions reductions within the system, jeopardising the environmental integrity of the joint market (Haites & Mullins, 2001; IISD, 2007). This concern may be countered with the introduction of non-financial penalties, such as surrendering additional allowances to make up for the missing allowances or criminal sanctions.

Economic issues. In a linked market with differing non-compliance penalties, there may be competitiveness concerns, as companies in one system would be penalised more heavily for their non-compliance than in the other system.

Political issues. If systems link with significantly different non-compliance penalties, regulated entities in the system with the higher penalty may lobby policymakers to lower the penalty that could result in a 'race to the bottom' between both linking partners.

4.4.6 Market oversight

Robust oversight provisions are crucial to guard against market fraud and manipulation, as well as increasing market liquidity and facilitating price discovery. Similar oversight provisions also ensure that market players and trading platforms are subject to the same conditions. Additionally, joint oversight structures can convey the appearance of shared governance and legal consistency, building confidence in the joint carbon market and its environmental targets. For instance, in the North American carbon markets, an independent market monitor has been contracted to guard against market manipulation, as well as recommend changes to the market rules (Görlach et al., 2015). Although both jurisdictions may want to jointly monitor the linked carbon market; this can also be carried out separately by the respective jurisdictions. What is important is that both jurisdictions mutually trust the other jurisdiction has robust and credibly enforced market oversight provisions. Furthermore, it is important that the registry guards against transaction manipulation and money-laundering, no matter if the systems are worked separately or in a joint registry (Burtraw et al., 2013).

4.4.7 Other links

A linking partner may already have pre-existing or planned links either with another ETS or a crediting mechanism like the CDM. This could be bilateral, unilateral or another form of restricted linking. Linking with a system that already has links to another ETS or market mechanism can complicate the linking negotiation and any final design on the joint market if one of the partners does not accept the third ETS or market mechanism. The exact degree to which the third party link raises issues for the joint carbon market depends on the nature of the link.

For instance, the case of California and Québec's planned link with the Ontario cap-and-trade program in 2018 is a special case as all three states and provinces are part of the WCI and their programs have been specifically designed with linking in mind. Not only did Ontario adopt most of the design features in the linked Californian-Québec carbon market but it is also using the same registry and auction platform via WCI. From a technical perspective, negotiating this multi-party link would be relatively uncomplicated. That being said, there are still certain requirements Ontario would have to fulfil before the link is established. For instance, California would have to be satisfied that the Ontario program is at least (if not more) stringent than the California cap-and-trade program.

A more complicated situation is the ongoing discussions between Mexico and California. Both parties have signed a MoU to cooperate on developing and implementing carbon pricing systems and other market-based systems (Office of Governor Brown, 2014). Two years later, a joint declaration to cooperate on carbon markets was also signed by Québec, Ontario and Mexico (Ontario Ministry of Environment, 2016). However, the exact relationship and nature of the links between the four jurisdictions remains unclear.

However, policymakers should consider whether they would want to directly link with both of the systems or just one – even though there would still be an indirect link with the other ETS even without a direct link to that system. Depending on the relative sizes of the linking partners, this would also affect the distributional impact of linking on all three systems. Given these impacts, it is likely that the other linked system(s) would want to be involved in the linking negotiation (Görlach et al. 2015).

4.5 Medium Risk

4.5.1 Allocation mechanism

Policymakers should bear in mind that the allocation mechanism, namely distributing allowances for free or auctioning, will create winners and losers even before a link is established. Parties who will generate revenue, or incur lower costs from the new market price will support linking, while those that incur higher costs will likely not. Buyers in the system with a higher pre-linking price will benefit from the lower, common carbon price, as their cost of compliance is reduced. Linking will bring in more revenue for sellers in the system with the lower pre-linking price, as they can sell their allowances at a higher price. In the case of auctioning, entities in the system with the lower pre-linking price that have to buy their allowances at auctions may not be as supportive of linking if this drives up the initial carbon price. On the other hand, the regulator of the lower pre-linking price system will generate additional revenue with auctioning at a new higher price (Burtraw et al., 2013; Flachsland, 2008).

Environmental issues. If the linked carbon market has a sufficiently stringent cap, differences in allocation mechanism should not undermine the environmental integrity of the carbon market (Sterk & Schüle, 2009). However, certain differences in allocation rules can compromise environmental effectiveness (see section below).

Economic issues. Many authors argue that linking does not cause additional competitive or economic distortions due to different allocation mechanisms, as such distortions already occur in the ETS regardless of linking (Sterk & Schüle, 2009; Tuerk et al., 2009a). Different allocation methods may nevertheless give rise to fairness and competitiveness concerns. For instance, if one jurisdiction allocates allowances for free and the other system auctions allowances, allocation in the first system may be seen as a lump-sum subsidy, resulting in a competitive advantage. This is especially true for companies that need to buy allowances at an auction, as they will be more affected by price changes than those who receive free allocations (DEHSt, 2013). Different cap nature may intensify such concerns. Namely, if allowances in the intensity-based system are freely allocated, then entities in the absolute cap system with auctioning might raise equity concerns - firms in the intensity-based system may be perceived as being ‘rewarded’ when they receive additional allowances for increasing their output.

Political issues. Depending on the size of the distributional implications of linking systems with different allocation mechanisms, this could give rise to political issues as stakeholders that have ‘lost out’ from linking put pressure on their policymakers. Additionally, the competitiveness concerns (outlined in economic issues) could also give rise to political issues with stakeholders raising equity and fairness concerns.

4.5.2 Allocation rules

Allocation rules can reduce or magnify existing concerns stemming from different allocation mechanisms but they do not pose a technical barrier for the functioning of the linked market if unaligned. Allocation rules include, for example, different approaches in free allocation, namely, grandfathering or benchmarking. Auctioning also has different design options and rules, e.g. auction format, schedule and frequency of auctions, available volumes, access to auctions, access to information, and management of auctions (PMR & ICAP, 2016). Allocation rules can remain different as long as they are robust and mutually trusted but a harmonisation or convergence could facilitate the linking process. For example, if both partners use auctioning as an allocation mechanism, harmonising auctioning rules will improve the technical operation of the system and reduce transaction and administrative costs, which in turn should spur positive effects in the overall market development.

Environmental issues. Linking two systems with different allocation rules does not create additional environmental distortions. However, linking partners should carefully analyse the differences. For example, if one of the partners uses output-based allocation, it could compromise the environmental effectiveness of the linked ETS as such an approach could incentivise entities under output-based allocation to increase their production in order to receive more allowances in future periods (Burtraw et al., 2013).

Economic issues. There are several economic issues related to differing allocation rules. First, when the systems have different rules in free allocation, this may raise fairness concerns. Namely, the benefits for the sellers will be greater in systems that use grandfathering (as entities receive more free allowances) than benchmarking. Second, differing treatment of new entrants and exits can also have distributional implications. For example, companies may have an incentive to start production in a system with free allocation or shut down production where they can still receive allocation for it (Tuerk et al., 2009a).

Furthermore, it is important to make sure that the auction design is transparent and does not lead to market manipulation. If both systems use auctioning, different auction designs can have an effect on the secondary market, affect the risk of market manipulations, openness and operational costs for all participants (PMR & ICAP, 2016). All existing systems that use auctioning do have a similar action design, except for the frequency of auctions. For instance, auctions in the EU ETS, RGGI, California and Québec use a single round, uniform price, sealed bid approach. But while Northern American systems hold their auctions quarterly, in the EU ETS, auctions are held several times a week on different trading platforms. Although the frequency of auctions can remain different when systems link, a harmonised approach will provide a more stable price signal and improve transparency. Thus, both California and Québec use the WCI trading platform and rules and also hold auctions jointly[52].

Political issues. There are no critical political barriers when it comes to different allocation rules. However, some issues could also arise depending on the allocation methods employed by the respective linking partners.

4.5.3 GHG covered

Greenhouse gas (GHG) coverage is closely related to sector coverage. If systems differ in terms of their GHG coverage this does not pose a technical problem for linking (Metcalf & Weisenbach, 2010; Ellis & Tirpak, 2006; Sterk et al., 2009; Haites & Mullins, 2001). Heterogeneity, in fact, can increase the economic efficiency of the linked systems by providing a larger variety of abatement options (with a range of cost profiles) across different GHGs and sectors (Burtraw et al., 2013; Sterk et al. 2006). Differences in GHG coverage also depend on the emissions profile of the respective linking partners, and it may not be such a significant issue if the missing gas is not emitted (or emitted in small doses) in the linking partner's jurisdiction. Even though Switzerland does not produce PFCs, technically it is covered under the Swiss ETS in order to harmonise its GHG coverage with the EU ETS.

[52] Ontario, whose cap-and-trade program was launched in 2017, will also use the WCI trading platform. Auctions will be held separately until the program links with California and Québec.

Environmental issues. Linking literature suggests that differing GHG coverage does not affect the environmental effectiveness of the linked system (Sterk & Schüle, 2009), but rather provides a greater variety of mitigation options. However, linking partners should carefully consider the differences and the existing mitigation potentials and costs in each system. This is especially important when or if one system decides to cover HFCs or N_2O, either directly through the ETS or through offset mechanisms, e.g. CDM and JI projects, which provide low-cost mitigation options, and the other system does not. If these usually large and low-cost mitigation options are not adequately reflected in the cap, linking might have significant price effects and potentially reduce incentives to reduce other GHG emissions. Finally, jurisdictions must also trust that their linking partners have the requisite technical and institutional capacity to accurately monitor and verify the GHGs covered in their system.

Economic issues. Linking systems with differing GHG coverage does not create additional competitive disadvantages, aside from those that have already existed before the link. However, linking will likely change the carbon price and have distributional effects, reducing or increasing existing competitive distortions steaming from unequal treatment of GHG sources (Flachsland, 2008). Based on the distributional effects, compliance entities might raise fairness and competitiveness concerns in the linking process.

One example can be a link between a system that covers HFC emissions and an ETS that does not cover HFC emissions, but accepts domestic offset credits from HFC-removal projects. Different treatment of HFC emissions could raise competitiveness concerns as one system would reward reducing HFC emissions with credits, whilst the other system makes such reductions mandatory. Such competitive distortions, however, will already exist before linking takes place. Nevertheless, linking could exacerbate these distortions. If linking results in a higher carbon price, this would further benefit the participants in the system that allows HFC offset credits. If the new carbon price is lower than the pre-link price in the system that allows HFC offsets, competitive distortions will be decreased.

Political issues. Differences in the coverage of GHG (as discussed above) may put some pressure on policymakers if compliance entities view this as a competitive disadvantage and raise their equity and fairness concerns. Furthermore, if policymakers adjust their GHG coverage, this may undermine previous political consensus and policy commitments to domestic stakeholders (Metcalf & Weisbach, 2010).

4.5.4 Sectors covered

Linked systems can function without harmonising their sector coverage if the linking partners have confidence in their respective MRV systems, as well as in the integrity and stringency of their caps (DEHSt, 2013). From an economic perspective, although there may be efficiency gains from linking systems that cover different sectors (Burtraw et al., 2013; Sterk & Schüle, 2009), this may also raise concerns of equity and competitiveness.

Environmental issues. There is no evidence for significant environmental issues if systems with unaligned sector coverage link with each other. The system coverage often reflects the unique circumstances of the jurisdiction, for instance, its emissions profile, mitigation potentials and costs, policy mix, sectors' structure, and other political decisions. Linking with a system with broader sector coverage delivers many of the benefits of having broader sector coverage, such as increasing the efficiency of the carbon market, diversifying mitigation options and increasing market liquidity.

On the other hand, there are arguments against the inclusion of various different sectors into an ETS: monitoring emissions in some sectors is challenging, mitigation options may be very costly, the willingness to pay may be very different, some sectors could be subject to other energy and climate regulations or policymakers may face significant pressure from certain sectors to be excluded from an ETS. Therefore, the impact of differences in scope should be carefully investigated.

Economic issues. Theoretically, linking systems with different sectors may be more cost efficient as it opens up a wider (and potentially cheaper) array of mitigation options (Sterk et al., 2006; Haites & Mullins, 2001). However, as Jaffe and Stavins point out, the more divergent the sector coverage across the linking partners, the less likely it is that linking will create an 'even playing field' across the linked market (2007). Rather, linking systems with differing sector coverage would heighten competitiveness concerns if a sector was subject to an ETS in one jurisdiction and not in the other (IETA, 2006; Haites & Mullins, 2001). On the other hand, some authors also argue that such competitiveness issues would also occur without linking, and therefore diverging sector coverage should not pose such a significant obstacle (Sterk et al., 2006). Changes in allowance prices will either reduce or reinforce existing adverse competitive distortions (Jaffe & Stavins, 2007; Flachsland, 2008). Additionally, such competitiveness concerns depend on the economic relationship of the linking partners. For instance, if they have sectors that compete directly with one another, it may be more important to ensure both jurisdictions cover that sector under their ETS. Finally, Comendant and Taschini argue that linking systems that have different sector coverage also exposes the joint market to different (and smaller) economic shocks than if systems that covered the same sectors were linked (2014).

Political issues. Similar to the discussion on competitiveness, the unequal treatment of sectors in a linked ETS may raise issues of equity and fairness by the compliance entities. The extent to which this becomes a significant concern depends on a number of factors, some of which include: whether the linking jurisdictions are trade partners, the level of trade exposure of the sector in question, the broader climate and energy framework they operate in and their ability to pass on the carbon cost to consumers. Finally, policymakers should also bear in mind that any amendments to the sector coverage in their respective jurisdictions will create new 'winners' and 'losers' and may undermine the level of political support for emissions trading.

4.5.5 Compliance periods

The compliance period is the timeframe during which entities must surrender enough allowances to account for their emissions in that same period. Multiple authors suggest that different compliance periods do not hold any significant implications for the linked carbon market, especially as entities can buy different vintage allowances in advance (Haites & Mullins, 2001).

Sterk et al (2006) argue a difference in compliance periods may improve market liquidity as a scarcity in allowances in one system at the end of their compliance period may be satisfied by purchasing allowances in the other system (Blyth & Bosi, 2004). While there may be some short-term price distortions, Blyth and Bosi outline that this would only be temporary and ultimately balanced out by the benefits in terms of flexibility and market certainty (2004). Despite this, in practice, linked systems have chosen to harmonise their compliance periods.

4.5.6 Registry design

The use of separate registries in a joint market is not a significant issue to linking. However, registries should be technically compatible in order to facilitate the transfer of allowances between system A and system B (Edenhofer et al., 2007). As registries, similar to the establishment of MRV provisions, are often designed to cater to the unique economic and political profile of a jurisdiction, full harmonisation may be problematic.

If not fully harmonised, the registries must be transparent, trackable and robust against fraud, criminal activity and double counting. In practice, existing linked systems have chosen to operate joint registries in order to improve market efficiency. Furthermore, the use of a single registry brings several advantages: the market becomes more transparent, it improves the ease with which transactions can be monitored and minimises risks like double counting.

Environmental issues. There are no significant environmental issues with using separate, unaligned registries if the above mentioned requirements are fulfilled.

Economic issues. While the use of a joint registry or completely identical registries are not necessary, the greater the differences between the two systems, the more costly and time consuming the tracking, processing and transfer of allowances will be (Haites & Mullins, 2001). Additionally, a joint registry can make it easier to guard against issues like market manipulation and fraud. In addition, software tools can be developed in order to adequately connect the registries if full alignment or establishing a completely new system are deemed too cost-intensive.

Political issues. Burtraw et al. note that a joint, single registry may increase market confidence in the credibility and longevity of the system by broadcasting the appearance of shared governance and legal consistency (2013).

4.6 Low Risk

4.6.1 Inclusion thresholds

Inclusion thresholds determine which entities fall under the ETS, policymakers should not only consider the actual threshold levels but also how such thresholds are measured. For instance, California uses emissions to determine thresholds, whereas RGGI uses megawatts of installed capacity. However, differences in how inclusion thresholds are calculated may not be an obstacle if the sources covered under the respective jurisdictions are not that different in practice (Burtraw et al., 2013). Although gross differences in inclusion thresholds may be problematic, having some difference in the inclusion thresholds does not form a significant barrier to linking, as it does not raise any serious environmental, political or economic issues.

Finally, there are also strong domestic considerations that may have led to the formation of these thresholds. For instance, lowering the threshold to include smaller emitters may impose an undue burden on these entities given the high transaction costs, or increase the administrative burden on the regulator beyond its institutional capacity to adequately monitor and regulate these additional entities.

4.6.2 Opt-in and opt-out provisions

Linking literature suggests that there is no need for harmonisation of opt-in and opt-out provisions. As they normally represent only a relatively small share the total ETS they should not pose a barrier to linking and can remain different. Authors are more concerned with differences in opt-out provisions rather than opt-in provisions (Sterk et al., 2006) as they may negatively affect the cost-efficiency and environmental effectiveness of the linked market.

Environmental issues. Differences in opt-in provisions may raise environmental concerns depending on the method of allocation. As Mullins and Haites outline, differences in opt-in provisions may raise overall emissions in the linked scheme if opt-in installations are given a generous allowance allocation (2001).

Economic issues. Linking to a system with more generous opt-in provisions may bring some economic advantages to the joint carbon market (e.g. more mitigation options and increased market liquidity). With generous opt-out provisions, net buyers are allowed to drop out, leaving more net sellers in the systems (Sterk et al., 2006). Additionally, if the allowances of entities that opted out from the system are not cancelled, this may further challenge the environmental performance of the linked system (ICAP, 2015).

Political issues. Depending on the scale and ease with which entities exit the ETS in the system with more generous opt-out provisions, this may raise issues of equity and fairness with regulated entities in the linking partner's jurisdiction. On the other hand, changes to the opt-out or opt-in provision may undermine existing political consensus reached through domestic stakeholder consultation processes.

4.6.3 Point of regulation

Two elements must be considered when dealing with the point of regulation in an ETS: (1) where is the ETS reporting and compliance obligation being placed along the supply chain, is it where emissions are being produced (upstream), closer to the consumer (downstream) or a mix of both?; and (2) are emissions being covered directly or indirectly? In both cases, policymakers need to ensure that a robust MRV and accounting regime is in place to avoid double and / or undercounting of allowances (DEHSt, 2013; Sterk et al., 2006; Haites 2003).

While the alignment of the points of regulation is not essential, its discussion as part of the linking negotiations will be useful. Policymakers need a comprehensive understanding of how and where on the supply chain the ETS obligations will be enforced in the other jurisdiction. This will also inform their discussions on the possible harmonisation of other design features, such as allocation and sector coverage. Finally, policymakers should also consider the difficulties of adjusting the point of regulation. For instance, some jurisdictions may have opted to put the point of regulation upstream to limit the number of regulated entities, and may then lack the necessary resources to shift to downstream regulation.

Linking systems, where at least one of them covers indirect emissions, is technically complex. Linking partners need to ensure that emissions are properly accounted for in such a mixed system. This requires technically complex solutions to avoid double- or under-counting of emissions that would also complicate the linked carbon market. Under- or double counting, however, can take place without linking. For example, if electricity producers included in the ETS with direct coverage export electricity to a jurisdiction with indirect coverage in the ETS, the end users will have to pay twice. On the other hand, if electricity producers in a jurisdiction with only indirect coverage in the ETS export electricity into a jurisdiction with only a direct coverage in the ETS, these actual emissions are not accounted by neither system. However, such undercounting issues exist also without linking. Therefore, during linking discussions, the partners need carefully investigate existing discrepancies and to make sure their accounting approaches do not allow for double- or under-counting. (Haites, 2003, Sterk et al., 2006, DEHSt 2013).

Environmental issues. In particular, if there is a trade relationship between the two jurisdictions and one regulates emissions upstream, particular attention must be paid to the issue of imported fuels. For instance, if the system with an upstream point of regulation exports fuel to the downstream system, care must be taken to avoid the double counting of the associated emissions. Conversely, undercounting emissions would threaten the environmental integrity of the system (Haites & Mullins, 2001). However, as DEHSt argue, most systems that have a hybrid point of regulation (regulating both upstream and downstream emissions) have provisions in place to avoid double counting (2013). Therefore, in practice this issue should not be particularly problematic when linking.

Economic issues. If linking partners have robust accounting systems to avoid double and / or undercounting of allowances, then differing points of regulation will bring about no serious economic issues. However, if not tackled, double counting of emissions may lead to consumers paying for the same emissions twice (Sterk et al., 2006).

Political issues. The double and / or undercounting that may take place in a linked system that covers both direct and indirect emissions could cause political concerns if it undermines the political goals of an ETS, such as achieving a certain level of emissions reductions.

4.6.4 Number and structure of market participants

Market participants include compliance entities covered by the linking ETS, as well as additional players that may be allowed to participate in trading, such as brokers, banks and other financial actors. The number and structure of compliance entities are closely tied to issues of scope and coverage, e.g. point of regulation or inclusions thresholds. They also depend on the size and structure of the overall economy or the individual sectors, namely, whether there are a few companies dominating the sector or whether there are many small companies.

Linking creates a larger carbon market with more participants in sum. A larger market with more diverse participants is assumed to reduce the carbon price volatility, which is a reason why smaller markets with fewer participants may find linking attractive (Hawkins & Jegou, 2014). Additionally, a larger, more competitive market tends to reduce the market power of larger emitters and their ability to manipulate their market. For smaller markets, like Switzerland and New Zealand, access to a more liquid market was an important reason for pursuing linking. Also, Norway had a relatively small carbon market with few participants before the EEA-countries joined the EU ETS (Iceland, Liechtenstein and Norway). Linking to the EU allowed them to join a more liquid carbon market. It also reduces the relative market power of regulated entities, reducing the risk of market manipulation.

As more market participants enter the joint carbon market, trading activity is likely to increase, thereby increasing the expected trading volume and liquidity of the joint system. This will, however, also depend on the kind of players admitted to trade in the linked market (e.g. compliance companies, financial institutions etc.). For example, currently in the Korean ETS only compliance entities and three state banks are allowed to trade allowance units. Similarly, Chinese pilots restricted trade to compliance entities at the initial stages, but due to low market liquidity later they opened access to trade for a wider range of actors, such as companies not covered by the ETS, institutional investors and to some extent individuals (Environomist et al., 2016).

4.7 Restricted linking options

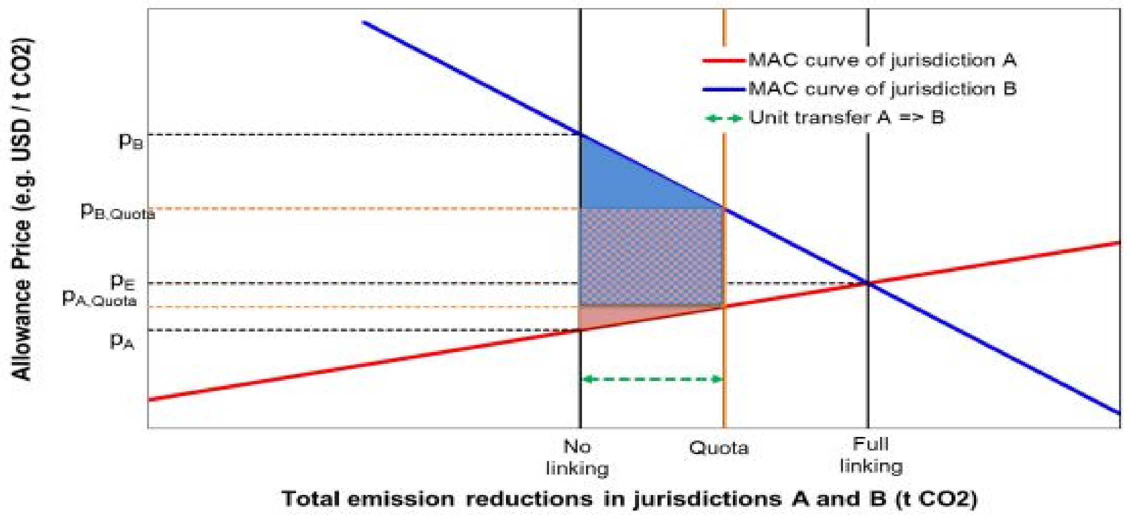
Although a full bilateral link that allows the mutual and unrestricted flow of allowances could deliver considerable benefits to both linking partners, this is often not possible or not wanted. Linking not only requires considerable time to negotiate and craft a solution that both allows for a functioning carbon market and appeals to both linking partners, it also carries considerable challenges and risks from a loss of regulatory control to imported shocks (for more see chapter two). As Burtraw et al. elaborate, the case of linking systems with significantly different allowance prices is likely to be politically challenging although it could be economically advantageous (2013). However, there are intermediate solutions that deliver some of the benefits of full linking, while minimising some of the potential downsides. These 'restricted' linking options make it easier for policymakers to 'de-link' or adjust the link in order to deal with the challenges of linking or changing local conditions (Lazarus et al., 2015). Additionally, if linking is envisaged along a spectrum, from no linking to full linking, such restricted linking options may provide a starting point from which policymakers from both sides can use to build towards full linking.

This section briefly outlines three potential 'restricted linking' options: quotas, exchange rates and discount rates.

Quotas. Quotas impose quantitative limits on the number of allowances from other jurisdictions that can be surrendered and used for compliance. In practice, most ETS have quotas on the use of offsets in order to drive a certain level of domestic emissions reductions in the ETS sectors and / or out of concern about the environmental integrity of such offsets. As Lazarus et al. state, the idea of quotas would not be foreign to ETS policymakers and from a technical perspective, would be relatively easy to set (2015). However, none of the linked systems have imposed a quota on the use of allowances from the other jurisdiction. Policymakers could set an absolute limit, similar to offsets, on the use of allowances from another system or set a combined quota on the use of both 'foreign' allowances and offsets to ensure a certain level of domestic reduction. Linking partners could set quotas not only on the use of allowances from system A allowed in system B (and vice versa) but also on the number of offsets recognised in system A.

Broadly speaking, the difficulties in predicting marginal abatement costs and emissions levels makes setting the 'right' quota very challenging. More specifically, given the difficulty in predicting the flow of allowances as a result of linking, the quota may be set above the actual level of allowance flow that would take place due to linking, undermining the main function of the quota. Nevertheless, quotas do guarantee that the flow of allowances is confined to a politically acceptable limit (Lazarus et al., 2015). Thus, although determining the 'appropriate' quota limit is technically challenging, in the end it may be formulated based on notions of political acceptability.

Figure 11: Model outcome of linking two ETS with a 50% quota

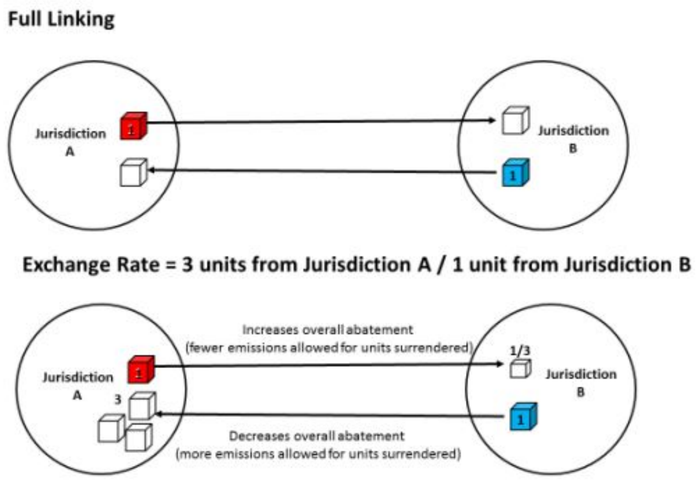


Lazarus et al., 2015

As outlined in Figure 13 (above), assuming the quota is set below the allowance transfer that would take place as a result of linking, this 'restricted linking' model can still deliver some of the cost efficiency gains of linking. It would also increase overall market liquidity by creating a linked market with more buyers and sellers. From a political perspective, policymakers still retain a level of regulatory control over the flow of allowances into their system (Lazarus et al., 2015). This can ensure that a certain level of ambition is sustained in the linked market, as the quotas could be adjusted to control the exposure to shocks and developments in the other system (eg. safeguard against over-allocation in the linking partner's system) (ibid).

Exchange rates Exchange rates permit allowances to be used in another system for compliance, subject to a trading ratio. They operate in a similar manner to currency exchange rates. For instance, if one allowance from system A is worth three allowances from system B, then one allowance from system B is worth a third of an allowance in system A (illustrated below, Figure 14)

Figure 12: Full linking v. linking with an exchange rate



Lazarus et al., 2015 adapted from Burtraw et al., 2013

The World Bank has proposed a similar system in its Networked Carbon Markets model in order to encourage links between differing climate action initiatives (World Bank, 2016). An exchange rate can be a means of linking between systems that may otherwise find it challenging given their differing carbon prices and abatement costs. Additionally, such a link can still deliver some of the benefits of full linking.

Imposing an exchange rate can be a means of limiting the resultant allowance flows between linking partners and securing a politically desirable carbon price. Thus, depending on how the exchange rate was designed, policymakers would reap some cost efficiency gains without sacrificing other policy preferences, like achieving a certain level of domestic abatement (ibid). Whether total emissions in the linked market would decrease or increase as a result of linking depends on how the exchange rate is set in relation to the cap and marginal abatement costs (Lazarus et al., 2015), see Figure 14. The direction of the net flow of allowances between jurisdictions would also affect the level of emissions.

Nevertheless, as Lazarus et al. highlight, there are considerable uncertainties in setting the exchange rate, which can affect total abatement costs and the cost-effectiveness of the linked carbon market (2015). If the exchange rate inflates the value of the allowances, abatement can decrease in both jurisdictions compared to full or no linking. Equally, rates that overstate the expected price difference between the linking partners in the case of no linking, the cost effectiveness of the linked market decreases as it incentivises abatement in the jurisdiction with higher-cost abatement opportunities (ibid). Unlike quotas, exchange rates also leave jurisdictions open to any shocks, system changes or market developments in the linking partner (as is the case with full linking). From a political perspective, policymakers may be sensitive to the use of an exchange rate if it is perceived as a judgment of a jurisdiction’s mitigation reduction efforts. Even if the rating were delegated to a neutral third body this would only work if both partners acknowledged its legitimacy and credibility.

The exchange rate is also not set in stone, therefore, as conditions and policy preferences change, the rate can be revisited and adjusted accordingly. The idea of an independent third body, like a central reserve, to evaluate and rate such allowances has also been promoted by the Networked Carbon Markets initiative (World Bank, 2016). However, adjusting the exchange rate may be challenging, not only in determining how frequently the rates should be adjusted but also what the new rate to be as assessing the effectiveness of the exchange rate can be quite difficult (Lazarus et al., 2015).

Discount rates

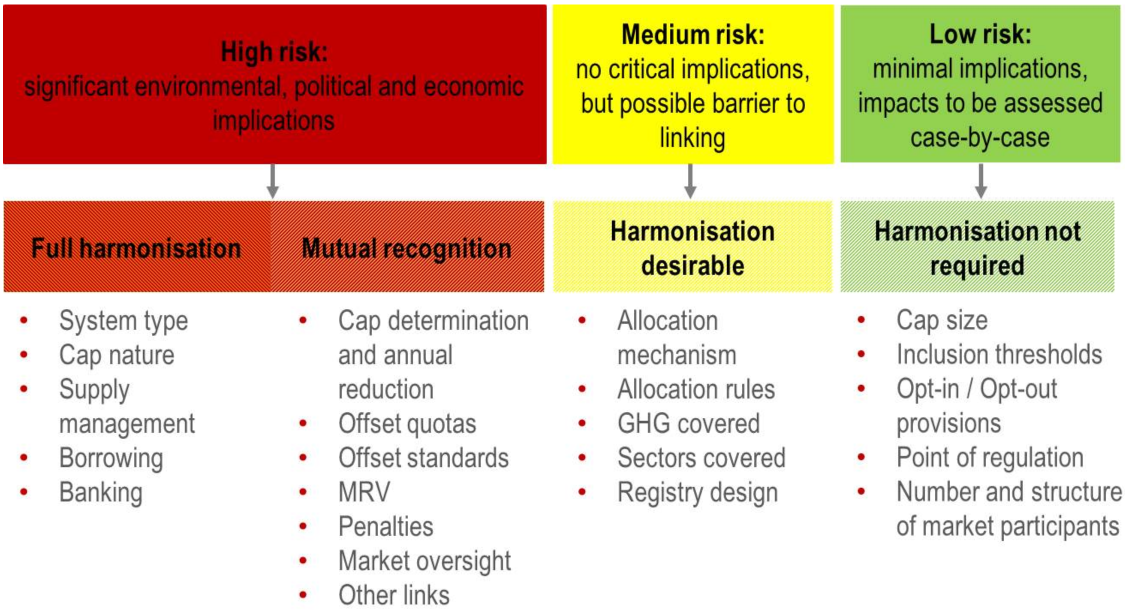
Discount rates are similar to exchange rates (see above discussion); the core difference is that they can be set asymmetrically. For instance, system A might set its rate at 3:1 but system B could set its rate at 5:1. Like the other restricted linking options, this can also be imposed one-way or two-ways. Lazarus et al. argue that discount rates make it easier for policymakers to set an effective exchange rate (2015) as the flexibility of discount rates can help avoid rates that lead to adverse outcomes (e.g. overstated exchange rates). While setting the discount rate, total abatement would increase as the discount rates would be activated. For instance, if a discount rate of 50% is in place for system B, entities in system A would need to surrender two allowances from system B to be counted as one allowance in their system. This doubles the amount of abatement occurring in system B compared to a linking scenario with no discount rate. Cost effectiveness would also increase as entities would only be incentivised to trade allowances if it is cheaper to do so (for more information see Lazarus et al. 2015 (esp pp 29-30). It also functions as a price containment mechanism as trade would only take place if the discount rate is less than the difference between allowance prices without linking (ibid).

4.8 Conclusions

Linking requires a thorough analysis of the potential linked systems and their compatibility with one another. Existing systems vary in their design, which reflect the jurisdictions' economy, emissions profile and policy priorities. When considering linking, partners need to identify differences in their systems, assess the potential implications such differences might bring and agree on a common ETS design harmonisation strategy. From the beginning, mutual trust and transparency between the linking partners will serve as a solid basis for the entire linking process and should be established prior to any detailed discussion and negotiations on the harmonisation of specific ETS design features. This will also be crucial to ensure the robust functioning of the joint carbon market.

This paper reviewed key ETS design features and assessed the extent to which they may pose significant environmental, political and economic risks for the effective functioning of the joint carbon market. Based on the severity of these implications, different design features will require different levels of harmonisation, running the full spectrum from full harmonisation (or comparable levels) to cases where harmonisation is not required. Figure 15 (below) summarises the findings of this analysis. Table 1 also provides an overview on the level of potential environmental, political and economic risks for each design element.

Figure 13: Harmonisation requirements of ETS design for linking



adelphi, 2017

Harmonisation necessary. There are quite a number of design features, which will have severe environmental, economic and political repercussions if not fully harmonised or set at comparable levels. Furthermore, they will apply to the whole joint carbon market, even if they are only present in one system, as the link will result in an immediate and automatic propagation. These elements are, among others, supply management instruments, such as the MSR in the EU ETS, price ceilings or floors. Banking and borrowing provisions will also become available to the entire joint carbon market after linking, even if one of the linking partners does not allow them. Other elements like the cap nature are also crucial design features that must be harmonised. They represent the environmental policy objectives of the respective jurisdictions and require a joint vision and level of ambition for a successful link to be established.

Harmonisation or mutual recognition necessary. Features under this group might be automatically propagated across linking partners. However, it may not always be possible to completely harmonise certain design features. For instance, MRV systems are often complex and reflect the unique economic, political and legal circumstances of a jurisdiction. Cap stringency, for example, is difficult to measure and align. Setting the cap and the annual reduction of the cap depends on national circumstances, mitigation potentials and climate targets. In such cases, harmonisation may neither be possible nor necessary if the design elements are mutually accepted and recognised by the linking partners as credible and potential risks are managed efficiently Offset provisions are also in this group as they may have significant implications for the environmental integrity and allowance price in the joint carbon market. They are also difficult to negotiate as offset provisions reflect domestic priorities and political compromises.

Harmonisation desirable. Design elements in this category reflect the jurisdictions' economic and emissions profile, such as sector and GHG coverage, as well as technical features such as registry design and compliance periods. However, differences in these design features will not undermine the environmental integrity of the joint carbon market or the achievement of long-term abatement targets. On the other hand, their harmonisation may be desirable for other reasons, such as facilitating the linking process, building political acceptance or reducing the administrative burden of operating a joint carbon market.

Harmonisation not required. Inclusion thresholds opt-in and opt-out provisions, point of regulation, cap size and the number of entities are placed in this group. These design features have minimal negative implications. Aligning and adjusting these design elements are not necessary in order to establish a functioning joint carbon market.

This categorisation is based on the existing linking literature and practical linking experiences but harmonisation priorities will vary for each specific linking case. The importance of certain linking objectives, sizes of the respective systems and their policy priorities, as well as their political cultures and institutional structures will affect the harmonisation requirements. Linking also takes time and requires trade-offs and compromises from both linking partners. Consequently, jurisdictions may prioritise certain design elements and / or more design features might be harmonised in the linking process than would be required for a functioning market.

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4.10 Annex Chapter 4

Table 11: High risk category: Environmental, political and economic implications of ETS design features when linked (full harmonisation)

Design Element	Potential implications		
	Environmental	Economic	Political
System type	• Voluntary programs: lower coverage, participants unlikely accept stringent target, no obligation to comply • Production shifts; circumvention of the system • No guarantee that the target will be met	• No significant issues but no significant advantages • Uncertainty of system, especially given opt-in/opt-out options	• Equity issues
Absolute or intensity-based cap	• Higher level of total emissions in the linked system • No guarantee target will be met (in contrast to absolute cap system)	• Allocation adjustment in intensity-based ETS risks liquidity shocks • Competitiveness concerns for participants in absolute cap ETS	• Emissions increase as a possible result of linking with an intensity-based cap may undermine broader climate targets
Supply management instruments	• Lack of supply management instruments may lead to sustained oversupply • Price ceiling: cap ceases to apply after a certain price has been reached • Price floor amendments: may undermine incentives for low-carbon investment and domestic abatement (if only one system has a price floor, it can be circumvented) • Quantity-based supply management (e.g. MSR): loses effectiveness unless applied to whole	• Price ceiling: amendments compromise the goal of cost containment, removal may undermine market confidence in price stability • Price floor: amendments may increase price volatility. If only one system has a price floor it can be circumvented, redirects revenues from selling allowances to ETS without price floor	• Abolishing/amending these instruments can undermine policy objectives of jurisdiction and / or key stakeholder support • There is little knowledge so far as to how price-based and quantity based supply management mechanisms could be aligned • Quantity-based supply management (e.g. MSR): linking requires review of quantity thresholds

	market.		
Banking	• Encourages entities to reduce emissions below target • Impact of returning allowances onto market may weaken carbon price signal • May transfer system failures (oversupply) into future compliance periods	• May reduce cost of abatement (intertemporal efficiency) • In case of different banking provisions: affects strategic decisions as to which allowances to hold	• No significant implications if sufficiently stringent caps and no oversupply problem
Borrowing	• May undermine environmental effectiveness of linked ETS • Risk companies borrow to artificially increase future compliance cost (pressure policymakers to adopt weaker target)	• Weakens carbon price signal, decreases incentive to mitigate and invest	• Policymakers concerned with environmental integrity / want certain level of domestic investment, may not link with system with generous borrowing

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Table 12: High risk category: Environmental, political and economic implications of ETS design features when linked (mutual recognition)

Design element	**Potential implications**		
	Environmental	**Economic**	**Political**
Cap determination and annual reduction	• Linking with less stringent ETS reduces investment and emissions reduction incentives in more stringent ETS	• Trade-off between cost efficiency gains and environmental/political benefits • Financial outflow • Incentive to relax cap if linking to less ambitious system	• Difficult to reconcile differing levels of ambition • Lower price after linking may undermine mitigation and investment incentives • Higher price after linking would impose higher carbon cost on the economy
Offset quotas	• Generous offset use weakens overall cap, increases total emissions	• Generous offset use lowers carbon price, undermine incentives for investment and mitigation, can also result in competitive distortions (if offsets cheaper than	• Amendments may undermine existing political compromises and objectives

		market price)	
Offset standards	• Lack of additionality and environmental integrity may compromise overall environmental integrity of the linked market	• May lead to low credit prices, allowance prices may also drop and decrease	• May undermine political objectives / level of domestic stakeholder support
MRV	• Lax MRV standards threatens environmental integrity of linked ETS • Risk of double / undercounting	• Alignment may increase stability and efficiency	• Harmonisation may be difficult as MRV provisions are usually based on legal and institutional traditions
Penalties	• If financial penalty is lower than carbon price, becomes default option, no incentive to comply, may act as price cap leading to lower emissions reductions	• Competitiveness concerns	• Competitiveness concerns may lead to political lobbying (race to bottom)
Market oversight	• Robust provisions necessary ensure environmental integrity of allowances and credits	• Robust provisions build market confidence, guard against fraud and manipulation • Harmonisation ensures players/trading platform subject to same conditions	• Joint enforcement of market oversight eases administrative burden, conveys impression of shared governance
Other links	• Can complicate linking negotiation and final design, policymakers need to consider who they want to link with and how, relative size of linking partner(s) will also affect the distributional impact		

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Table 13: Medium risk category: Environmental, political and economic implications of ETS design features when linked (harmonisation desirable)

Risk category: Medium [no critical implications, but possible barrier to linking]

Harmonisation: Harmonisation desirable

Design element	Potential implications		
	Environmental	Economic	Political
Allocation mechanism	• No issues if significantly stringent cap • Free allocation re-	• Competitiveness concerns and economic distortions	• Competitiveness concerns may raise equity concerns • If both systems auction, should

	duces abatement incentives compared to full auctioning	(free allocation vs auction) may occur regardless of linking • Depends on distributional implications of systems with different allocation methods	align design to avoid bidder collusion • Distributional implications for new entrants and exits

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Table 14: Low risk category: Environmental, political and economic implications of ETS design features when linked (harmonisation not required)

Design element	Potential implications		
	Environmental	Political	Economic
Inclusion thresholds	• Only problematic if gross differences in thresholds		
Opt-in / opt-out provisions	• Differences in opt-in provisions may raise overall emissions if opt-in installations are given a generous allowance allocation	• Potentially oversupplied ETS, lower market liquidity • Generous opt-in provisions of linking partner increase mitigation options and increase liquidity	• More generous opt-out provisions in one system may raise equity concerns
Point of regulation	• Risk of double/under counting	• No serious economic issues if double / undercounting is avoided, otherwise risk consumers paying twice	• Double / undercounting risks achieving ETS reduction targets
Number and structure of market participants	• It will be a broader issue for policymakers to consider when choosing their linking partner		

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5 Annex I: Model Factsheets

Julia Bingler, Dorothea Hauptstock, Johannes Thema, Christiane Beuermann

Chapter 3 of the final report focuses on how and to which extent the requirements for assessing the economic effects of linking ETS (assessment criteria and regional coverage) are fulfilled by the models ("models by requirements"). The following model descriptions analyse the same topic from the opposite viewpoint: they describe the models in light of the requirements ("requirements by model").

The previous analysis has shown that none of the models perfectly fulfils the requirements. Some models perform better in terms of regional coverage, some perform better in terms of criteria coverage (usually the general equilibrium models, CGE), some provide a compromise with good but not optimal regional and criteria coverage at the same time.

The extensive analysis of all eleven models resulted in a selection of five models as being most suitable[53], they will be described first:

- E3ME (Macro-econometric model)
- GEM-E3 (general equilibrium model)
- PACE (general equilibrium model)
- POLES (partial equilibrium model)
- TIMES-MARKAL (partial equilibrium model)

Subsequently, the six models considered less suitable will be described in a similar level of detail to enable for comparison.

Each description starts with an overview table on the fulfilment of the model requirements (Table 8 in Chapter 3).

The colour-code in these overview tables reads as follows:

Model requirement fulfilling – colour code:

Green = Model sufficiently fulfils the respective model requirement

grey = Model partly fulfils the respective model requirement

Red = Model does not fulfil the respective model requirement

The Annex concludes with an overview table on the fulfilment of criteria by model.

[53] However, it is important that the suitability of the model for the analysis does not hinge on a simple counting of the numbers, for example by adding up the "green" (i.e. fulfilled) requirements. The colours only provide a first hint on how well the respective model requirement is covered. Models may more or less easily be adapted to fulfil requirements or public information may be insufficient to assess the fulfilment level appropriately. Comparing between the models, the fulfilled requirements differ in terms of quality. Further, not all the requirements are equally important. Therefore, simply adding up the amount of green requirements in a model and selecting the model with the largest amount of green requirements does not necessarily lead to the most useful model for analysis.

Table 15: Economic perspectives related to linking of ETSs.

Model	Requirement
Type	Ideally CGE with bottom-up PE-elements in the energy sector + ideally in the industry sector; and ideally many econometrically estimated parameters
Time horizon of the agents	Ideally limited foresight optimisation
Time horizon of the model	Short- (less than 5 years) and long term (more than 10 years, ideally more than 35 years) (until 2020 annual steps, end date around 2050)
Economic fields	Domestic economy, international trade, linked permit market
Sectors	All ETS-sectors (energy, industry, domestic and partly international aviation for EU-ETS) + rest of the economy
Regions	EU-ETS31 + potential linking partners (e.g. China, South Korea, Mexico, Turkey) + Rest of the world (ROW)
Emissions	All ETS-gases from all ETS-sectors at disaggregated level (CO_2, N_2O, PFCs; from fossil fuel combustion and processes for a symmetric link of the EU-ETS)
Sectoral disaggre-gation	Disaggregation should be detailed enough to provide meaningful results, depending on the selected assessment criteria. When, for example, sectoral competitiveness-effects are to be assessed, a single-industry-sector model does not provide the information required (cf. Alexeeva-Talebi et al. 2012).

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5.1 E3ME

Table 16: Summary E3ME

Model	Energy-Environment-Economy Macro Econometric Model (E3ME)
Author	Cambridge Econometrics
Type	Macro-econometric, Demand-driven flows in input-output tables, non-equilibrium model (markets do not necessarily clear),
Time horizon of the agents	myopic agents
Time horizon of the model	Short- and long run 1995-2050 (latest calibration period: 1970-2014), annual time steps
Economic fields	Domestic economy, bilateral international trade, linked permit market
Sectors	EU: 69 product/industries; defined in terms of NACE Rev.2 (with separate aviation) Other countries: 43 product/industry classifications, defined in terms of the NACE Rev1.1 (with separate aviation)
Regions	Global: 53 countries (incl. **28 EU-member states + Norway, Iceland** (not Liechtenstein), 11 other major economies in countries (incl. China, South Korea, Mexico, Turkey), rest of the world in aggregated regions)

Emissions	CO2, SO2, NOx, CO, CH4, PM10, VOC, CFCs, N2O, HFCs, PFCs, SF6; from fossil fuel combustion and processes; reported only CO2 per sector, others reported by region
Main databases	- Accounting balances for commodities from input-output tables and for institutional incomes and expenditures from the national accounts: Eurostat, AMECO, Asian Development Bank, OECD's STAN database, UN, OECD, World Bank, IMF, ILO and national statistics - Bilateral trade: Comtrade (for manufacturing), OECD (services), national statistics - Energy fuel use and energy efficiency technology development: IEA energy balances and IEA Energy Technology Perspectives for FTT:Power - Energy price data: IEA Energy statistics by country and fuel - CO2 emissions by fuel and user: EDGAR, Eurostat

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The E3ME (Energy-Environment-Economy Macro Econometric Model) is not a CGE model but an economy-wide macroeconometric model that can be used to answer similar questions like CGE models with econometrically estimated, rather than calibrated parameters. The energy modelling in E3ME is top-down, but with bottom-up elements in the electricity supply sector (Cambridge Econometrics 2014, p.17 + 120). Its econometric parameter estimation provides a strong empirical basis for analysis and avoids making strong assumptions about agents' behaviour.

Since it is an econometric model, no production functions are defined. The model is rather based on national accounts for incomes and expenditures, input-output tables for commodities and energy balances for energy carriers. It has two-way linkages between each of the energy-environment-economy component and solves 33 sets of time-series econometrically estimated equations, including all GDP components, prices, energy- and materials demand; all by country and by sector (Cambridge Econometrics 2014). By providing results by yearly time steps until 2050, the model captures short- and long-run impacts of linking.

The driving principles are demand-driven flows in input-output tables. The econometric model is a non-equilibrium model, which means that markets do not necessarily clear. It is hence not an optimisation model. However, it assumes myopic agents. Since myopic agents discriminate against potentially fundamental (i.e. very low-carbon) investments in technologies that pay off only in the mid- or long-run, the analysis of dynamic efficiency effects provides limited results in this model setting. However, for analysing the effects of linking on the selected criteria in the short-run, the model can be used. By its econometric specification it provides results that build on observed values.

The domestic economy, bilateral international trade and the linked permit market are all covered. The endogenous GHG emissions are reported by sector and fuel (Cambridge Econometrics 2014, p. 14).

Permit market

The model simulates the permit market by taking either the annual emission caps or emission prices as exogenous input. The cap can be set for any choice of the 22 energy users in the model via a switch. This allows for a differentiated treatment between ETS-sectors and non-ETS-sectors. The default-version of the model covers the EU-ETS sectors, including aviation (Cambridge Econometrics 2014, p.39 + 106). The main constraint highlighted by the modellers is that the IEA energy users do not match up 100% with the ETS coverage. For example, no allowance is made for small installations and the 'other industry' category that includes multiple use plants.

The estimated annual permit price corresponds to the shadow-value of carbon for those sectors covered by the ETS. It is hence not possible to account for permit market distortions and price volatility in the model (Cambridge Econometrics 2014, p.106f.). Plotting different levels of endogenously estimated annual permit prices to the corresponding pre-defined emission caps gives the MACC.

Two different allocation methods, auction or free allocation (setting the auction price at zero), can be chosen. It is assumed that the allocation method does not have an impact on the firms' product pricing decision (marginal pricing); yet this assumption can be altered by changing the model code (Cambridge Econometrics 2014, p.106f.). E3ME assumes that the price signal resulting from permit trade corresponds to the signal of a carbon tax, i.e. that there is no uncertainty and volatility with regard to future permit prices (Cambridge Econometrics 2014, p.107). This limits the usefulness of the model to analyse dynamic efficiency, since investment decisions are strongly influenced (get more expensive) with increasing uncertainty and volatility.

Unfortunately the model only reports CO2 by sector, the other ETS-gases are reported by region. Therefore, separating between ETS- and non-ETS sectors is only possible for carbon trading (Cambridge Econometrics 2014, p.20).

Modelling an ETS that covers GHG other than CO2 is in principle possible, according to the modellers. However, the coverage of non-CO2 emissions would be much more limited, i.e. the model cannot provide details on the agricultural sector since this sector is out of scope of the model.

According to the modellers, the model can be used for modelling a basic linking scheme with free trading between regions. Further, E3ME can be adapted to model a linked permit market with constraints on the number of allowances traded between the regions or, as Australia was suggesting, only a one-way trade.

By default, the model is solved on an annual basis, hence annual caps / permit prices are required as an input. According to the model manual, prices are set in two ways: When the allowance price is exogenous, it is entered by the model user. For an endogenous allowance price, the user must set the emission cap. The model will then estimate the price required to meet the cap through an iterative process. Banking and borrowing might be an option when being imposed by the assumption of perfect foresight (Cambridge Econometrics 2014, p.106 and 108).

Albeit the model provides a wide range of permit market features and specifications like offset quota or banking and borrowing, it is not suited for analysing market liquidity, since it does not include transaction costs and does not model the amount of firms in the market (Cambridge Econometrics 2014, p.107). A model that solves on a monthly basis would be more appropriate for estimating the effects of linking ETS on permit market liquidity. Further, the number and size of market participants cannot be reflected in E3ME. The model defines the permit market by sectors and all the participants in each sector are assumed included. Therefore, more sectors implies more participants. Market power and market concentration in the permit market is neither modelled. There is only some of this implicitly in the pricing equations: More powerful market operators have more freedom to set the industry price and the econometric equations should reflect this. The number of trades in the permit market is only modelled in net terms, i.e. if allowances are allocated to one sector and used by another. Secondary trading is not covered by E3ME.

International trade

In combination with the detailed sectoral and regional coverage (see below), especially the endogenous bilateral trade flows enable a sound analysis of the effects of linking on competitiveness and carbon leakage. E3ME models bilateral trade flows by region and sector and distinguishes between imports and exports intra-EU and to third countries (Cambridge Econometrics 2014, p.55f). It takes into account the effect of innovation on the long-run trade performance, which is an important component in the area of dynamic efficiency to analyse carbon leakage and competitiveness effects. Further, the model assumes oligopolistic pricing in international markets, which further has an effect on carbon leakage and competitiveness (Cambridge Econometrics 2014, p.65).

The model explicitly reports competitiveness effects through several equations. In E3ME, competitiveness is defined as production levels of a two-digit sector due to changes in its cost base. The two-digit base[54] is a shortcoming (common to most macroeconomic models) as competitiveness effects are felt at a much more detailed level (e.g. aluminium rather than non-ferrous metals, cement rather than non-metallic mineral products). When estimating the effects of linking ETS on competitiveness, the assumed underlying reaction chain is higher (lower) carbon prices – higher (lower) production costs – higher (lower) product prices (depending on how much the cost change is passed through to the consumer) with separate price variables for domestic production, imports and exports – loss (gain) of output. A loss of output occurs through substitution of domestic products with imports and/or reduced exports. Gains are realized through increased consumption of domestic products and/or increased exports. The loss (gain) of output due to the increase (decrease) of production costs is then the competitiveness-effect. Overall, modelling the competitiveness-effects of domestic ETS-sectors in relation to the ETS-sectors of the linking partner and in relation to similar sectors in the rest of the world is possible with E3ME.

Domestic economy

Sectoral output (Gross Value Added, GVA) at market prices and factor costs and investments are endogenous in E3ME (Cambridge Econometrics 2014, p.14), which is useful to analyse static and dynamic efficiency effects for the domestic economy.

As mentioned above, production functions are implicit through input-output tables, with the input-output coefficients related to energy changing in response to the energy equations. So if e.g. a higher carbon price reduces coal consumption by the steel sector, the economic part of the model will show both reduced demand for coal and also (assuming the elasticity <1 and costs are passed on) a higher price for steel.

The model has a very detailed sectoral coverage of all EU-ETS sectors and sectors in the rest of the economy. For the EU, it disaggregates 69 industries, which are defined in terms of NACE Rev.2, including aviation. For the other countries, 43 industries are covered, defined in terms of the NACE Rev.1.1, including aviation. In combination with the detailed regional coverage, and the simulation of bilateral trade flows, the model is very well suited to analyse effects of linking on carbon leakage and competitiveness, regarding the linking partner and third countries. The model even explicitly reports competitiveness effects.

Regional coverage

[54] In these model, industrial details are often very aggregated. Usually aggregation is done at the one-digit Standard Industrial Classification (SIC) level or, at most, the two-digit SIC level. SIC codes have a hierarchical, top-down structure that begins with general characteristics and narrows down to the specifics. The first two digits of the code represent the major industry sector to which a business belongs. The third and fourth digits describe the sub-classification of the business group and specialization, respectively.

E3ME provides output at a very detailed regional disaggregation, which perfectly fits the requirements for the present project. It explicitly reports results for 53 countries, including the 28 EU member states plus Norway and Iceland. An aggregation of the 28 EU member states plus Norway and Iceland comes close to the EU-ETS-31 group (only Liechtenstein lacks in the country coverage which is unlikely to have a significant impact on results). The model covers further 11 other major economies as countries.

This level of disaggregation further provides a solid basis for a meaningful analysis of carbon leakage and competitiveness effects for linked ETS sectors with regard to third countries or the linking partner.

Dynamic efficiency and technological progress

The model's approach to energy technology usage and (energy efficiency) technological development differs between the power sector and the industry. In the power sector, a model of technology diffusion, called FTT:Power, is employed. The model is based on evolutionary economics and predicts the uptake of new and existing technologies based on a range of different policy factors, including carbon prices. There are 24 power-technologies available, each with data on capital, fuel, operation and maintenance costs and other costs from which a levelised cost is calculated and fed into the diffusion dynamics. Nuclear and CCS are included in this list. Yet, according to the modellers, nuclear is often modelled by assumption as its application is mostly a political decision.

For the other industries, the modellers are recently working on a similar technology diffusion model like for power, FTT:Industry. The current treatment is however still top-down econometric equation. Price elasticities are either estimated from time series data or, cross-sectional econometric estimates from the available literature or by the modellers are used. The exact econometric equation specification is: Energy consumption = F(economic activity, price, investment, R&D) - with the last two terms accounting for efficiency in the capital stock. The model accounts further for fuel switching. Like when estimating total energy consumption equation, there are similarly estimated equations for coal, oil, gas and electricity, with the totals scaled to be consistent with total energy consumption.

Data sources for technology expansion rates and associated costs (learning curves) for renewable energy and energy efficiency are mainly IEA Energy Technology Perspectives for FTT:Power (updated recently) and for the other industry IEA Energy Balances balances linked to Eurostat or equivalent data, updated roughly once per year.

In general, the model does not deal explicitly with dynamic efficiency. Any hint on dynamic efficiency would need to be extracted from the empirical data. For example in the power sector, if there is a shift to capital-intensive renewables or nuclear then there will be a short-term boost to economic activity that is funded by higher debt levels. Over time, however, this debt must be paid off through higher electricity prices, so there is a dampening effect. Nevertheless, dynamics such as learning effects and path dependency are taken into account, which mean that the net impact will not necessarily be zero over time.

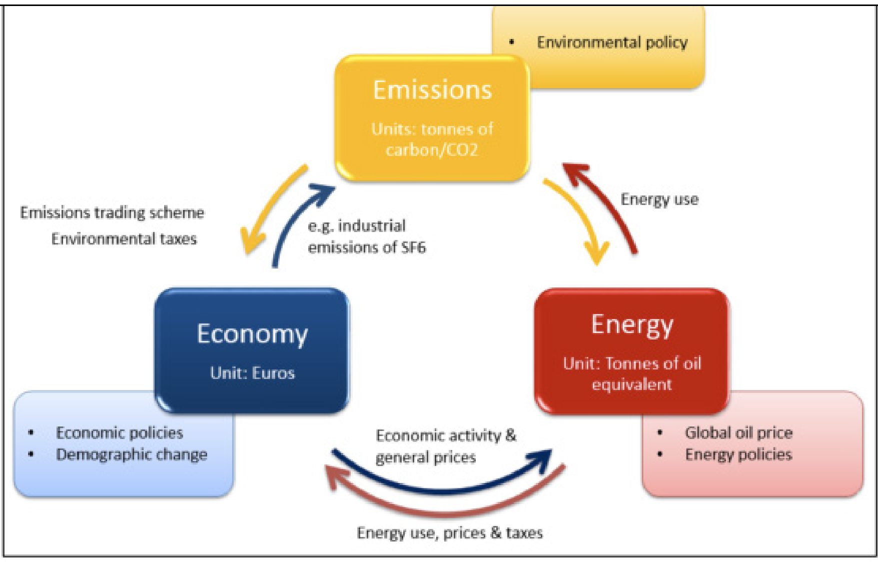
Investments in E3ME are reported as Gross Fixed Capital Formation, which is determined through econometric equations estimated on time-series data. Key determinants of investments in E3ME are expectations of future output, relative prices and interest rates (Cambridge Econometrics 2014, p.13).

The model estimates innovation and technological progress with a quality-adjusted measured of cumulative gross-investment, altered by using data on R&D expenditure. Technological change occurs in the form of product and process innovation (efficiency improvements of existing technologies and replacement of technologies by more efficient technologies) (Cambridge Econometrics 2014, p. 24ff + p.46.).

Latest update

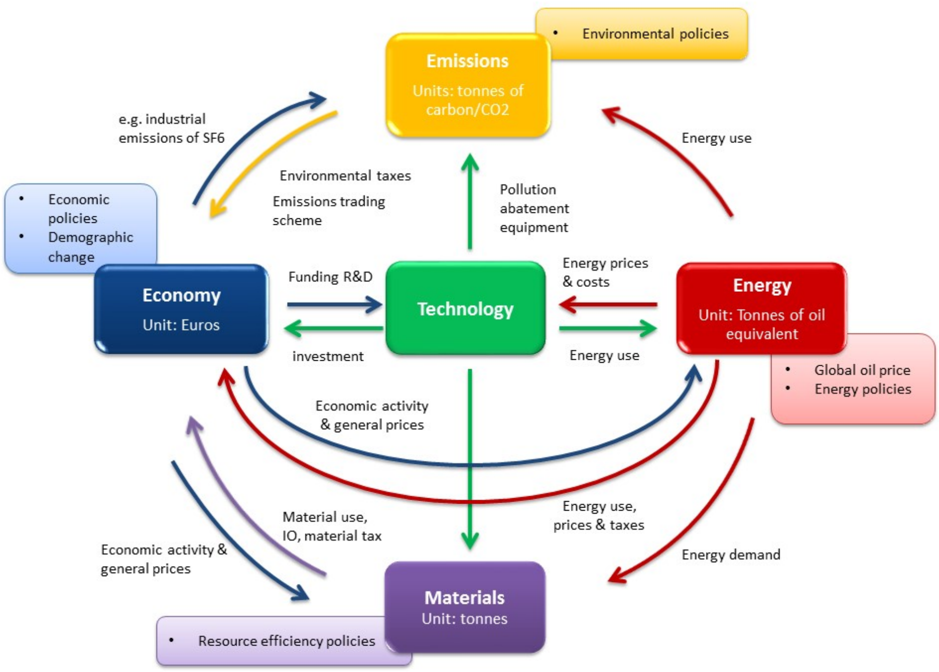
The latest model version 6.0 is from 2014, which replaced the 2012 version. However, the manual for version 6.0 lists some further improvements planned like the incorporation of measures of consumption-based emissions, revisions to the energy equations and price elasticities, revision to the system used to estimate model parameters, a more disaggregated treatment of taxes within the model and the investigation of coupling further bottom-up submodels (e.g. transport) (Cambridge Econometrics 2014, p.8). A data update will be carried out before the end of 2016, when Eurostat published data for 2015.

Figure 16: E3ME model structure as an E3 model without additional modules



So

Figure 17: E3ME model structure as an E3 model with additional modules



Source: http://www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/Modelling Capability/E3ME/purpose_and_design.aspx

5.2 GEM-E3

Table 17: Summary GEM-E3

Model	General Equilibrium Model for Economy - Energy – Environment (GEM-E3)
Author	National Technical University of Athens/ E3M Lab/ European Commission (JRC Sevilla) / (formerly) KU Leuven
Type	General equilibrium with bottom-up technology representation in the energy sector
Time horizon of agents	Myopic optimisation, recursive dynamic
Time horizon of model	2004-2050, 5-year time steps,
Economic Fields	Domestic economy, international trade, linked permit market
Sectors	Up to 56 sectors (GTAP database aggregation), default: 31 production sectors (of which 5 energy sectors and 10 power production technologies; 9 industry sectors, 1 agriculture, aviation, no forestry)
Regions	Global : Aggregation flexible, up to 140 regions (GTAP database) Default: 38 regions - **28 EU member states** (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Sweden, Romania) - USA - Japan - Canada - Brazil - China - India - Oceania - Russian federation - Rest of Annex I (incl. Turkey) - Rest of the World (incl. South Korea, Mexico)
Emissions	CO2, CH4, N2O, HFCs, PFCs, SF6; from fossil fuel combustion and processes; by sector
Main databases	- Social accounting matrix: world version uses GTAP (European version ceased to exist as an independent version and has been integrated in the world version) . JRC Sevilla (European Commission) collaborates with GTAP in order to guarantee the consistency between the GTAP dataset and EUROSTAT) - Bilateral trade matrices incl. duties and transportation costs: GTAP, UN Comtrade, COMTEXT - Capital stock data by production sector: own calibration - Population and population growth, labour force, involuntary unem-

	ployment: EUROSTAT, ILO and World Bank, CESifoDICE Standard assumptions are (but can be adapted according the context): - Economic growth projections: European Commission growth projections for EU countries; IMF and World Bank growth projections for rest - GHG emissions: UNFCCC database - Process-related GHG MACC: Global mitigation of non-CO2 GHG, EPA report (2006), and IIASA GAINS database

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GEM-E3 (General Equilibrium Model for Economy – Energy – Environment) is a recursive dynamic multi-regional computable general equilibrium model with bottom-up technology representation in the energy sector (Capros et al. 2013, p.123f.). The large-scale model provides information about the macro-economy and its interaction with the energy system and the environment. It is based on social accounting matrices (SAM). Amongst others, the model input and output consists of national accounts, full input-output tables, household consumption, energy use and supply and GHG emissions (Capros et al. 2013, p.13). The parameters are mostly calibrated by a calibration module, which is written as a separate model with recursive structure (Capros et al. 2013, p.81, cf. the extensive treatment of calibration and estimation in general with a variety of references to the literature in the same document, p.80ff.).

The model provides results in 5-year time steps until the year 2050 and is hence especially useful for the analysis of structural change in the medium run (Hedenus et al. 2012, p.19). One cannot use the CGE methodology to analyse short-run fluctuations, which might be important for analysing the development of the emission permit price shortly after having linked two ETS. The driving principle is myopic optimisation.

GEM-E3 provides a useful treatment of the areas required for the criteria analysis like the domestic economy, bilateral trade and the linked permit market. It endogenously calculates GHG emissions by region and sector (Capros et al. 2013, p.13, 16). In terms of permit market coverage, it is the most suited model compared to the other models considered in this annex for the present purpose.

Permit market

GEM-E3 features a detailed environment and emissions module that allows for a variety of ETS design options like different allocation schemes, various systems of exemptions like a carbon leakage list and revenue-recycling, etc., for sectoral, national and worldwide policy evaluation (Capros et al. 2013, p.19 + p.115ff.). Modelling the permit price of linked ETS is possible with GEM-E3.

GEM-E3 is very flexibly adaptable for analysing the effects of linking ETS on economic indicators. Differentiation between caps for the ETS-sector and the non-ETS-sector is possible, since the switch parameter for the scenario definition can be adapted with respect to the target level (branch level, regional level or club level, all relative to 2005 emissions), pollutants (hence all EU-ETS pollutants can be considered), activities, countries and time (Capros et al. 2013, p.126). The module allows for user-defined regional trade and trading-bubbles (Capros et al. 2013, p.14, p.114-127).

The permit price is the market clearing price from the permit market supply- and demand equilibrium. Therefore, it might differ from the emission shadow price (Capros et al. 2013, p.123f.).

There is no explicit abatement cost function applied to determine the permit price. Emissions can be reduced either by end-of-the-pipe solutions (not for CO2), output reductions, substitution towards low-carbon inputs, low-carbon production or buying emission permits.

As mentioned above, in order to reduce CO2 emissions, firms have to substitute fuel input or reduce overall production or make it more carbon-efficient. For non-CO2 emissions, end-of-the-pipe abatement is an option. For the firm to decide between purchasing emission permits and the optimal level of end-of-the-pipe abatement, the emission price is taken into consideration. Emissions will be abated until the cost to abate an additional ton of emissions equals the permit price per ton (Capros et al. 2013, p.118f.).

In line with these emission abatement options, the model provides information on the links between emission constraint and pollution abatement investments (Capros et al. 2013, p.15f.), as well as on permit purchases with the corresponding expenditures and on sales with the respective monetary receipts, by branch (Capros et al. 2013, p.123f.). This enables an analysis of the trade volume in the permit market, which could serve as a proxy for market liquidity. Assuming perfect market clearance, GEM-E3 is not able to explicitly model market liquidity constraints.

GEM-E3 is, according to the modellers, not useful to model market power and market concentration, unless major model changes are undertaken.

GEM-E3 provides as well estimates of total abatement costs. Production prices reflect the costs of technologies for process-related emission reductions and expenditures for permit purchases. When using grandfathering as the allocation method, the unit costs of production might optionally be reduced by the amount of free permit endowments, depending on how opportunity costs are to be treated in the model.

International trade

Full endogenous input-output-tables with bilateral trade flows and capital mobility by sector allow for a detailed analysis of carbon leakage and competitiveness effects with regard to the linking partner and third countries (Capros et al. 2013, p.58, 62). This analysis might be more realistic than in other models regarding trade elasticities: GEM-E3 not only differentiates goods between domestic and foreign for the Armington assumption, but between domestic, EU and the other countries (Capros et al. 2013, p.16, 58).

In addition, GEM-E3 allows for alternative competition regimes in addition to perfect competition and for different market clearing mechanisms, which might give even more realistic results regarding the analysis of competitiveness-effects and carbon leakage (Capros et al. 2013, p.14).

Domestic economy

GEM-E3 models sectoral output, capital stock, exports and imports by sector and region in terms of GVA (Capros et al. 2013, p.29, 53). Cross-border investments are as well covered, which is important for the analysis of competitiveness-effects of linking (Capros et al. 2013, p.17). Production is modelled through capital, labour, energy and materials (KLEM) production functions, which involve many intermediate goods and three primary factors (capital, natural resources, labour). The model captures complexities in behaviour via micro-economic mechanisms and institutional features within the macro-economic framework to avoid making simplistic behavioural assumptions.

Three ways of emission abatement are specified: Input substitution (between intermediate goods input, fuels and between energetic and non-energetic inputs), reduction in production and consumption, investment in emission abatement technologies.

Costs for complying with the policy instruments, i.e. the permit market, are added to the input price. Thereby, they enter the final consumption prices (Capros et al. 2013, p.115). Increasing (decreasing) prices lead to reduced (increased) final demand, which can serve as another proxy to overall economic effects of linking and the effects of linking ETS on sectoral production.

The model disaggregates 31 production sectors, including 9 industry sectors, 5 energy sectors with 10 power production technologies and aviation. Hence, all EU-ETS sectors are covered. Possible model extensions to provide more technological detail in the energy sector can be done by using the TECHPOL, Enerdata, POLES or PRIMES model databases (Hedenus et al. 2012, p.31).

Regional coverage

GEM-E3 is a global model with 38 regions, which enables in principle a meaningful analysis of carbon leakage and competitiveness-effects for linked ETS-sectors with regard to third countries and the linking partner. Regional coverage of the EU-ETS-31 countries is relatively good in GEM-E3: The individual 28 EU member states can be aggregated to the EU-28 region, which comes close to the EU-ETS-31 region (only Liechtenstein, Iceland and Norway are missing, yet since these are relatively small countries, this should be acceptable). However, China is the only potential linking partner in the focus of this analysis for which the model provides country-level results. South Korea and Mexico are both included in the "Rest of the World" region, and Turkey enters the "Annex 1"-group, where the non-EU-ETS-countries are included as well.

Dynamic efficiency and technological progress

According to the modellers, assumptions on technological deployment, technological usage and technology costs are introduced in GEM-E3 through the linkage with identical scenarios modelled by partial equilibrium energy models like POLES and PRIMES (or other). For the macroeconomic figures, there are assumptions on the factor-specific technical progress factors (i.e. capital, labour, energy).

Technological change is, amongst others, mainly reflected by price-changes of end-of-the-pipe abatement and by changes in the relative productivity of different production factors.

Data and assumptions for reflecting technological progress are constantly updated.

Since GEM-E3 is not a forward-looking model (i.e. firms' decisions are not based on expectations but on profit maximization for the current period), and innovation is exogenous to the model, GEM-E3 is not well-suited to analyse dynamic efficiency. Any dynamic behaviour in the energy system is, according to the modellers, implicitly introduced through the linkage with POLES, PRIMES or other suitable partial equilibrium models.

Latest update

Since the model uses the GTAP database for the world version, GEM-E3 could be re-calibrated with each update of the GTAP database. According to the modellers, the model is continuously being updated and improved.

5.3 PACE

Table 18: Summary PACE

Model	Policy Analysis based on Computable Equilibrium model (PACE)
Author	ZEW Mannheim
Type	General equilibrium with technology-discrete bottom-up electricity sector representation
Time horizon of the agent	Forward-looking rational expectations or myopic, maximisation of lifetime-utility, 3 different time treatments: comparative-static, dynamic-recursive, inter-temporal
Time horizon of the model	target year 2050 in 5-year time-steps,
Economic Fields	Domestic economy, international trade, linked permit market
Sectors	36 production sectors incl. 9 disaggregated energy intensive sectors
Regions	Global: 23 world regions, flexible with available data EU-27 regions: - Germany - France - UK - Italy - Spain - Poland - XEO: Rest of old EU Member States plus Cyprus and Malta (Denmark, Sweden, Finland, Austria, Belgium, Netherlands, Luxembourg, Ireland, Portugal, Greece, Malta, Cyprus) - XMT: Rest of new EU Member States (Czech Republic, Slovakia, Hungary, Slovenia, Bulgaria, Romania, Estonia, Latvia, Lithuania) Other Annex I regions: - USA - Canada - Japan - Russia - Australia - Turkey - RAX: Rest of Annex I (Switzerland, Norway, Iceland, Liechtenstein, Ukraine, Belarus, New Zealand) Non-Annex I regions: - China (incl. Hong Kong, excl. Taiwan) - India - Brazil - South Korea - Indonesia - Mexico - South Africa

	- Rest of the World
Emissions	CO2 (process emissions and emissions from burning fossil fuels reported by sector), no other emissions;
Main databases	- Production, Consumption, bilateral trade flows: GTAP 9 (140 regions, 57 sectors) - alternative databases for production, imports, exports, intermediate and final consumption e.g. EXIOPOL 2011 (http://www.exiobase.eu/, for free, very detailed sectoral classification with 129 sectors and 43 countries) - Further more disaggregated Input-Output data: Eurostat 2011 Structural Business Statistics; UN Industrial Commodities Statistics, WIOD (World Input-Output database) - Import and Export shares: Eurostat External Trade Data; UN Comtrade data - Energy and emission data: IEA - Exogenous technological progress (AEEI): derived from GTAP data - BAU projections non-EU regions: most recent projections from the International Energy Outlook US Department of Energy 2013 for GDP growth, fossil fuel production and prices, carbon emissions, future energy prices - BAU projections EU regions: project specific baseline based on projections by PRIMES used for calibration

Wuppertal Institut, 2017, own compilation

The PACE model is a flexible global general equilibrium model system with bottom-up discrete energy technology modelling (formerly PACE-BU module, now part of in the standard model). It provides a framework for the analysis of global trade and energy use (Alexeeva-Talebi et al. 2012, p.4f.).

The model is based on a set of equations like zero profit, market clearing and income balance that reflect a set of assumptions like profit-maximizing behaviour, constant returns to scale in production and perfect competition. It is therefore a classical optimisation model where a solution algorithm finds the set of endogenous quantities and prices that solve the equations simultaneously.

The user can choose between static, dynamic-recursive and inter-temporal time treatments. The driving principle is either forward-looking with rational expectations or myopic, it unfortunately lacks the limited foresight option. Parameters are calibrated with benchmark data from the base year (regularly updated with every new GTAP version; recently it is the year 2011, using extrapolated data from the GTAP 9 database (Source: modeller in interview). The model proceeds in 5-year time steps until the target year 2050.

The model covers CO2 emissions from burning fossil fuels and process based CO2 emissions. Other GHG are not included. According to the modellers, including them is in principle possible, but not planned at the moment.

PACE covers the areas, which are relevant for the present analysis: The domestic economy, international trade, and the linked permit market.

Permit market

When simulating emission trade, one can run the model with a cap on ETS-sectors, and a carbon tax for non-ETS sectors (at least in the EU) to meet the national overall emission cap. Therefore, the model is well suited to analyse not only the effects of linking ETS on ETS-sectors, but as well on the abatement burden of further non-ETS sectors, assuming that the overall national emission caps are binding. Allocation is centralised and mostly done via auctioning; however there are several allocation rules available, that distinguish as well between sectors. For example, the recent EU-ETS allocation scheme can be replicated in the model, which is very useful for the present analysis. Revenues from allocation other than free allocation are redistributed in a lump-sum way to the agents.

Permits are connected directly to the fossil fuel inputs with zero elasticity of substitution (Leontief). Hence, the permit price is computed directly as a consequence of increased/decreased demand for fossil fuel inputs. It therefore equals the shadow value of carbon, resulting from the implementation of the carbon constraint (Böhringer & Löschel 2004, p.4). With different levels of stringency of the carbon constraint, the MACC can be derived for each region or each ETS. By this, the relative permit prices in each region and the expected changes through linking can be calculated[55]. It is important to note that the resulting permit price relies on perfectly competitive markets without information asymmetries and other market failures; otherwise, the shadow value of carbon is not necessarily equal to the permit price.

With respect to permit allocation, the zero profit condition plays an important role: With zero profits, firms cannot pass on any permit costs to the consumer under a free allocation scheme.

The model allows for free trading of allowances. Therefore, the EU ETS can be modelled. Yet, market regimes other than perfect competition are not an option.

Further, linked permit markets can be explicitly analysed with PACE. The previous PACE-FlexMecs module, which simulates emission trading between countries, is now part of the standard PACE model. Again, only markets with perfect competition can be modelled.

Since financial markets are not included in the current model version (and are not planned to be included in the future according to the modellers), permit market liquidity cannot be modelled. Neither is PACE suited to model the number of market participants in the permit market, nor market power and market concentration (only perfect competition), or the number of trades in the permit market. Yet, the size of market participants can be modelled.

The model distinguishes explicitly between ETS and non-ETS sectors. In order to guarantee that the total national emissions target is met, the model estimates country-specific carbon taxes such that the national specific emission reduction targets are met.

International trade

Trade in goods occurs under the Armington-specification, and trade elasticities are, like the other parameters, estimated with the base year data (Alexeeva-Talebi et al. 2012, p.4f). PACE endogenously provides estimates for sectoral production per region and trade exposure, i.e. the share of exports for a specific sector in a certain region and aggregate exports and imports per sector and region (Alexeeva-Talebi et al. 2012, p.8).

PACE further provides the effect of a policy on competitiveness (Alexeeva-Talebi 2009, p.13) and the carbon leakage rate as part of the model output. Yet the model's definition of carbon leakage ("Change in foreign emissions relative to share of domestic emission reductions", see (Böhringer

[55] Permits are connected directly to the fossil fuel inputs with zero elasticity of substitution (Leontief). Hence, the permit price is computed directly as a consequence of increased/decreased demand for fossil fuel inputs.

et al. 2009, p.7) is not entirely correct (it would be "Change in foreign emissions due to (policy-induced) domestic emission reduction"). The competitiveness-effects are reported by policy-induced sectoral output changes, sectoral value added changes, sectoral employment effects and sectoral market shares. It is possible to model the competitiveness-effects of domestic ETS-sectors in relation to the ETS-sectors of the linking partner and in relation to similar sectors in the rest of the world.

Since the latest PACE version, capital is mobile between regions. Hence, net capital flows can be calculated.

Domestic economy

GDP and production per sector and region are endogenous in PACE (Alexeeva-Talebi et al. 2012, p.8). Investments per region are endogenous, too; yet they are not disaggregated by sector (Böhringer et al. 2009, p.21). Production in the domestic economy is calculated with aggregate production functions, where technology is characterised through different substitution possibilities between the inputs (Böhringer & Löschel 2004). The substitution possibilities between capital, labour, intermediate inputs, energy and non-energy are specified by nested CES (constant elasticity of substitution) cost functions at three levels. CES functions are a particular type of aggregator function, which combines two or more types of inputs into an aggregate quantity. In presence of a carbon pricing scheme, fossil fuels as production input (i.e. oil, natural gas, coal) are tied to a fixed proportion of emission permits. Hence, the CES function allows for substituting the fossil fuel input by other inputs as reaction to an increasing carbon price.

The endogenous price of each output is given by the unit costs to produce this good, which corresponds to the marginal and – due to constant returns to scale – the average costs of production.

The sectoral coverage in PACE is very detailed, and distinguishes between ETS and non-ETS sectors. This is very useful for a meaningful analysis of the economic effects of linking on individual ETS and non-ETS sectors. The most recent model version distinguishes 36 sectors in total, of which 26 industrial sectors that include nine disaggregated energy intensive sectors (Fertilizers and other nitrogen compounds; Organic chemicals; Inorganic chemicals; Cement; Bricks, tiles and construction products; Glass; Ceramics; Manufacturing of iron and steel; and Aluminium) beyond the sectors in the GTAP 9 data base as an extended feature. In addition to the industrial sectors, five extractive activities (from agriculture to mining) and five services (including transport) are covered.

The electricity sector is modelled in a bottom-up module, which entails different power producing technologies (coal, refined oil, gas, nuclear, renewable energy carriers) (formerly PACE-BU model, now part of the standard version). Like for the other sectors, the electricity sector can substitute between different inputs. The bottom-up technological choices in the electricity sector influence permit prices, capital flows etc. in the entire economy (i.e. in non-electricity sectors as well).

Regional coverage

The default model specification covers 23 world regions, of which the EU-ETS-31 is not explicitly reported. However, the EU-27 member states are reported at a relatively high level of detail. The six largest economies of the old EU member states as well as Poland as the largest economy of the new member states are included as separate regions. The remaining EU-27 countries are gathered in two groups. Croatia is not covered, yet. Further, Iceland, Norway and Liechtenstein, are only covered in the regional aggregate "Rest of Annex I". Nevertheless, model results should be useful to gain a first insight in economic effects of linking ETS. Potential linking partner countries like China, Mexico, South Korea and Turkey are all included as separate regions, which makes the model in total very useful for an analysis of linking effects.

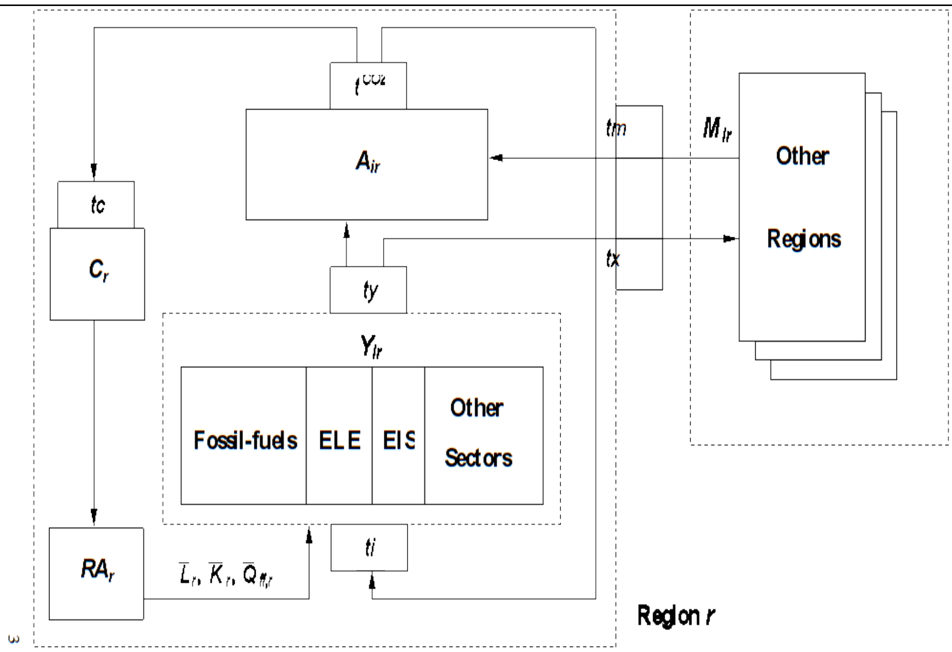
Dynamic efficiency and technological progress

PACE does not deal explicitly with dynamic efficiency. Regarding technological progress, only exogenous technological change, i.e. autonomous energy efficiency improvement (AEEI) is included, which shifts the production possibility frontier outside. Learning curves are not used. The AEEI parameter is derived from the Global Trade Analysis Project (GTAP) database. It is regularly updated as soon as the GTAP database is updated.

Endogenous technological change is planned to be included by some point in 2017. CCS is not yet included but it is planned to be by the end of 2016.

Figure 18: PACE model structure

A_{ir} =



Source: Böhringer et al. 2009, p.1-3

Armington aggregate for demand category d of good i in region r

C_r = Aggregate household consumption in region r

M_{ir} = Aggregate imports of good i and region r

RA_r = Representative agent in region r

Y_{ir} = Production in sector i and region r

ELE = Electricity

EIS = Energy-intensive sectors

L_r = Aggregate labor endowment for region r

K_r = Aggregate capital endowment for region r Endowment

Q_{ir} = Endowment of natural resource i for region r ($i \in FF$ (subset of fossil fuels))

tc = Consumption taxes

t^{CO2} = Carbon tax

ti = Intermediate taxes

ty = Production taxes/subsidies

tm = Import tariffs

tx = Export tariffs

5.4 POLES

Table 19: Summary POLES

Model	Prospective Outlook on Long-term Energy Systems (POLES)
Author	LEPII-CNRS, Enerdata
Type	Partial equilibrium (Energy markets)
Time horizon of agents	Myopic optimisation, recursive dynamic
Time horizon of the model	Long-term: 1990-2050/2100 (1990-2010: period set by data and used for calibration), annual time steps
Economic Fields	(Domestic economy), linked permit market
Sectors	22 energy demand sectors (of which 4 industry sectors: Steel, Chemistry, Non-metallic minerals and Other industry), 1 agriculture, aviation
Regions	Global: 57 full energy balances (7 regions, 11 sub-regions, 32 countries); 80 fossil fuel supply regions *Region (sub-region) (country):* - North America (-) (United States; Canada) - Europe (EU-15; EU-25; **EU-27**) (Austria; Belgium; Denmark; Finland; France; Germany; Greece; Ireland; Italy; Netherlands; Portugal; Spain; Sweden; UK; Turkey; Bulgaria; Czech Republic; Hungary; Poland; Romania; Slovak Republic) - Japan-South Pacific (South Pacific) (Japan; Australia + New Zealand) - CIS (-) (Russia; Ukraine) - Latin America (Central America; South America) (Brazil; Mexico) - Asia (South Asia; South-East Asia) (India; South Korea; China) - Africa/Middle East (North Africa; Sub-Saharan Africa; Middle-East) (Egypt)
Emissions	CO_2, CH_4, N_2O, HFCs, CFCs, SFs, PFCs; from fossil fuel combustion and energy use; reporting not sure whether by region or sector
Main databases	ENERDATA, updated annually, take information from: - Population growth: UN World Population Prospects - GDP growth: latest IMF forecasts (for the short run), MIT and CEPII forecasts (for the longer run) - Energy demand; energy prices: Eurostat, IEA, Enerdata - Industry sector energy use: Enerdata, Eurostat, IEA, IISI, World Bank - GHG emissions (+MACC?): UNFCCC GHG inventories, IPCC Assessment Reports, EDGAR database, IEA, EIA. - ENDOW (LEPII-EPE) (Emission quota endowments per sector database) organises all relevant information on national emission targets and sectoral National Allocation Plans, with particular detail for those countries under the EU ETS - Technologies: TECHPOL (more than 300 time-series on 30 technologies, 5 main economic performance parameters)

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POLES (Prospective Outlook on Long-term Energy Systems) is a global partial equilibrium model, developed to analyse energy markets and energy-related GHG mitigation policies. The model connects three levels of analysis: international energy trade, regional energy balances and national/sectoral energy demand. It is solved by a year-by-year dynamic recursive modelling until the year 2100 with lagged adjustments of energy supply and demand by world region (Kitous et al. 2010. p.79). It can hence be used to analyse short- and long-term effects of linking ETS.

Data is yearly updated to capture recent developments in energy markets in different regions. The parameters, especially price and activity elasticities, were calibrated in previous studies with the model. Further parameters are estimated by the model, based on historical data (Kitous et al. 2010, p.80).

By definition, the partial equilibrium model does not cover the entire domestic economy, but focuses on domestic and global energy markets. As such, the overall economic activity (GDP) is exogenous, which is a main limitation. Further, international trade in non-energy goods is neither simulated. Still, linked permit markets can be modelled.

Permit market

Emission permit trade is included in the model, and can be analysed in more detail via the ASPEN-module (Analyse des Systèmes de Permis d'Emission Négociable) (LEPII-EPE & Enerdata 2009, p.3; LEPII-EPE & Enerdata 2006, p.55f.).

The ASPEN module was developed to simulate development of the EU-ETS carbon price. Endogenous marginal abatement cost curves are used to determine emission permit flows (endogenous permit imports and exports by country) and the equilibrium permit price, which is assumed to be equivalent to a shadow carbon tax (Criqui & Mima 2001, p.2,4). Hence, the model could be used to analyse the effects of linking on the equilibrium permit price, and on net capital flows between the linking partners.

The permit trade volume, a proxy for permit market liquidity, can be analysed by aid of several output variables: endogenous global or (linked) ETS-wide permit supply; endogenous global or (linked) ETS-wide permit demand; endogenous imports and exports of permits by country (LEPII-EPE & Enerdata 2006, p.53).

Further, ASPEN can be used to compare marginal and total abatement costs with and without a permit system, and to evaluate the gains from trade for different market structures (Criqui & Mima 2001, p.2). For the European Union, the model provides estimates of ETS- versus non-ETS splits. One can specify different trading rules and emission quota endowments (via the ENDOW-database for the EU-ETS) (LEPII-EPE & Enerdata 2006, p.55ff., 58ff.). Like it is common to most models, an exogenous emission constraint is a necessary model input.

Domestic economy

In contrast to most partial equilibrium models, POLES provides endogenous information about economic activity at the sectoral level, i.e. sectoral value added. This is important to assess the effects of linking ETS on competitiveness and carbon leakage. Aviation is covered explicitly. Yet, POLES, only differentiates 4 industry sectors in a total of 22 energy demand sectors (Steel, Chemistry, Non-metallic minerals and Other industry), which is too aggregated for meaningful carbon leakage and competitiveness analysis for the ETS-sectors in linked permit markets.

The model provides an endogenous simulation of full annual energy balances for a wide range of regions and international energy commodity trade. It simulates all steps of the energy system by sector and energy vector, including energy demand, primary energy supply and energy transformation. Investments in the energy sector are modelled endogenously (but not for the rest of the economy) (Kitous 2006, p.28).

International, regional and sectoral energy prices are endogenous. Yet, the model does not capture market power such as the influence of OPEC on the oil (and hence indirectly the natural gas) price (Hedenus et al. 2012, p.27). Energy demand is determined by economic growth, autonomous technological change as well as short- and long-term demand elasticities (Hedenus et al. 2012, p.28). Agents decide about the investments and the utilisation rate, with a myopic anticipation of future costs and constraints, considering resource potentials, vintage and other inertia (Hedenus et al. 2012, p.27). Hence, unfortunately, the model does not use the more realistic limited foresight as major driving force for investments.

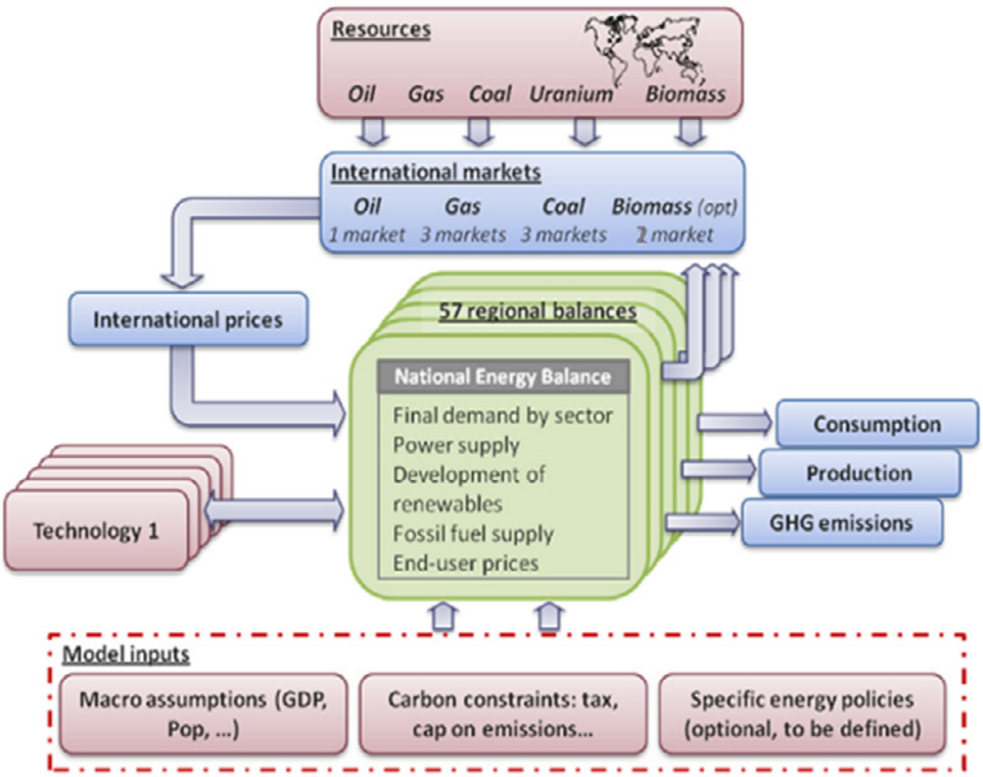
Regional coverage

With more than 57 full energy balances, the regional coverage of POLES provides flexibility in the level or regional aggregation. This relatively detailed global coverage is a good starting point for the analysis of carbon leakage and competitiveness-effects for linked ETS sectors with regard to the linking partner, third countries or the rest of the world. The EU-27 can serve as a proxy for the EU-ETS-31, since only the relatively small countries Liechtenstein, Iceland and Norway would lack this aggregate. Some major economies that have already introduced an ETS or are considering to do so later (e.g. China, Mexico, South Korea, Turkey) are covered at the individual country-level.

Dynamic efficiency and technological progress

Since technological change is exogenous in the model, the endogenous simulation of dynamic efficiency is not possible.

Figure 19: POLES model structure



Note: The Red boxes are the main assumptions, calibration and scenario settings; the Green box represents the energy balance resolution by country / region and the Blue boxes represent the trade and key outputs (demand, supply, emissions).

Source: https://wiki.ucl.ac.uk/display/ADVIAM/Model+concept%2C+solver+and+details+-+POLES

5.5 TIMES

Table 20: Summary TIMES

Model	**The Integrated MARKAL-EFOM System (TIMES) (MARKAL = MARKet ALocation; EFOM = Energy Flow Optimisartion Model)**
Author	International Energy Agency (IEA)/ Energy Technology Systems Analysis Program (ETSAP)
Type	Partial equilibrium (Energy markets); TIMES-MACRO: combine TIMES with one-sectoral CGE model
Time horizon of the agents	Default: Perfect foresight optimisation, but limited foresight, myopic and stochastic options are available
Time horizon of the model	TIMES: Flexible (evolution over a period of usually 20 to 50 or 100 years, with flexible time steps and different time-slices for each annual variable month to hour; can have time slices of different lengths, too (eg. short in short-run, longer in long-run)) ETSAP-TIAM: 2005-2100 (2005 is IEA data base year) with 1-year time steps
Economic fields	(Domestic economy), permit market
Sectors	TIMES: Flexible (as many as desired energy producers & energy consumers) NOTE: Only energy producers have endogenous values Times Integrated Assessment Model (TIAM): 42 primary energy resources in 13 forms, large energy sector representation (up to 1000 technologies energy conversion), energy demand sectors: 6 industry sectors, 1 agriculture, no explicit forestry, aviation TIMES-MACRO: + 1 macro-sector
Regions	TIMES: Flexible: Up to 27 regions at the global, multi-regional, national, province or community level (Some TIMES modules cover up to 30 regions) ETSAP-TIAM: Global: 15 regions - Africa - Australia + New Zealand - Canada - Central and South America - China - **EU** - Central Asia Caucasus - Other Eastern Europe - Russia - India - Japan - Mexico - Middle East (incl. Turkey) - Other developing Asia - South Korea - USA
Emissions	CO2 from energy consumption (including process emissions into the

	model is possible), CH4, N2O from energy consumption and adipic and nitric acid industries, no PFCs
Main databases	TIMES: Own data collection required, unless the user has access to an existing model. Yet, publicly available data sources are abundant (see below). ETSAP starter model contains a limited technology database ("base-dataset") from documented data sources. - Energy data base year calibration: IEA Extended Energy Balances of OECD and non-OECD countries - Population: UN estimations - GDP: Figures for future economic growth are based on an assumption of economic convergence between regions; alternatively GEM-E3 model inputs, e.g. set of coherent growth rates - International and region-specific data (installed capacities and resource potentials) form various sources: IEA-ETP, USDOE, USEPA, USGS, EGRID, NRCAN, WEC, World Energy council, IPCC-TAR, US Geological Survey etc.) - Technology characteristics: based on literature or expert knowledge (IPCC reports, US-Environmental Protection Agency, IEA-Energy Technology Perspectives, US-Department of Energy, US Geological Survey, World Energy Council, etc.) TIAM: includes a large technology database, but sources are not well documented

Wuppertal Institut, 2017, own compilation

TIMES(-MARKAL) is a partial equilibrium model family, developed by the IEA and maintained by the Energy Technology Systems Analysis Programme (ETSAP) (Loulou et al. 2005, p.22). The TIMES model generator was developed as a successor of the MARKAL energy model generator, and has some additional features like endogenous energy trade between the regions, stochastic programming with risk aversion and vintage of technologies (Loulou & Labriet 2008, p.8f.). The parameters in TIMES are calibrated by using data from the baseline period (Loulou & Labriet 2008, p.13+18ff.+29 for endogenisation of technological parameters+p.31f. for stochastic programming).

TIMES can be flexibly adapted to the users' needs for analysing local, national or multi-regional energy systems or specific energy sectors. The ETSAP-TIAM (ETSAP-Times Integrated Assessment Model) is one of its widely-used multiregional specifications with a climate module extension.

The time horizon and steps in TIMES are flexible, which allows a detailed analysis of short- and long run effects of linking ETS. ETSAP-TIAM for example has a long time horizon (up to the year 2100), with 1-year time steps.

Usually, TIMES assumes competitive energy markets with perfect foresight. Yet, limited foresight over some periods can be chosen, and the stochastic programming function allows for uncertainty (Loulou & Labriet 2008, p.25f.). Running the model several times under stochastic programming might provide a range of potential results, which is especially useful in the context of volatile and uncertain future permit prices.

Since TIMES is a partial equilibrium model, the domestic economy and international trade in goods and services is only superficially simulated. The permit market is covered, since regions are linked via energy-, material- and, optionally, permit trading. As such, actions in one region affect the other regions (Loulou & Labriet 2008, p.16, 21f.). In its default-version, TIMES only reports GHG per region, sector and fuel from energy consumption (Loulou & Labriet 2008, p.12, 16), but according to the modellers, constructing a TIMES-based model that accounts for emissions from production processes is possible. TIMES-based models further are suited to model the real emissions of ETS-sectors, in addition to their exogenously given ETS-market-cap.

Permit market

Via the ETS constraint and the permit market, TIMES-based models provide endogenous emission shadow prices and permit prices (Loulou & Labriet 2008, p.1, 16, 24). It is possible to run any TIMES-based model with a cap on selected ETS-sectors – there is no need for an economy-wide emission cap to calculate the shadow prices and the permit prices. The user has full control over which emissions matter for calculating the permit price. The resulting endogenous MAC give the MACC when plotted against different abatement levels. However, according to the modellers, such a curve would never be unique, because the assumed emission targets for other model years will of course affect the marginal abatement costs in any single year.

Overall, TIMES is in parts useful to model the impacts of linking. Albeit there is no trade in manufactured goods in TIMES, permit trade can be optionally included (e.g. in TIAM-UCL) in addition to trade in raw materials/commodities (Loulou & Labriet 2008, p.21). Net capital flows from permit buyer to permit seller are not explicitly modelled. Yet, one can alternatively multiply the amount of permit trade with the simulated permit price to obtain the value of total capital flows.

Since international permit trade is modelled, one obtains the overall trading volume, which is used as a proxy for assessing permit market liquidity. However, the model assumes perfect competition and perfect markets as well in the permit market. Therefore, the usefulness of the results for assessing the impacts of linking accounting for market imperfections is limited (Loulou & Labriet 2008, p.21). One can however simulate some market imperfections by adding transaction costs in the model. Permit banking can be modelled via inter-period storage.

TIMES-based models are not capable of calculating the number and size of market participants in the permit market, to estimate market power or to calculate the number of trades in the permit market.

Domestic economy

GDP is exogenous in TIMES (Loulou & Labriet 2008, p.10). The TIMES-MACRO version links TIMES to a one-sectoral CGE model (Loulou et al. 2005, p.22; Remme & Blesl 2006). This might be useful to simulate overall economic performance, i.e. to obtain endogenous GDP values. Yet, a one-sectoral model is not disaggregated enough for analysing the effects of linking on competitiveness and carbon leakage.

Regarding overall sectoral coverage, the amount of included energy producer and consumer sectors and the level of sectoral disaggregation is flexible in TIMES, as long as data is available. TIMES-based models however do not report any endogenous production by secto, i.e. in terms of gross value added (GVA). Instead, endogenous changes in relative production costs can serve as an alternative proxy to analyse competitiveness-effects of linking. Alternatively, one could use output from GEMINI-E3 to obtain "endogenised" values for industrial production (Loulou & Labriet 2008, p.10). Endogenous investments are only simulated for the energy sector (Loulou & Labriet 2008, p.21).

The energy sector in ETSAP-TIAM is characterised by a very high level of technological detail: Several thousand technologies in all sectors of the energy system can be chosen for each region (Loulou & Labriet 2008, p.21). Yet, within the group of energy demand sectors, the model disaggregated only 6 industry sectors, which is too aggregated for competitiveness and carbon leakage analyses for the ETS-sectors.

In ETSAP-TIAM, energy demand is influenced by prices while, at the same time, it affects the prices. The supply of energy services is subject to resource and policy constraints and a set of exogenous technological specifications. The model finds the cost-minimising solution by simultaneously making decisions on energy supply, trade and technology investments. Markets are in equilibrium in each time period.

Since TIAM-models are partial equilibrium models, macroeconomic competitiveness-effects between regions are not included. Technology competiveness effects are automatically included whenever multiple competing technology alternatives available in the model.

Regional coverage

The regional coverage in TIMES is as well flexible. Up to 27 regions at the global, multi-regional, national, province or community level can be included. It is important to choose a global coverage for the analysis of carbon leakage and competitiveness-effects for linked ETS sectors with regard to third countries and the linking partner.

Regional coverage in ETSAP-TIAM does fulfil the requirements of the present analysis to large extend. The EU can be taken as a proxy for the EU-ETS-31. China, South Korea and Mexico are included as individual countries. Turkey cannot be analysed with the ETSAP-TIAM specification, since it is part of the "Middle East" regional aggregate.

Dynamic efficiency and technological progress

In a bottom-up model like TIMES, (energy) efficiency is modelled explicitly at the technology level. The assumptions are defined directly in terms of process efficiencies, and efficiency losses due to partial loads. Yet, TIMES does not prescribe any assumptions regarding technology usage and technological change. It is fully up to the user to specify the assumptions on technological development, technology usage and associated technological costs. Therefore, it is as well up to identify relevant data sources and to gather the required data for simulating (low-carbon) technology usage, technological costs and technological change.

Technological change is usually defined by exogenous learning curves for new technology vintages (= decreasing costs, improving efficiencies and capacity factors), and constraints on learning as a function of cumulative past investments. Endogenous (non-convex) learning can be modelled by using the ETL option. Since there is no explicit production function, nor MACCs in TIMES, the technology parameters for each vintage are directly reflected in the physical results and cost accounting. The production function for each sector is constructed implicitly.

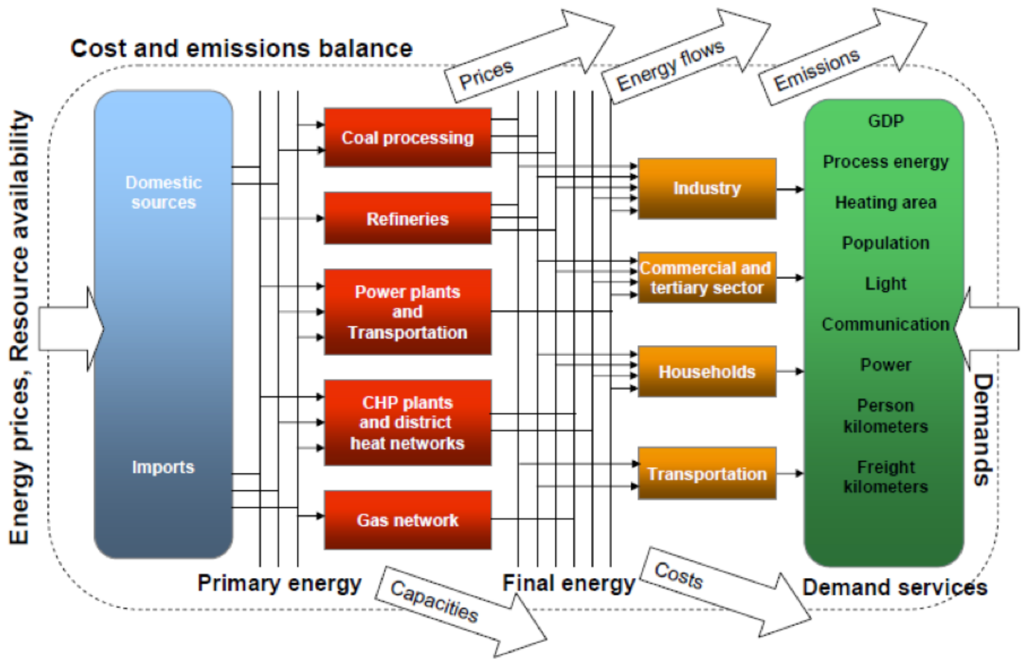
Macro-economic dynamic efficiency is not dealt with in TIMES. In a bottom-up model like TIMES, dynamic efficiencies are modelled explicitly at the technology level. The efficiency of any technology can be defined to be dependent of technology vintage (efficiency varying by vintage 2010, 2015, 2020, 2025,…) the age of the installation (efficiency varying by age of 1,2,3,… years), the operating timeslice (efficiency varying by season, or by time of day), or the operating level (efficiency varying according to load levels 10%–100%).

Efficiency improvements due to increased labour productivity can be taken into account in labour costs (operating costs), but the labour market is not represented.

Latest update

The latest version of TIME is from September 2016. Data updates need to be done by the users individually, depending on which data sources they use.

Figure 20: TIMES model structure



Source: http://www.iea-etsap.org/web/Times.asp

5.6 AIM-CGE

AIM-CGE was not shortlisted.

Table 21: Summary Aim-CGE

Model	Asia-Pacific Integrated Model (AIM-CGE)
Author	National Institute for Environmental Studies Kyoto University
Type	General equilibrium with technology-explicit modules in the power sector
Time horizon of the agent	Myopic optimisation, recursive-dynamic
Time horizon of the model	2005-2050/2100, annual time steps,
Economic fields	Domestic economy, international trade (but no bilateral trade matrices), linked permit market
Sectors	44 sectors (of which 20 energy sectors, 13 industry sectors, 9 agricultural sectors + forestry, aviation is in transport and communications sector)
Regions	Global: 17 regions - Japan - China - India - Southeast Asia - Rest of Asia (incl. South Korea) - Oceania - **EU-25** - **Rest of Europe** - Former Soviet Union

	- Turkey - Canada - United States - Brazil - Rest of South America - Middle East - North Africa - Rest of Africa
Emissions	CO, NH3, NMVOC, NOx, SO2, BC, OC, CO2, CH4, and N2O, no PFC; from fossil fuel combustion and processes; reported by sectors
Main databases	- Social accounting matrix: GTAP, IEA Energy balance tables OECD and non-OECD - GHG emissions: EDGAR4.2 - Socioeconomic assumptions: SSP2 (Shared socioeconomic pathways database v.0.9.3) from IIASA - Autonomous Energy Efficiency Improvements (AEEI): EPPA output

Wuppertal Institut, 2017, own compilation

AIM-CGE (Asia-Pacific Integrated Model) is a dynamic recursive general equilibrium model with bottom-up elements in the energy sector. It provides annual output until the year 2100. This allows for flexible analyses of the short- and the long-run effects of linking ETS. The model is based on Social Accounting Matrices (SAM). Parameters are mostly calibrated, not estimated. Four blocks make the model: production, income distribution, final consumption, and the market (Fujimori et al. 2012, p.5).

AIM-CGE uses myopic optimisation instead of limited foresight as the main principle that drives agents' decisions. It is hence not most useful to analyse dynamic efficiency effects, since myopic decision-making adversely affects investments in technologies, that pay off in the long-run. However, for analysing the effects of linking on the selected criteria in the short-run, the model can be used.

The domestic economy, international trade and the linked permit market are covered for assessing the impact of linking on most of the selected operationalised criteria. AIM-CGE reports energy- and non-energy related GHG emissions by region and sector.

Permit market

The model uses several explicit equations to model the permit market, i.e. international emission trading and the resulting permit price with flexible permit import and export quota (for more details see Fujimori et al. 2012, pp. 33, 43, 50f.). Marginal abatement cost curves (MACC) can be derived from plotting different levels of emission abatement with the corresponding permit price, which reflects the MAC under the assumption of a perfect permit market. Yet, permits are no explicit inputs to the firms' production functions (Fujimori et al. 2012, p.6f.), which limits the validity of results with regard to competitiveness effects and carbon leakage.

The modelling of emission permit imports can be used to calculate expected net capital flows by multiplying the amount of permit imports with the expected permit price (Fujimori et al. 2012, p.33, 51). Yet, the modelling of the permit market is not detailed enough to assess the impact of linking on market liquidity (objective 5).

International trade

Trade of goods and services occurs under the Armington-assumption, which has an important influence on the impacts of linking ETS on carbon leakage and competitiveness. The current account is balanced in each period.

Domestic economy

Capital accumulation and production are endogenous in AIM-CGE (Fujimori et al. 2012, p.5). The production sectors maximise profit under multi-nested Constant Elasticity of Substitution functions (CES) and the input prices (Fujimori et al. 2012, p.5). All relevant ETS-sectors are included at quite high detail. The model covers 44 disaggregated sectors, of which there are 20 energy- and 13 industry sectors. The model has technology-explicit modules in the power sector, and the energy sector is disaggregated into energy supply- and energy demand sides. This is a useful disaggregation to analyse the effects of linking on carbon leakage and competitiveness on the ETS-sectors (and as well on non-ETS sectors in further studies) with regard to the linking partner and third countries. Aviation is not reported explicitly, but included in the "transport and communications" sector. This is a shortcoming to the sectoral coverage, yet, since the largest part of the EU-ETS consists of the energy- and industrial sector, this should be an acceptable disadvantage for the present analysis.

Regional coverage

AIM-CGE is a global model, which is a basic prerequisite for a meaningful analysis of carbon leakage and competitiveness effects for linked ETS sectors with regard to third countries or the rest of the world. Yet, in terms of the more detailed regional coverage, AIM-CGE has some shortcomings with regard to the requirements of the analysis. The EU-ETS is represented in the group of the EU-25 and not as EU-28, or, ideally, the EU-ETS-31. The rest of Europe, including the remaining EU-ETS countries (other than the EU-25), is aggregated into another group. The potential linking partners China and Turkey are individually included, but South Korea and Mexico are only part of a regional aggregate ("Rest of Asia" and, respectively, apparently "Rest of South America", which is geographically not correct).

Figure 21: AIM-CGE model structure for one region

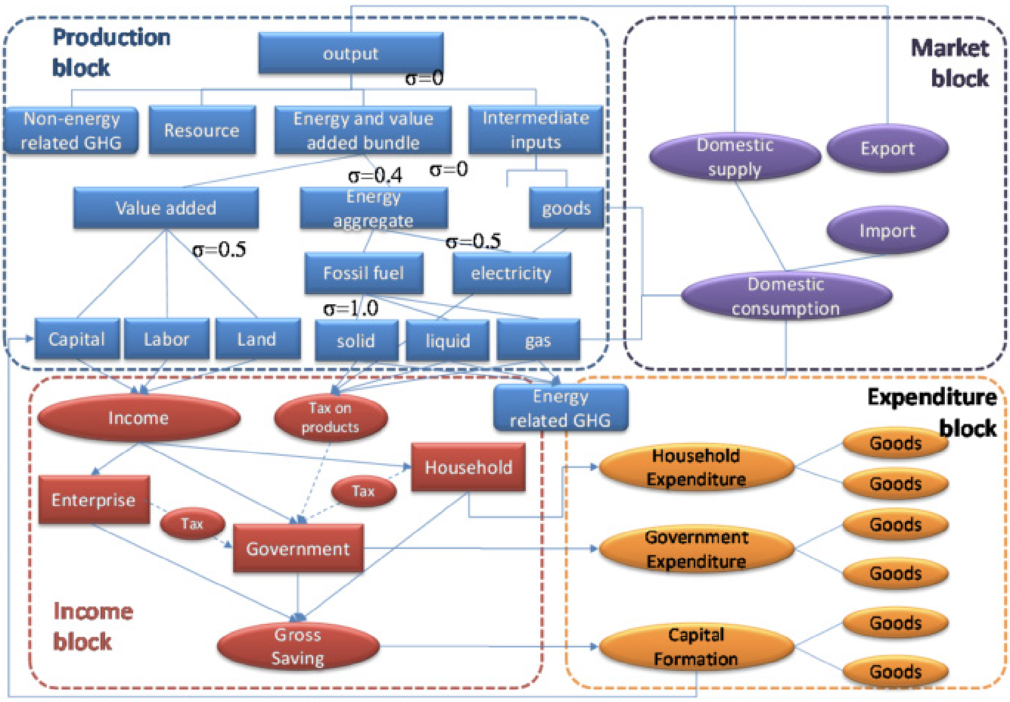


Figure 1 Overview of AIM/CGE model structure (for one region)[3]

Source: Fujimori et al. 2012, p.5

5.7 EPPA

EPPA was not shortlisted.

Table 22: Summary EPPA

Model	MIT Economic Projection and Policy Analysis (EPPA)
Author	Massachusetts Institute of Technology (MIT)
Type	General equilibrium with technology-explicit modules in the power sector
Time horizon of the agents	Myopic and forward-looking optimisation (profit/welfare maximisation)-versions, recursive dynamic
Time horizon of the model	2010-2100, 5-year time steps,
Economic fields	Domestic economy, bilateral international trade, linked permit market
Sectors	14 sectors, of which 6 energy sector with 14 energy backstop technologies, 3 agriculture, aviation aggregated in transport, only 2 industry sectors, no forestry
Regions	Global: 18 regions (flexible) - USA - EU-27, Croatia, Norway, Switzerland, Iceland, Liechtenstein (as one region) - Eastern Europe and Central Asia (incl. Turkey) - Japan - Russia - Australia+New Zealand - Canada - China - India - East Asia - Middle East - Indonesia - South Korea - Mexico - Brazil - Africa - Latin America - Rest of Asia
Emissions	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, +more non-Kyoto, from fossil fuel combustion, processes and LULUCF, by sectors
Main databases	- Social Accounting Matrix: GTAP8 (more disaggregated than EPPA -> it is likely possible to have more industrial sectors) - GDP growth projections: until 2018 from IMF World Economic Outlook 2013 + For later years Paltsev et al. (2005) adjusted to reflect long term regional GDP from recent studies, including the World Bank (2013), United Nations (2013), Gordon (2012), and Empresa de Pesquisa Energética (EPE) (2007)

	- Energy use: IEA World Energy Outlook - GHG: EDGAR v4.2 2013

Wuppertal Institut, 2017, own compilation

EPPA (MIT Economic Projection and Policy Analysis, earlier versions: Emissions Prediction and Policy Analysis) is a global recursive-dynamic general equilibrium model, with technology-explicit modules in the power sector. It employs a 5-year time steps solution procedure that simulates scenarios until 2100. The model is designed to simulate the long-run. Hence, short-term fluctuations and ETS distortions due to economic business cycles or external shocks are not covered (Chen et al. 2015, p.3). Like many CGE models, it is based on social accounting matrices (SAM). Parameters are mostly calibrated or adjusted with historical data (Babiker et al. 2008, p.45)

The model reaches into all relevant areas to analyse the criteria: The domestic economy, international trade and the linked permit market. Energy- and production-related GHG emissions are covered (Chen et al. 2015, p.12).

Permit market

The model simulates regional permit prices or the world permit price, depending on whether international permit trade is allowed or not. An emission cap is introduced as an additional sector-specific constraint to the production function (Babiker et al. 2008, p.8). The sector-specific constraint allows for a differentiation between ETS- and non-ETS sectors (Chen et al. 2015, p. 21). The resulting shadow value of carbon is then assumed to be equivalent to the regional (sector-specific) or the world permit price (Babiker et al. 2008, p.25). This equality is only true in case of a perfectly functioning market with marginal pricing and without market power and information asymmetries. Regional MACC are obtained by plotting the relationship between emission caps and the resulting permit price (Chen et al. 2015, p.29).

The permit price then behaves like a carbon tax, i.e. there is no uncertainty and volatility around the price signal. Since uncertainty and volatility make investments more expensive and distort incentives for R&D, the model likely overestimates static and dynamic efficiency.

EPPA is not useful to analyse the effects of ETS linking on ETS market liquidity, since simulation is not possible for the true permit trade volume (only the perfect market permit trade volume, which assumes perfect liquidity and hence is not useful as a proxy to assess the effects of linking on liquidity) and neither market participants relative to the market size.

International trade

With regard to international trade, the model provides bilateral trade matrices, explicitly reporting as well tariffs, taxes and transport margins, which is very useful to analyse carbon leakage and competitiveness effects (Babiker et al. 2008, p.22). Trade of goods and emission permits are covered, but no trade in capital and labour. Therefore, current account imbalance in the initial period are assumed to disappear gradually (Babiker et al. 2008, p.5). Some commodities like emission permits and crude oil are modelled as perfect substitutes in international trade, whilst for the majority of goods, the model uses the Armington-assumption (Chen et al. 2015, p.12).

Domestic economy

As common to CGE models, the zero-profit condition, the market clearing condition and the income-balance condition holds for each economic agent. Producers maximise their profits, given the market prices and available technology, under limited foresight. As such, EPPA is one of the few models that uses limited foresight as the driving principle of the model, which is very useful to analyse short and long-run efficiency effects.

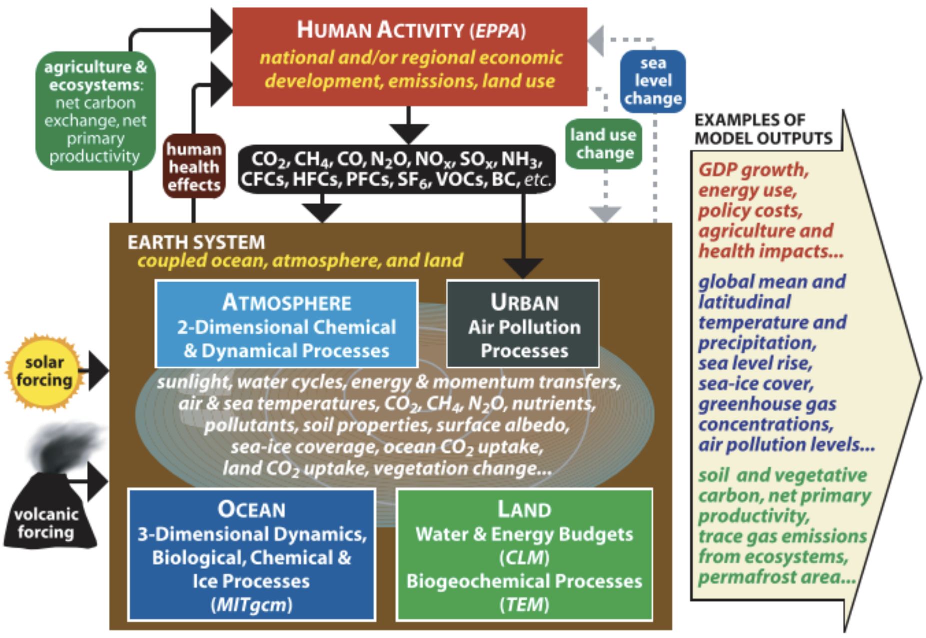
The endogenous sectoral production comes in form of a SAM in the model output (Chen et al. 2015, p.11). Each sector has a production function, which describes its substitution possibilities (CES-type) and technical requirements (Chen et al. 2015, p.4). The model contains a full set of inter-industry transactions, where output of one industry is used as an input to another production process (Babiker et al. 2008, p.5). Investments are as well endogenous (Chen et al. 2015, p.2), and can be used as an alternative possibility to estimate competitiveness and carbon leakage effects.

With only 14 sectors, the model has a relatively undetailed sectoral disaggregation. It reports 6 energy technologies and just 2 industrial sectors, which is not detailed enough to analyse the competitiveness- and carbon leakage effects of linking ETS in a meaningful way. Further, aviation is included in the aggregated transport sector. The model provides some technology-explicit modules in the power sector, and it can be further modified to incorporate higher resolutions for some technologies or activities. However, these modifications require the substantial collection of data beyond the basic economic database (Chen et al. 2015, p.2f.).

Regional coverage

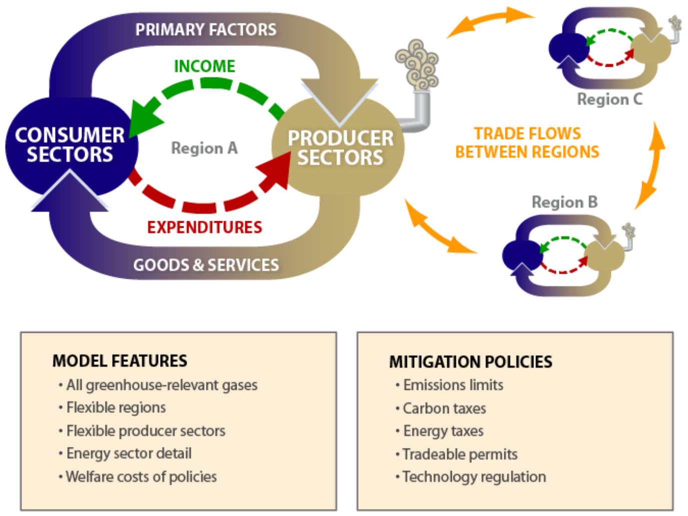
Regions in EPPA cover the global economy, which is a basic prerequisite for a meaningful analysis of carbon leakage and competitiveness effects for linked ETS sectors with regard to third countries or the rest of the world. The regional aggregation of Europe matches the EU-ETS-31, plus Norway and Switzerland. Yet, since Switzerland is a relatively small country compared to the EU-ETS, the regional aggregation might be acceptable. With regard to further linking partners, EPPA reports results for China, South Korea and Mexico on an individual country level. It only does not provide disaggregated results for Turkey, which is included in the aggregated "Eastern Europe and Central Asia" region.

Figure 23: EPPA model structure main components



Source: Babiker et al. 2008, p.2

Figure 24: EPPA model economic structure



Source: http://globalchange.mit.edu/research/IGSM

5.8 G-cubed

G-cubed was not shortlisted.

Table 23: Summary G-cubed

Model	G-cubed
Author	Peter J. Wilcoxen, Marxwell School Syracuse University
Type	General equilibrium with econometric elements
Time horizon of agents	2 types of decision-makers: forward-looking investors and rule-of-thumb
Time horizon of the model	Not available in model descriptions
Economic fields	Domestic economy, international trade, linked permit market
Sectors	Flexible, depending on data, for energy issues usually 12 sectors: 5 energy, 7 non-energy of which 3 industry: mining, durable goods and non-durable goods, 1 agriculture, 1 forestry, aviation aggregated in transportation
Regions	Global: 9-12 regions - USA - Japan - Australia - **Western Europe** - Rest of the OECD (incl. South Korea, Mexico, Turkey) - China

	- Other developing countries - **Eastern Europe and former soviet union** - Oil exporting countries and middle east
Emissions	Apparently only CO2, apparently only by country
Main databases	- Parameterization of Production: Used US Data (US input-output transactions from the Bureau of Economic Analysis, US National Income and Production Accounts; prices from the output and employment data set constructed by the Office of Employment Projections at the Bureau of Labor Statistics (BLS), for regions other than the US used GTAP7 for share parameters - Trade shares: 2009 UN Standard Industry Trade Classification (SITC)

Wuppertal Institut, 2017, own compilation

G-cubed is a general equilibrium model with econometric elements. It aims to bring together econometric general equilibrium modelling with international trade theory and macroeconomics. Many of the model's parameters are estimated rather than calibrated. Yet, the model developers mainly used data from the US for the parameter calibration. The substitution possibility for each industry sector in the US is hence assumed to be the same across all considered countries, which is a shortcoming to the estimation of parameters (McKibbin & Wilcoxen 2013, p.1008).

Inter-temporal decision making by forward-looking and rule-of-thumb-driven agents, together with adjustment rigidities, enable G-cubed to simulate the transition between the short- and the long run (McKibbin & Wilcoxen 2013, p.996). G-cubed covers the domestic economy, international trade and the linked permit market.

Permit market

The model assumes a perfectly competitive market for emission permits with endogenous emission prices. It hence cannot be used to model liquidity in the permit market, since the perfect market assumption precludes any liquidity effects beyond perfect liquidity (Pezzey & Lambie 2001, p.42). Curiously, the model assumes that emission permits are owned by households, and that they hence count towards the household's wealth. Despite the detailed modelling of financial flows, the model only accounts for financial flows in the sectoral goods trade, not in the permit market (McKibbin & Wilcoxen 2013, p.1006). Hence, one cannot analyse expected net capital flows from the permit trade.

International trade

G-cubed models the world economy as autonomous regions, which are linked through bilateral trade flows under the Armington assumption. Unlike most trade models, G-cubed explicitly models financial flows and makes a distinction between free-floating financial capital, driven by decisions of forward-looking investors who make use of arbitrage opportunities, and immobile physical capital that cannot be removed from the region or sector, once it was invested (mostly FDIs). The model imposes inter-temporal budget constraints, which means that trade deficits need to be repaid by trade surpluses in the future. International trade flows are hence a result of inter-temporal optimisation, which is quite uncommon in CGE models (McKibbin & Wilcoxen 2013, p.996). The model is hence very useful when analysing the impacts of linking on international financial markets, which is, however, not the focal point of the present analysis.

Domestic economy

Production is represented in a CES-function. Firms try to maximise their profits via cost-minimising production and by choosing the level of investments that maximises the own stock market equity value. Firms' output by region by sector is, like GDP and investments, endogenously modelled (McKibbin & Wilcoxen 2013, p.996, 999).

The sectoral coverage is flexible. For energy-related issues, G-cube usually models 12 sectors: 5 energy, and 7 non-energy-sectors. The non-energy sectors include only three industry sectors (mining, durable goods and non-durable goods), which is not detailed enough for a meaningful analysis of the impact of linking on the ETS sectors' production, competitiveness etc. Further, aviation is not reported explicitly, but part of the transport sector aggregate (McKibbin & Wilcoxen 2013, p.998).

Regional coverage

G-cubed is a global model, which is important for a meaningful analysis of carbon leakage and competitiveness-effects, especially with regard to third countries. Yet, in detail, the regional coverage of G-cubed does not satisfy the needs for the present analysis. The EU-ETS-31 countries are spread over the "Western Europe" and the "Eastern Europe and former soviet union" aggregates, which, if added up, reach far beyond the EU-ETS-31. The only potential linking partner that is covered individually is China. The three other potential partners are together included in the "Rest of OECD" region.

5.9 IMACLIM-R

IMACLIM-R was not shortlisted.

Table 24: Summary IMACLIM-R

Model	IMpact Assessment of CLIMate policies – recursive dynamic (IMACLIM-R)
Author	Centre International de Recherche sur l'Environnement et le Développement (CIRED)
Type	Hybrid: General equilibrium with technology-explicit modules
Time horizon of the agents	Myopic or imperfect foresight, recusive dynamic
Time horizon of the model	2001-2050/2100, annual time steps,
Economic fields	Domestic economy, international trade
Sectors	12 sectors (of which 5 energy sectors, 2 industry, aviation, agriculture, no explicit forestry)
Regions	Global: 12 regions - USA - Canada - **Europe** (incl. Turkey) - OECD Pacific - Commonwealth of Independent States - China - India - Brazil

	- Middle East - Africa - Rest of Latin America (incl. Mexico) - Rest of Asia (incl. South Korea)
Emissions	CO2 from fossil fuel combustion, in 2010 there was ongoing work for other GHG from fossil fuel combustion, ongoing work for CO2 and other GHG from processes and LULUC (completed?)
Main databases	- Population growth: UN World Population Prospects, medium scenario, United Nations, 2005 or 2007 - Calibration: GTAP6 database which details the world economy in 87 regions and 57 sectors for the year 2001 - Energy data: IEA Energy balances 2001 - Transport: Passenger mobility in passenger-km from Schafer and Victor 2007 - Coal and gas extraction costs: from POLES

Wuppertal Institut, 2017, own compilation

IMACLIM-R is a recursive dynamic ("-R", another version is IMACLIM-S, which is static) hybrid model, which combines a macroeconomic general equilibrium architecture with technology-specific bottom-up sectoral modules. It hence can be classified as a hybrid model that simulates the economy by annual top-down static equilibria, which are dynamically linked via the bottom-up modules that provide information on the evolution of the technological parameters between the yearly equilibria (Waisman et al. 2010, p.4). Due to this structure, parameters, although being in principle calibrated, change over time depending on the investment and production decisions in-between two periods. This is an interesting feature of the model.

IMACLIM-R models all CO2 emissions from fossil-fuel combustion. Emissions from land use and land use change can be included by the land-use nexus.

The model is solved until 2100 with one-year time steps. Hence, short- and long-run effects of linking can be both estimated. In contrast to most CGE models, IMACLIM-R provides a rather realistic model setup with imperfect markets, limited foresight, disequilibrium mechanisms, path-dependencies of technical change (putty-clay assumption in technology investments) and routine behaviour (expectations based on past trends) (Sassi et al. 2010). These second-best world options would have been especially useful to analyse the effects of linking on carbon leakage and competitiveness, if bilateral trade flows were included (Waisman et al. 2010, p.4). The imperfections would as well have been an interesting option to analyse liquidity in the permit market, if the permit market was included in the model.

Permit market

IMACLIM-R only covers the domestic economy and international trade, it does not explicitly simulate the permit market (although the effect of different permit allocation schemes on the economy can be studied).

International trade

Regions are linked by trade in goods, services and capital. Hence, each component of total demand is composed of domestic and imported goods. In the aggregated international market, the Armington assumption is employed for all non-energy goods (Waisman et al. 2010, p.5). Export prices for all goods consist of the producer price, export taxes, transportation costs, and a mark-up for oil products (Sassi et al. 2010). This allows to capture the effect of rising energy prices on transportation costs, which might have an impact on international trade flows and is hence important for the analysis of carbon leakage and competitiveness-effects of linking ETS. However, a major shortcoming of the model is that it does not report bilateral trade flows (Sassi et al. 2010). This is as well the reason why the linked permit market cannot be simulated. Therefore, one cannot use the model for the analysis of the permit market or carbon leakage- and competitiveness effects of linking with regard to the linking partner or selected third countries, only with regard to the entire rest of the world. For the latter, the model gives the market share of exports for a specific region in the international market as output (Waisman et al. 2010, p.3). The model apparently explicitly models competitiveness; however a detailed description is not given.

Domestic economy

With regard to the domestic economy, the IMACLIM-R model differs substantially from standard CGE models in terms of the production function: It does not employ a CES production function with full input utilisation. Instead, substitution between input factors in production occurs between two equilibria in the sector-specific dynamic modules, where investment choices, technological progress and the evolution of preferences are represented. Changes in these modules give the updated parameters for the next equilibrium in t+1 like installed production capacity etc. The model is recursive in the sense that equilibrium values from previous equilibria serve as signals for the agents' decisions in the dynamic modules. This means as well that agents operate under imperfect foresight, which is optimal for the needs of the present analysis (Waisman et al. 2010, p.4).

Producers are assumed to operate under short-run constraints of fixed maximal production capacity, depending on the equipment installed, and fixed input-output coefficients. Production is determined by adjusting the utilisation rate, given input and output market prices and taking into account decreasing returns when capacity utilisation approaches saturation. Given this, input factors are not necessarily completely employed at each point in time. Further, to capture imperfect competition, consumers set the prices with a mark-up above production costs. Investments are endogenous (Waisman et al. 2010, p.3; Sassi et al. 2010, p.6, 10)

A specific feature of the model is the dual representation of economic flows in monetary and physical units. This allows for a detailed representation of the sectoral characteristics. However, the sectoral aggregation of IMACLIM-R with 12 sectors in total (of which 5 energy sectors) is quite high; as such, it differentiates only between 2 industry sectors. Hence, although aviation in contrast is reported explicitly, the model is not very useful to analyse carbon leakage and competitiveness-effects of linking ETS.

Regional coverage

Having a global model is a requirement for the analysis of carbon leakage and competitiveness-effects for linked ETS sectors with regard to third countries or the rest of the world. However, the regional coverage of IMACLIM-R does not fulfil the needs of the present analysis. Amongst the 12 regions, there is one aggregated "Europe" region that goes far beyond the EU-ETS-31 and includes the potential linking partner Turkey. China is included individually, but the other potential linking partners, South Korea and Mexico, are part of the "Rest of Asia" and respectively the "Rest of Latin America" aggregates.

5.10 PRIMES

PRIMES was not shortlisted.

Table 25: Summary PRIMES

Model	Price-Induced Market Equilibrium System (PRIMES)
Author	National Technical University of Athens
Type	Partial equilibrium (Energy markets), dynamic equilibrium
Time horizon of the agents	Limited foresight (perfect foresight in the short-term) for energy demand sectors, perfect foresight (in the long-run) for energy supply sectors
Time horizon of the model	1990-2010, 2020, 2030, 2050 (1990-2005: model calibration), 5-year time steps,
Economic Fields	(Domestic economy), linked permit market
Sectors	25 sectors of which 6 energy sectors with very detailed different technologies, 18 industry sectors (with energy demand details in sub-model), 1 agricultural, no explicit forestry, aviation; 45 energy commodities
Regions	Only Europe: - **EU28 Member States** - Switzerland - Norway - Turkey - Albania - Bosnia-Herzegovina - Macedonia - Montenegro - Serbia (Global (permit) market simulation: need combine PRIMES with for example Prometheus or GEM-E3, POLES)
Emissions	CO2 (from fossil fuel combustion and processes), SO2, NOx, PM, VOC, no N20 and PFC; reporting ETS and non-ETS split
Main databases	- Energy consumption by sector and fuel: Eurostat - Other: MURE, IKARUS, ODYSSE, UNFCC databases and national sources - Macroeconomic exogenous figures: might use GEM-E3 model output - Technologies: VGB, SAPIENTIA, TECHPOL, NEMS, US DoE, IPCC BAT Technologies IPTS - World fossil fuel prices: Can use utput from PROMETHEUS or POLES

Wuppertal Institut, 2017, own compilation

PRIMES is a partial equilibrium model for the European energy market. It provides detailed projections of energy demand, energy supply, energy prices, investments in the energy system, GHG emissions, energy technology penetration, prices and costs by sector, country and for the whole European energy system. Since it uses 5-year time steps until 2030, it does neither really provide annual short-run effects and fluctuations of linked ETS systems, nor does it report the long-term trends until 2050 or, better, 2100. Yet, with data available, analyses longer than until 2035 should be possible.

The model parameters are calibrated. There are some important non-linear functions in the model, like for energy demand, discrete technology choice, efficiency improvements or infrastructure (NTUA, E3M-Lab/ICSS 2014, p.8). Like in most partial equilibrium models, energy and emission demand and supply are balanced through endogenously determined prices, which yield a dynamic multi-market equilibrium (NTUA, E3M-Lab/ICSS 2014, p.2).

Since PRIMES is a partial equilibrium model, it does not simulate the entire domestic economy. Further, international trade in goods and services is neither included. Yet, linked permit markets are covered. The model reports endogenous GHG emissions from processes and fossil fuel combustion per sector and sub-sector by region, differentiating between ETS and non-ETS sectors (NTUA, E3M-Lab/ICSS 2014, p.19, 149, 185f.).

Permit market

ETSs (i.e. the EU-ETS) are explicitly simulated at a high level of detail (NTUA, E3M-Lab/ICSS 2014, p.18, 148). There simulated allocation methods are grandfathering, auctioning; and different regulations by sector are possible. The permit price is either the carbon value or an explicit payment. For the latter, the model derives the permit price by aid of the Hotelling rule, which is a iterative and time-consuming process (NTUA, E3M-Lab/ICSS 2014, p.146-148). MACC can be derived by using model results for abatement costs over a variety of abatement levels (NTUA, E3M-Lab/ICSS 2014, p.146).

The model can handle price floors and price caps. PRIMES differentiates between ETS and non-ETS sectors, and emission constraints can be defined EU-wide or by region or by sector, separately for ETS and non-ETS sectors (NTUA, E3M-Lab/ICSS 2014, p.16, 146f.). When modelling permit trade, the influence foresight and risk-related behaviour is considered (NTUA, E3M-Lab/ICSS 2014, p.16). Banking is allowed but limited, borrowing is not allowed in the model (NTUA, E3M-Lab/ICSS 2014, p.147). For a global permit market simulation, PRIMES can be combined with Prometheus, GEM-E3 or POLES.

Domestic economy

Within its partial equilibrium framework, PRIMES covers 25 different sectors, of which 6 energy supply sectors with very detailed different technologies and 45 energy commodities; aviation and 18 industry sectors with energy demand details in a sub-model. This level of sectoral disaggregation of the ETS-sectors is quite useful for the analysis of carbon leakage and competitiveness effects.

Investments are endogenous in the model; yet, as it is common to partial equilibrium models, sectoral and overall economic activity (GDP) are an exogenous input (NTUA, E3M-Lab/ICSS 2014, p.2). This limits the validity of competitiveness and carbon leakage analyses significantly. An option to obtain macroeconomic data would be to link PRIMES to GEM-E3 (NTUA, E3M-Lab/ICSS 2014, p.15; Hedenus et al. 2012, p.28). Further, the model provides endogenous estimates of unit costs per sector and regional overall energy system costs (NTUA, E3M-Lab/ICSS 2014, p.20, 185), which could be used to analyse competitiveness-effects.

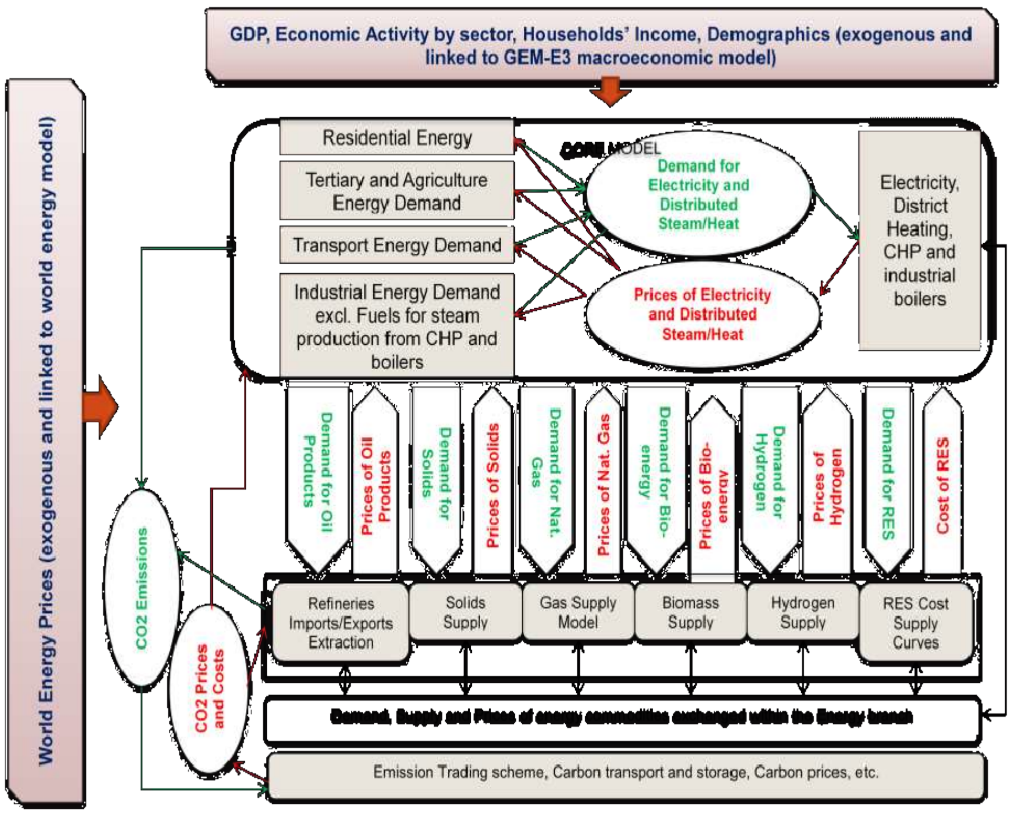
The model combines microeconomic modelling of individual behaviour with engineering aspects, by adding technological constraints to the agents' decision problem. A representative agent maximises benefits from energy demand and non-energy inputs, subject to various constraints, which includes as well technological feasibility. Firms aim to meet demand whilst maximising their profits or minimising their costs, subject to capacities, fuel availability, infrastructure, the environment etc. A variety of around 250 efficiency and energy saving options can be modelled. Substitution activities are possible between processes, energy forms, technologies and energy savings (NTUA, E3M-Lab/ICSS 2014, p.3f.+7; Vabitsch 2006, p.69).

Decisions are influenced by perceived costs and uncertainty. Hence, depending on investments and technological development, constraints change over time. Further, depending on policy measures, uncertainty and perceived costs can be altered (NTUA, E3M-Lab/ICSS 2014, p.3f.+7).

PRIMES provides several options regarding future anticipation in agents' decision-making. Usually, it assumes limited foresight for the demand sector (called perfect foresight in the short run in the model description) and perfect foresight for the supply sector (in the long run). This differentiation seems to be meaningful and likely provides rather realistic results when analysing the effects of linking ETS. Since demand and supply models are simultaneously solved over the entire time horizon, the market equilibrium is dynamic (NTUA, E3M-Lab/ICSS 2014, p.4).

PRIMES allows for different competition regimes in the energy market. Usually, the energy supplier is characterised as a price-maker with exogenous mark-ups. Self-supply of energy or production by-products (e.g. blast furnace gas) is also possible, especially in the industry sector (NTUA, E3M-Lab/ICSS 2014, p.4).

Figure 25: PRIMES model structure

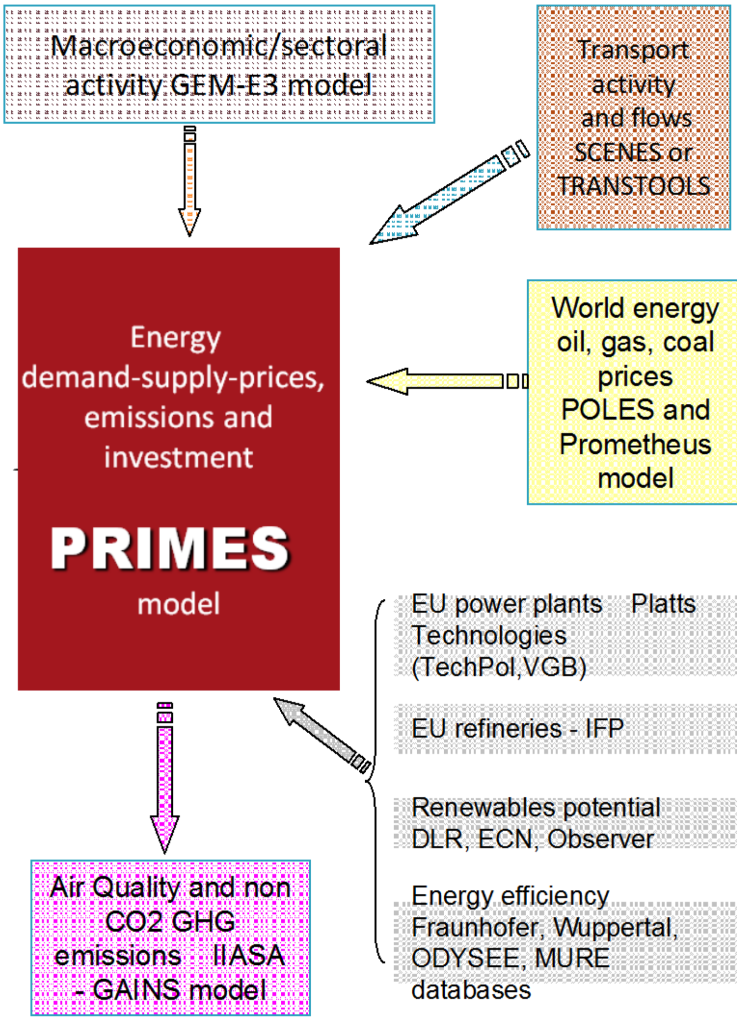


Source: NTUA, E3M-Lab/ICSS 2014, p.15

Regional coverage

PRIMES is a European and not a global model. This means that the EU-ETS-31 group can easily be established, and a (hypothetical) link e.g. with Turkey could be analysed. However, any further global links cannot be simulated with PRIMES. Apart from the fact that the model does not cover international markets of goods and services in detail, the regional coverage also limits the ability of PRIMES to analyse carbon leakage and competitiveness-effects of linking with regard to countries outside Europe or the entire rest of the world.

Figure 26: PRIMES links with other models



Source: NTUA & E3M-Lab/ICSS 2014, p.25

5.11 REMIND-R

Remind-R was not shortlisted.

Table 26: Summary REMIND-R

Model	Regional Model of Investments and Development - Recursive form (REMIND-R)
Author	Potsdam Institute for Climate Impact Research (PIK)
Type	Hybrid: Economic growth with detailed energy system model and simple climate model
Time horizon of the agents	Perfect foresight optimisation (Ramsey-type inter-temporal welfare maximisation)
Time horizon of the model	2005-2150, flexible time steps but the default is 5-year time steps until 2050 and 10-year time steps until 2100 (run until 2150 to avoid end effects distortions), inter-temporal optimisation
Economic fields	(Domestic economy), linked permit market
Sectors	>50 energy technologies; 1 aggregate sector in macro-economic part
Regions	Global: 11 regions - Sub-Saharan Africa - China - **European Union (EU-27)** - Japan - India - Latin America (incl. Mexico) - Middle East, North Africa, and Central Asia - Other Asian countries (mainly South-East Asia, incl. South Korea) - Russia - Rest of the World (Australia, Canada, New Zealand, Norway, South Africa, incl. Turkey) - USA
Emissions	CO2, CH4, N2O, F-gases, Montreal gases, CO, NOx, VOC, SO2, BC, OC, nitrate, mineral dust; from fossil fuel combustion by source (only for CO2 + no process-related GHG), PFC exogenous, N2O only LULUC
Main databases	- Energy taxes and subsidies data: Historical data IEA subsidies database and International Energy Database, Enerdata - Population growth: Shared Socio-economic Pathway (SSP) scenarios (SSP2data); IIASA - GDP growth: Shared Socio-economic Pathway (SSP) scenarios (SSP2data); OECD - Policy-independent production function efficiencies parameters for different fuels: For 2005, the parameters calibrated based on IEA energy balance

Wuppertal Institut, 2017, own compilation

REMIND-R is the recursive version of REMIND (Regional Model of Investments and Development) (Luderer et al. 2013, p.1). It is hybrid in nature and combines a one-sector macroeconomic model with a detailed energy system model and a simple climate model. The more than 50 energy technologies in the bottom-up energy system module require a substantive set of parameters, which are determined by the modellers (Luderer et al. 2013, p.13).

The time horizon goes from 2005 to 2100 with flexible time steps, but the default is 5-year time steps until 2050 and 10-year time steps until 2100. When switching to 1-year-time-steps for the short run analysis, the model allows for the analysis of short- and long-term effects of linking ETS.

The solution driving principle is perfect foresight, hence an inter-temporally optimal solution with full where-flexibility (permit and goods trade), when-flexibility (inter-temporal optimisation) and what-flexibility (choice of most efficient energy technology, given the imposed constraints) will be simulated (Luderer et al. 2013, p.1+20). This does not correspond to the model requirements, since the decentralised decisions by agents with only limited foresight likely yield different results than the inter-temporally optimal solution.

REMIND-R does not simulate the domestic economy and international trade in a way that is very helpful for the present needs. Further, it only calculates GHG emissions from energy generation, no process-related emissions from other production (Bauer et al. 2011, p.29).

Permit market

International permit trade is covered, but since there is no bilateral trade (regional trade is modelled via a common pool), this does not enable the analysis of a link between two specific countries. Further, there seems to be no possibility to distinguish between ETS and non-ETS sectors, since an economy-wide emission cap needs to be defined. Hence, the resulting permit price should be different from a permit price where only parts of the economy are covered by an ETS. The same holds for the MACC (Bauer et al. 2011, p.12, 40). REMIND-R allows for implicit borrowing and lending; but the global system sums up to 0 at each point in time (Luderer et al. 2013, p.7). The model reports emission permit im- and exports, which allows to calculate the expected net capital flows between countries (Bauer et al. 2011, p.31).

International trade

Trade occurs only in the final composite macroeconomic good and the energy carriers. Further, all traded goods are Heckscher-Ohlin substitutes, which might lead to unrealistically strong specialisation patterns. Hence, REMIND-R is not suited for a meaningful analysis of sectoral competitiveness and carbon leakage effects.

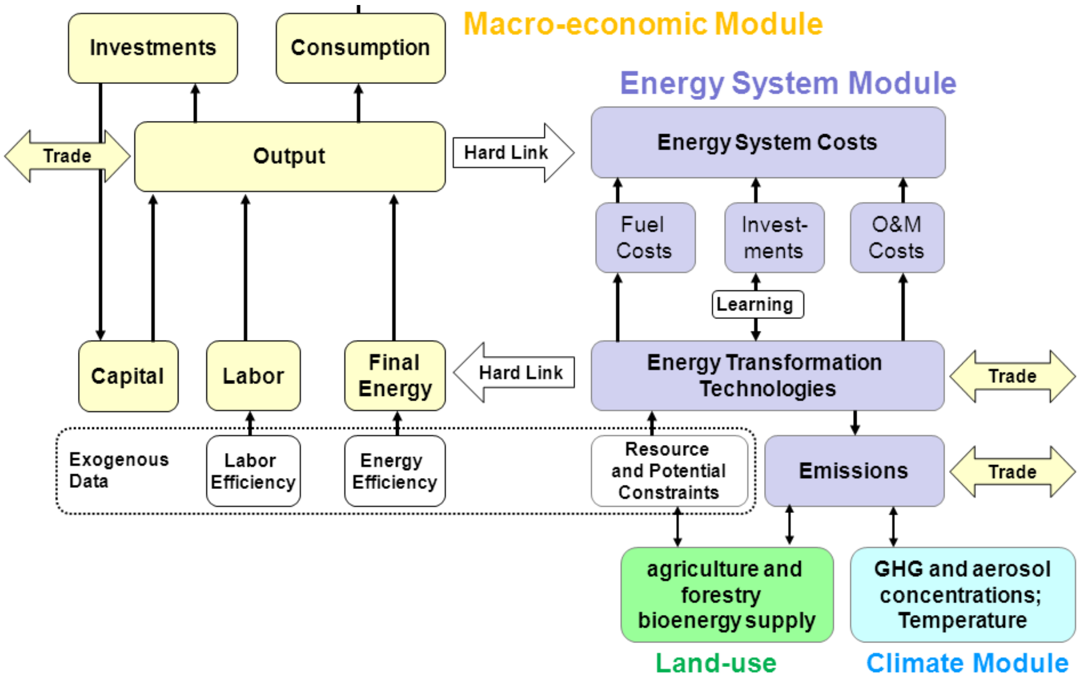
Domestic economy

In terms of domestic economy and sectoral coverage, the macro-economic core of REMIND consists of one single macro-economic sector, which means that GDP is endogenously calculated (Luderer et al. 2013, p.1). It is determined by a nested CES-production function with labour, capital and energy being the inputs at the upper level. Further, investments in the macroeconomic sector and the energy sector are endogenous (Luderer et al. 2013, p.6). Yet, further disaggregated sectoral economic activity is not simulated. This level of aggregation is not useful for the needs of the present analysis. It is by far too aggregated for any meaningful analysis of carbon leakage and competitiveness-effects of linking ETS, and does not distinguish between non-ETS and ETS sectors.

Regional coverage

REMIND-R is a global model, which is a prerequisite for the analysis of carbon leakage and competitiveness-effects, especially with regard to third countries. The model covers the EU-27 as one region, which can be used as a proxy for the EU-ETS-31 group. Yet, the only potential linking partner that is covered at the individual country-level is China. South Korea is included in the “Other Asia” group, Mexico in the “Latin America” aggregate and Turkey in the “Rest of the World”.

Figure27: REMIND model structure



Source: Luderer et al. 2013, p.2

Table 27: Overview over the fulfilment of criteria by model (models in alphabetical order)

Model	AIM-CGE	E3ME	EPPA	GEM-E3	G-cubed	IMA-CLIM	PACE	POLES	PRIMES	REMIND	TIMES
Type											
Time											
Econo-											
Sectors											
Regions											
Time			n.a.								
Emis-											

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