**Fachbereich Wirtschaftswissenschaft**

# Supply Chain Greenhouse Gas Management under Emission Trading

**Dissertation**

**zur Erlangung der Doktorwürde**

**durch den**

**Promotionsausschuss Dr. rer. pol.**

**der Universität Bremen**

**vorgelegt von**

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**Ort, Datum des Kolloquiums**

**Bremen, 06.12.2016**

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**Declaration**

I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. The work was made without unauthorized aid. No other than the specified sources and aids were used. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

**Date & Place**

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**Abstract**

To curb global warming man has to reduce greenhouse gas emissions (GHGs) created to the atmosphere by human activities, and it cannot neglect the efforts of corporate communities. Indeed, companies' direct emissions are dwarfed by supply chain GHGs from an industry sector. No matter to prepare for future environmental regulations or to improve competitive advantages, companies are realizing that they have to reduce and mitigate GHGs from the supply chain perspective. Emission trading (also called cap and trade) is one of market-based instruments to reduce GHGs released from industrial areas. The Paris agreement in 2015 has announced that emission trading plays an essential role in forming part of international climate action to achieve national emission reduction targets. Moreover, due to offering flexibility in choosing compliance levers to the targeted firms or industries emission trading is considered by forward-thinking communities as one effective measure to manage supply chain GHGs. With optimization models, literatures have quantified the impacts of emission trading on the supply chain performance by incorporating the emission cost. Their results show that emission trading is cost-effective to reduce supply chain GHGs. However, rare work addresses how emission trading could be employed in the context of supply chain and what problems would the implementation processes encounter from business and political perspectives.

To fill in this research gap, this paper presents one conceptual study as well as one case study. Firstly, it proposes the concept "supply chain emission trading" to describe the application of emission trading in the context of supply chain and provides three programs to realize the application: supply chain permit trading program, supply chain credit trading program, and supply chain offset trading program. Secondly, this paper conducts one case study so as to quantify and compare the cost-effectiveness of each program. At last, this paper discusses the challenges and opportunities related to implementing each program, and it demonstrates supply chain knowledge management concerning GHGs reduction under emission trading.

The results of this paper indicate that supply chain permit trading program is the most cost-effective one among the three to reduce the same amount of supply chain GHGs. Supply chain credit and offset programs are including additionally the cost of administration for emission reduction projects. All three programs allow the transfers of emission reduction units within the supply chain. Supply chain permit trading program emphasizes the supply chain collaboration in meeting the supply chain GHGs reduction target while the other two programs assign the focal company in the supply chain to be responsible for the supply chain GHGs. Implementing supply chain permit trading program is challenged by including the Scope 3 emissions of the focal company into emission trading scheme (ETS) and requires one cost/benefit allocation method among supply chain partners. The other two programs are comparatively easier to be implemented since they can directly employ the experiences of ETS and credit projects.

This paper is believed to be one leading edge in proposing one conceptual initiative connecting supply chain GHGs management to the emission trading policy, and in addressing supply chain GHGs management with emission trading from both quantitative and qualitative aspects. It provides insights for both business managers and policy-makers that are concerned with reducing supply chain GHGs.

**Key word:** Supply chain GHGs, emission trading scheme, supply chain emission trading, and knowledge management

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**List of Abbreviations**

| | |
|---|---|
| AAU | Assigned Allowance Unit |
| AU | Australian Unit |
| AVR | Accreditation & Verification Regulation |
| B2B | Business to Business |
| B2C | Business to Consumer |
| CCA | California Carbon Allowance |
| CCER | Chinese Certified Emission Reduction |
| CCX | Chicago Climate Exchange |
| CDG | Consumer-packaged Goods |
| CDM | Clean Developed Mechanism |
| CDP | Carbon Disclosure Project |
| CEM | Continuous Emission Monitor |
| CER | Certified Emission Reduction |
| CITL | Community Independent Transaction Log |
| CLSC | Closed-loop Supply Chain |
| $CO_2$ | Carbon Dioxide |
| $CO_2e$ | Carbon Dioxide Equivalent |
| CoP | Conference of Parties |
| CR | Climate Registry |
| DC | Distribution Center |
| EC | European Commission |
| EEA-EFTA | European Economic Area – European Free Trade Association |
| EEP | Energy Efficiency Program |
| EEX | European Energy Exchange |
| EICC | Electronics Industry Citizenship Coalition |
| EIO | Environmental Input-Output |
| EMS | Environmental Management System |
| EPA | Environmental Protection Agency |
| ERU | Emission Reduction Unit |
| ETS | Emission Trading Scheme |
| EU | European Union |
| EUTL | EU Transaction Log |
| FV | Freight Village |
| GDP | Gross Domestic Product |
| GHGs | Greenhouse Gas Emissions |
| GRI | Global Reporting Initiative |
| GI | Green Investment |
| GSCM | Green Supply Chain Management |
| Gt $CO_{2e}$ | Giga ton $CO_2$e |
| ICAP | International Carbon Action Partnership |
| ICE | Intercontinental Exchange |
| IET | International Emission Trading |

| | |
|---|---|
| IETA | International Emissions Trading Association |
| IM | Information Management |
| INDCs | Intended Nationally Determined Contributions |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Organization for Standardization |
| IT | Information Technology |
| JI | Joint Implementation |
| KM | Knowledge Management |
| LCA | Life Cycle Analysis |
| LCV | Longer Combination Vehicle |
| LDRC | Local Development & Reform Commission |
| LSP | Logistics Service Provider |
| MAC | Marginal Abatement Cost |
| MILP | Mixed Integer-linear Programming |
| MIP | Mixed Integer Programming |
| MRR | Monitoring & Reporting Regulation |
| MRV | Monitor, report, and verification |
| Mt $CO_2e$ | Million metric ton $CO_2e$ |
| NAP | National Allocation Plan |
| NDRC | National Development & Reform Commission |
| NGO | Non-governmental Organization |
| NMM | New Market-based Mechanism |
| NZ | New Zealand |
| NZU | New Zealand Unit |
| OEM | Original Equipment Manufacturer |
| OTC | Over the Counter |
| RGGI | Regional Greenhouse Gas Initiative |
| SME | Small and Medium-sized Entrepreneur |
| $SO_2$ | Sulphur-Dioxide |
| SSCM | Sustainable Supply Chain Management |
| UK | United Kingdom |
| UNFCCC | United Nations Framework Convention |
| UPCM | Unified Project Crediting Mechanism |
| US | United States |
| USA | United States America |
| VER | Verified/Voluntary Emission Reduction |
| WBCSD | World Business Council on Sustainable Development |
| WBS | Work Breakdown Structure |
| WRI | World Resources Initiative |

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# 1. Introduction

## 1.1 Research motivation

According to the United Nations Intergovernmental Panel on Climate Change (IPCC), by 2005 the average world temperature was 0.76°C above the level in pre-industral times and is rising by almost 0.2°C every 10 years (IPCC, 2007). Scientific evidence suggests that an average temperature rise of more than 2°C above the pre-industrual level – equivalent to around 1.2°C above today' temperature – will greatly increase the risk of large-scale, irreversible changes in the global environment (IPCC, 2007). The vast majority of the world's leading climate experts attribute this warming to a build-up of Greenhaus Gase emissions (GHGs) emitted by human activities, in particular the burning of fossil fuels – coal, oil and gas – and the destruction of forests. The six types of GHGs are carbon dioxide ($CO_2$), methane, nitrous oxide, hydroflurocarbons, perfluorocarbons and sulphur hexafluoride. Emissions of the primary GHG $CO_2$ from fossil fuels are now over 50% higher than 1990 levels (the reference year for the Kyoto Protocol) and growing rapidly, particularly in the emerging economies of China and India (Peters, 2012). This paper works on the base of three main motivations, and the relations among them are depicted in Figure 1-1.

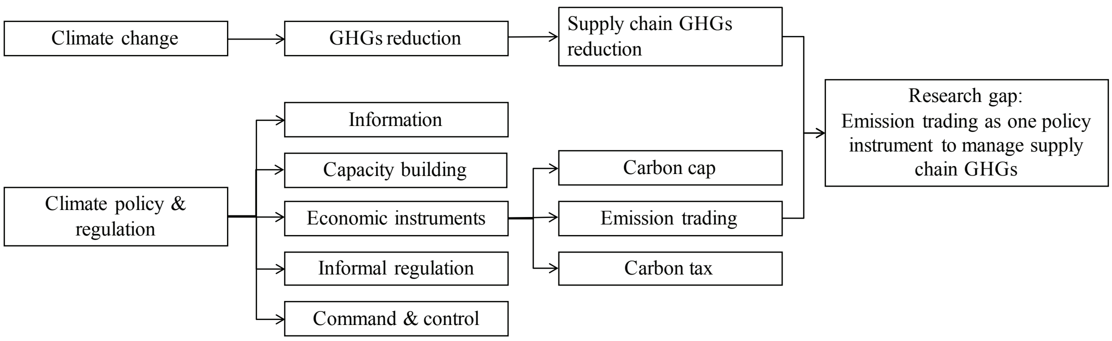


Figure 1-1 Research motivation of dissertation

1) Necessity to manage supply chain GHGs

To curb global warming, it cannot neglect the efforts from corporate communities. On one side, companies seeking to reduce their GHGs often find that their direct emissions are dwarfed by the emissions in their supply chains (Kingsbury et al., 2012). In fact, it is found that across all industries, companies' direct emissions average only 14% of their supply chain emissions prior to use and disposal; accounting for the emissions in use and disposal of goods would make that percentage even lower (Huang et al., 2009). The production and transportation of goods causes approximately 45% of those emissions, and the energy consumed when people use those goods accounts for much of the remainder; energy use in buildings alone accounts for approximately 25% (IPCC, 2007).

On the other side, experiences from leading companies that have started managing their supply chain GHGs tell that managing supply chain GHGs might surprisingly offer opportunities for risk mitigation, cost reduction, and competitive advantages (EPA, 2015). Anticipating a stringent carbon world, managing supply chain GHGs could reduce the risk of exposure to environmental regulations. It would not necessarily increase cost because by looking through the whole supply chain, it provides opportunities to identify the emission reduction hotpots and reach the low hanging fruits. In addition, as customers and stakeholders are increasingly demanding the transparency of product emissions and corporate emissions, companies might gain competitive advantages by providing the required information.

Thus, it is both necessary and significant to reduce GHGs from the supply chain perspective, through tremendous changes in the design and operation of supply chains, encompassing the multi-stage production, transportation, use, and eventual disposal of goods, and the energy generation and transmission that supports all of those activities. However, supply chain GHGs management practices are still in an infancy stage due to lack of proper policies and regulations on the supply chain GHGs. Government regulation and legislation are identified with the highest ranking among drivers for greening supply chain (Diabat & Govindan, 2011). Governments' control plays an indispensable role in encouraging firms to adopt sustainability actions across their supply chains (Gupta & Palsule-Desai, 2011; Tseng & Hung, 2014). With climate change estimated to decrease global economic output by 5-20%, the question is no longer whether or not to develop a corporate climate change policy, but what that policy should be and how it should be implemented (Kingsbury et al., 2012).

2) Emission trading

A range of policy responses is available to tackle climate mitigation objectives, including command and control, taxes, cap and trade, information-based instruments and voluntary approaches, etc. Among them, emission trading scheme (ETS), also called cap and trade, is becoming one of cost-effective instruments and gaining higher and higher concern from all over around the world to achieve the goals of environmental sustainability in a variety of fields. In the United States, the markets for Sulphur-Dioxide ($SO_2$) permit now account for more than USD 8 billion a year in trade (Talberg & Swoboda, 2013). In the European Union (EU), the ETS is the cornerstone of the Kyoto Protocol implementation and affects more than 12,000 producers in 30 countries (EC, 2016).

This market-based instrument works on two bases: "cap" and "permits trade". "Cap" gives a limit to the emissions amount of targeted participants, and "trade" allows firms to buy and sell permits in emissions markets according to their needs. It is cost-effective for firms with high marginal abatement costs to buy permits instead of reducing their emissions to reach their goals. Besides, it also motivates firms to adopt green investment measures by creating revenue from saving emissions.

The Paris agreement in 2015 highlights further the potential role of emission trading in mitigating GHGs towards a sustainable low carbon future. It encourages public and private entities in both parties and non-parties to make voluntary efforts in GHGs reduction and advocates the international transfer of mitigation units on the base of voluntary cooperation. This concept lays the foundation for applying emission trading to manage supply chain GHGs.

3) Research gap of managing supply chain GHGs with emission trading

It is increasingly being recognized that supply chain GHGs could be managed through goal-oriented and market-based mechanisms, like "cap and trade", that provide flexibility in choosing compliance levers to the targeted firms or industries (Gupta & Palsule-Desai, 2011). Greening supply chain will gain in richness and mind share if they leverage the opportunities offered by ETS for those companies pursuing a green strategy or having to regulate their GHGs (Lee K. H., 2011). With such intention in mind, researchers are interested in employing emission trading as one policy instrument in the context of supply chain to control supply chain GHGs (Abdallah et al., 2010; Bing et al., 2015; Chaabane et al., 2012). It is an innovative way in managing supply chains to realize the trade-off between economic and environmental impacts.

A price is given to each unit of GHGs and therefore the cost of emissions is internalized into the objective functions. GHGs in research are most often from raw material production, finished product manufacturing, warehousing, and distribution. Some studies also take the reverse logistics into account by incorporating the GHGs created from recycling center, combusting center, handling, sorting, and transportation. Mathematical models are constructed and solved to optimize the supply chain and provide companies the optimal decisions. Such quantitative analysis is able to evaluate the impacts of emission trading on supply chain performance, i.e., supply chain cost and GHGs. However, literature is limited in several aspects:

- Though the mathematical models are able to optimize the supply chain and provide decision-making for companies, they don't address how emission trading could be implemented in the context of supply chain considering different supply chain structures. For example, how should the responsibility of supply chain GHGs be assigned in the supply chain?
- Most of literature assumes that the supply chain is owned and operated by one big company and this company is able to make strategic decisions that influence the whole supply chain. Nevertheless, this is the rare case in practice where multiple companies compose supply chains. The application of emission trading in the context of supply chain needs to provide understanding for the normal supply chains.
- They didn't suggest any framework for supply chain GHGs management under ETS. The framework is necessary to provide companies with instructions and help them understand what options they have and how they should act.
- Rare literature analyzes the challenges and opportunities of implementing emission trading in the context of supply chain from the qualitative perspective.

## 1.2 Research questions

In order to fill in the research gap, this paper aims to answer three research questions:

1) What is the status quo about the topic?
- What is the state of art of supply chain GHGs management?
- What is the state of art of ETS construction around the world?
- What is the state of art of emission trading application in the context of supply chain?

2) How could emission trading be applied in the context of supply chain, from a theoretical point of view?
- What kind of programs/mechanisms could be designed and applied to different supply chain structures?
- How could the application of emission trading affect the supply chain performance?
- How differ between these programs in cost-effectiveness?

3) What are challenges and opportunities in implementing emission trading in the context of supply chain, from a practical point of view?
- How to assign the responsibility of supply chain GHGs among supply chain partners?
- How to make use of existing experiences of ETS?
- What are insights derived for business managers and policy-makers?

## 1.3 Research methodology

Main research methodologies involved in this paper include:

1) Literature review

One of the main methodologies adopted in this paper is literature review. It reviews literature in four topics: element design of ETS, impacts of ETS on business, supply chain GHGs management, and supply chain design under emission trading. Literature sources are mainly journal papers, official reports on websites, and business sustainability reports. The results of literature review are analyzed through summarization, categorization, or comparison.

2) Conceptual study

This paper applies the knowledge of emission trading in the context of supply chain as one innovative way to manage supply chain GHGs. Based on this background, it proposes one concept "supply chain emission trading" to describe the application of emission trading in the context of supply chain and suggests three programs to realize this concept from the theoretical perspective. It illustrates the working principle of each program, supposing different scenarios in each program, constructs mathematical models and frameworks to analyze the cost and benefit of each scenario, and discusses the pros and cons of them.

3) Case study

In addition, this paper conducts one case study to quantify the cost and benefit of each program. The case from HP is selected because HP aims to manage its supply chain GHGs which complies with the objective of this paper. The data about the supply chain GHGs reduction targets is collected from its annual sustainability report. The other part of data about GHGs reduction measures is collected from the 4flow company. 4flow company is the leading consultancy company in Germany and its main business is to optimize supply chain and logistics. It releases one report called "Costs and Benefits of Green Logistics" in its supply chain management study 2013. This report provides the data about cost and benefit of selected emission reduction measures. This paper makes use of the two parts of data in the case study. The specific data used in this paper doesn't affect the differences between the three programs, and therefore this paper provides meaningful and adaptable insights through comparing the results of each program.

4) Comparative analysis

In order to understand the state of art of ETS construction and operation around the world, besides one overview, this paper also selects two representatives: the EU ETS and China ETS pilots to conduct a detail analysis. It compares the two schemes in terms of the design elements of ETS, and provides suggestions for China national ETS construction through learning the experiences from the EU ETS and the China ETS pilots.

Besides, this paper compares different programs proposed under the concept "supply chain emission trading" from both quantitative and qualitative perspectives. In the conceptual study, the differences of the working principle are emphasized. In the case study, this paper also highlights the comparative analysis between the results of different programs and scenarios. Furthermore, these programs are also compared in terms of opportunities and challenges involved in the implementation processes.

## 1.4 Research structure

The dissertation is structured in 6 chapters, as shown in Figure 1-2.

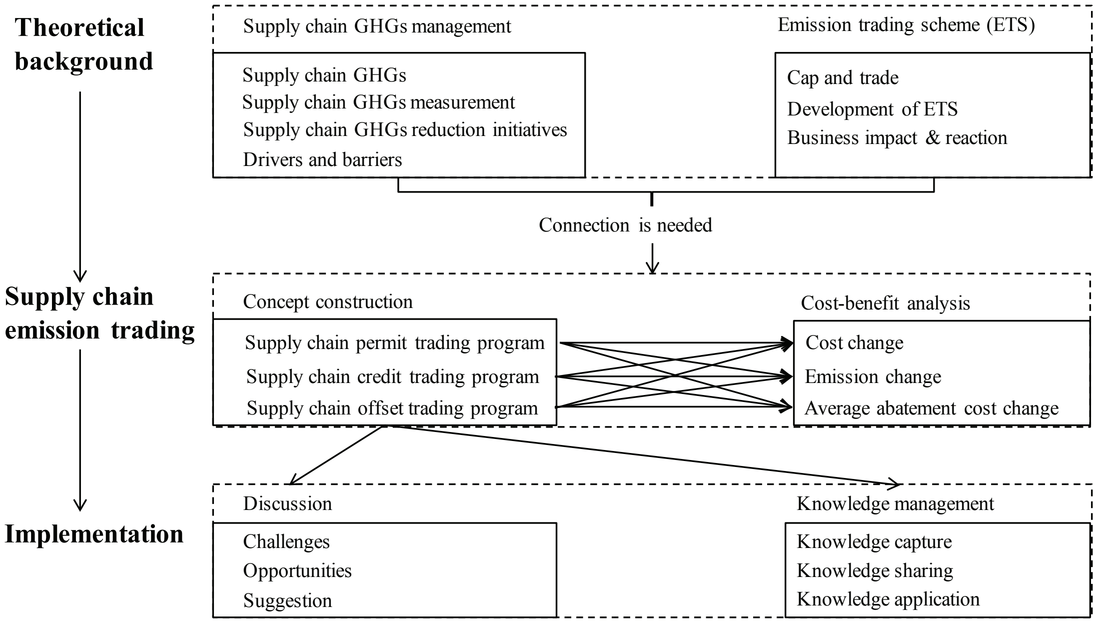


Figure 1-2 Research structure of dissertation

Chapter 1 introduces motivations behind this research topic and research questions. Chapter 2 describes the working principle and design elements of ETS and ETS development around the world with special focus on the experiences of establishing China ETS and the EU ETS. Chapter 3 presents the frameworks, drivers, practices, and barriers of supply chain GHGs management. Chapter 2 and 3 form the theoretical background of this paper and they are conducted through literature review and comparative analysis. Chapter 4 elaborates the application of emission trading in the context of supply chain through literature review, conceptual study, and case study. Chapter 5 discusses the challenges and opportunities involved in the implementation processes of supply chain emission trading programs, and supply chain knowledge management concerning GHGs reduction under emission trading is demonstrated as well.

## 1.5 Research significance

This work contributes in both theoretical and practical aspects:

Theoretically significant in:

- Providing a framework for supply chain GHGs management
- Proposing one concept 'supply chain emission trading' to describe the application of emission trading in the context of supply chain
- Presenting three mechanisms/programs for supply chain emission trading
- Providing frameworks for the cost-benefit analysis for each supply chain emission trading program

Practically significant in:

- Providing suggestion for constructing the China national ETS
- Enlightening supply chain companies that are concerned with managing supply chain GHGs by leveraging market-based instruments
- Providing insights for related policy-makers regarding to controlling GHGs from the supply chain perspective

# 2. Emission trading scheme

As one product of flexible mechanisms initiated to assist realizing the GHGs reduction targets of the Kyoto Protocol countries in 1997, emission trading is getting prosperous developed around the world in subnational, national, and regional levels. This market-based instrument gives a limit to the overall amount of GHGs from a defined scope and allows the exchange of emitting rights at a market-based price in this scope. It gives a GHGs reduction target, and then provides one marketing tool for countries and entities to realize the target. By giving a price to each unit of GHGs, emission trading put companies into the financial board and might affect the whole economy as a result. This chapter introduces the working principle of emission trading and its key design elements. In addition, it investigates how ETS is developed around the world, especially in the EU as one developed region and China as a developing country. At last, by reviewing literature this chapter also summarizes the impacts of emission trading on business.

## 2.1 Emission trading

### 2.1.1 Policy history

International climate policies started with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. This agreement marked the beginning of a long process of international policy development on climate change. UNFCCC was a broad plan for action, but it did not set clear targets and programs for the reduction of GHGs. It asserted that developed and developing countries have common but different responsibilities in reducing GHGs (UNFCCC, 1998). Since developed countries have created huge emissions to achieve their economy progresses in the last decade, developed countries should take a larger responsibility of GHGs reduction than developing countries.

In 1997, the Conference of Parties (CoP) agreed in the Kyoto Protocol that 38 developed countries (Annex I countries) committed themselves to respective targets and timetables for the reduction of GHGs (UNFCCC, 1998). At the same time, three flexible mechanisms were proposed for the first time to help countries reach their GHGs reduction targets. They are emission trading, Clean Developed Mechanism (CDM), and Joint Implementation (JI). While emission trading and JI are restricted to transactions between Annex I countries, CDM allows Annex I countries to invest into offset projects in developing countries (Grubb et al., 1999). In the following years, negotiations about the exact rule for implementing the Kyoto Protocol have gone through a turbulent process, which was mainly affected by the dispute between the United States (US) and the EU, seen in Tab 2-1.

Tab 2-1 Milestones of emission trading

| Year | Event |
|---|---|
| **1992** | Foundation of UNFCCC |
| **1992 & 1995** | EU carbon tax proposal |
| **1997** | Kyoto Protocol agreement on GHGs reduction targets, and initiation of 3 flexbile mechanisms |

| | |
|---|---|
| **2000** | Disagreement on the use of flexible mechanisms |
| **2001** | US rejection and alternative science-based climate plan |
| **2002** | EU ratification of Kyoto Protocol |
| **2003** | Private emission trading scheme – Chicago Climate Exchange (CCX) |
| **2005** | Kyoto Protocol in force, launch the EU ETS |
| **2011** | New market-based mechanism (NMM) |
| **2015** | Paris agreement, all nations submit Intended Nationally Determined Contributions (INDCs) and emission trading needs to be one part of future international climate framework. |

Source: adapted from Pinkse (2007)

At first, the US advocated emission trading as one flexible support for countries to realize their Kyoto targets on emission reduction. Tradable emission permits have been successfully used in the US since 1995 to tackle the problem of acid rain by reducing $SO_2$ and nitrous oxide emissions (Grubb et al., 1999). This positive experience generated the interest of the potential use of emissions trading to combat climate change. However, the EU initially opposed it, because emission trading was regarded to allow countries to avoid domestic action altogether. In fact, the EU, as a frontrunner on GHGs trading, proposed to implement a EU-wide carbon tax scheme in 1992 and 1995. However, they are rejected due to disagreement between member states (Christiansen & Wettestad, 2003).

Due to disagreement on the rules of implementing the Kyoto Protocol, the US declared its withdrawn from the Protocol in 2001 and launched one alternative 'science-based' climate plan in response to climate change as a softening stance (Blanchard & Perkaus, 2004). This program increased research expenditure for energy efficiency improvement and gave incentives for industry to adopt voluntary GHGs reduction targets. In addition, a private ETS called Chicago Climate Exchange (CCX) was opened in 2003, for which participants made a voluntary commitment to reduce GHGs.

In order to save the Protocol and move on without the US, the EU compromised on the unrestricted employment of the flexible mechanisms and limited use of forests and farmlands as carbon sinks. It adopted one proposal to start the EU ETS in 2005. After negotiation at the CoP in Marrakech in 2001, most parties, including the EU, Japan, Canada and Russia, ratified the Kyoto Protocol which came into force on 16 February 2005, but the US and Australia pulled out of the process.

After the initiation of the EU ETS, countries have built numerous ETS at either national, regional, subnational levels. More countries are preparing or considering implementing their domestic ETS. The ultimate situation is that there's a unified carbon market across all the economy and one single price for all participants (ICAP, 2016). For this aim, countries defined a new market-based mechanism (NMM) to connect all existing ETS at CoP 17 in Durban 2011 (Ecofys, 2013). NMM focuses on two simple functions: providing access to a central, harmonized transfer mechanism for Parties interested in linking their systems and enabling transfers of mitigation units produced by a new Unified Project Crediting Mechanism (UPCM) (UNFCCC, 2014).

In 2015, Parties to the UNFCCC reached a landmark agreement – the Paris agreement – at CoP 21 in Paris to prevent global surface temperatures from rising above 2 °C. The Paris Agreement builds upon the Convention and – for the first time – encourages all nations to submit Intended Nationally Determined Contributions (INDCs). Besides the Annex I countries living up to Kyoto Protocol targets, developing countries are also motivated to undertake ambitious efforts to combat climate change. The agreement also welcomes the voluntary efforts of all non-Party stakeholders to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other sub-national authorities (UNFCCC, 2015). At the end of 2015, 187 countries emitting 98.6% of global GHGs have submitted INDCs through the negotiation process for the Paris agreement (WRI, 2015), as shown in Figure 2-1.

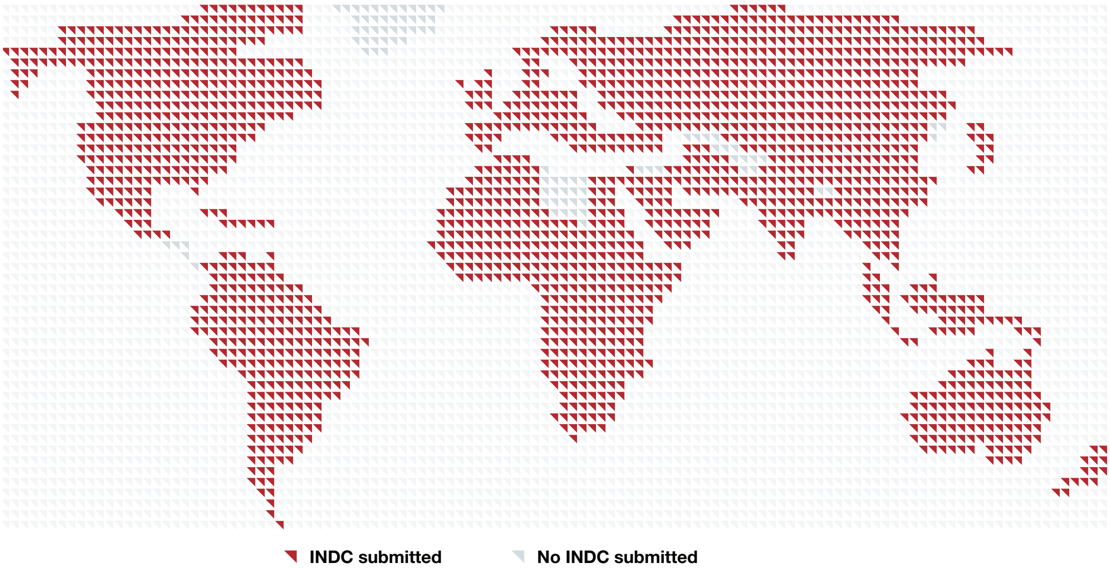


Figure 2-1 INDCs of the Paris agreement
Source: WRI (2015)

In addition, many countries at CoP 21 indicated that carbon markets would form part of their national climate policies. It is probable that emissions trading will continue to play a key role in helping Parties to reduce their GHGs. Meanwhile, the International Carbon Action Partnership (ICAP) and the International Emissions Trading Association (IETA) co-hosted a side event at the UNFCCC (CoP21) in Paris. It highlighted why "transfers" of emission reduction units and linkage of international climate policies need to be a part of our future international climate framework – one that effectively enables jurisdictions to achieve the greatest mitigation outcome at the lowest possible cost.

### 2.1.2 Working principle

Emission trading is a market-based instrument for climate change mitigation. It works on the principle of "cap and trade". In an ETS, a regulator defines an upper limit (cap) of GHGs that may be emitted in clearly defined sectors of an economy (scope and coverage). Emission permits or allowances are given out or sold (allocated) to the entities that are included in the ETS (ICAP, 2016). By the end of a defined time period, each covered entity must surrender a number of permits corresponding to their emissions during that period, or else they would be punished. Entities that emit less than its allocated permits may bank the spare permits to cover its future needs or sell them to other entities that are short of permits. Entities whose cumulative emissions exceed their allocated permits may buy permits from the carbon market in order to meet their excessive emission. The "trade" creates a market for carbon permits, helping liable entities innovate in order to meet, or come in under their allocated limit. The price of permits is theoretically decided by the demand and supply of permits in the market, but also subject to government regulation as well. Emission trading allows that GHGs are neutralized in the atmosphere and it acts as one important instrument for climate mitigation.
In a word, entities under ETS are allowed to exchange the carbon permits via carbon market with a certain carbon price as needed. Since the compliance cost usually is much higher than the carbon price,

emission trading offers one solution to meet cap before suffering heavy fines. Allowing entities to determine when and where to reduce emissions makes ETS a flexible and cost-efficient policy instrument.

Entities in different sectors and adopting different strategies have different marginal abatement costs (MACs), seen in Figure 2-2 , for example, polluter $A$ with a MAC curve $A$, and polluter $B$ with a relatively steeper MAC curve $B$.

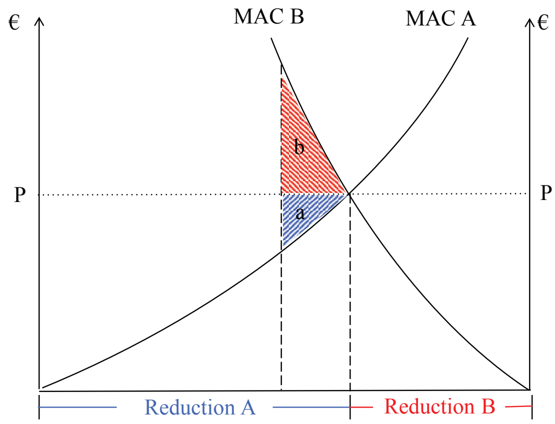


Figure 2-2 Efficiency enhancing effect of emission trading
Source: Brunner et al. (2009)

For polluter $A$, it will reduce emissions more than required (marked as the left dot line) in order to sell the extra permits to the carbon market for an earning. For polluter $B$, it would like to reduce less than required amount of emissions and chooses to buy permits for the rest quota. The emissions reduction amount moves to the right dot line until the MACs of two converge at price $P$. The efficiency gain of polluter $A$ is illustrated by area $a$ which comprises the benefit from increasing emission abatement and selling freed up permits to polluter $B$. The efficiency gain of polluter $B$ is illustrated by area $b$ which represents the amount of saved abatement cost net of the money paid to polluter $A$.

Emission trading offers an alternative for entities to meet their emission reduction targets besides internal emission abatement measures. Entities that are cost-effective to realize abatement measures would be carbon permits' sellers while the others would be buyers. Herewith, a carbon industry rises cause carbon trading is giving entities the economic incentives that they could earn by investing into cost-effective emissions reduction projects.

### 2.1.3 Fundamental element

To construct an ETS, there're several fundamental elements to be designed. Each regulator of ETS has to explore specific rules for the implementation according to emission reduction targets, national situations, economic features, development strategies, and so on. The elements are categorized into four groups in below.

1) Cap & coverage

The cap is the sum of permits that is available for a given compliance period for covered entities. The price of permits is affected by the cap since cap defines the total supply of permits in the carbon market. To set the cap, it is essential to take into account emission reduction targets and feasible emission abatement measures. In addition, the cap could be adjusted through two flexible options from periodic and geographical aspect. Allowing banking and borrowing gives entities opportunities to store and use the future permits budget. Allowing importing offsets and credits generated from emissions abatement projects outside the boarder of entities would increase the value of cap. For example, the International Emission Trading (IET) generated under the Kyoto Protocol allows ETS-jurisdictions to use credits (to various extents) from JI and CDM. Credits under JI are called Emission Reduction Units (ERU) and credits under CDM are called Certified Emission Reduction (CER). Other ETS systems have developed their own offset options focusing on domestic mitigation. Allowing the import of offsets will lower compliance costs if the marginal costs of creating credits are lower than the permit price in the cap-and-trade system. However, importing international credits would decrease emission abatement measures taken place in domestic area, and the use of credits should therefore be limited to a certain extent from both quantitative and qualitative aspect.

The coverage means the scope of ETS in terms of emission sources and GHG types. Emissions sources subject to ETS are called points of obligation which are responsible for surrendering permits at the end of a compliance period. According to the position of point of obligation in the respective supply chain, they could be classified into up- and downstream coverage. These two methods of coverage could be used separately or simultaneously. Upstream coverage applies to affecting small sources and finally increases the energy price for downstream users. Downstream coverage works on the large emitter like energy-heavy installations and plants. Combining them allows covering small emissions sources as well as large emitters.

Most ETS choose to initially include only the main GHG type – $CO_2$ in order to simplify the operation of ETS. Other GHG types are covered in later phases after the operation of ETS becomes mature and experienced.

Emission sources are usually covered at the sector level and it’s suggested to cover as broad as possible to equalize the marginal cost across the entire economy. Böhringer & Löschel (2005) find that the EU significant cost-savings would result from economy-wide coverage compared to exclusion of certain sectors. For instance, abatement measures in some sector such as transport and heating show great potential to realize substantial emission reductions even at negative economic cost (McKinsey, 2007). Hence, including such sectors into ETS would be profitable and effective. In addition, broad coverage may be supposed to widen the potential for carbon market liquidity and efficiency as well (Baron & Bygrave, 2002). More sources and sectors coming into ETS would reduce the impact of economic shock of any sector on the trading system as a whole, and also reduce the affects of large players on the overall price level.

However, including sectors which are not easy to be measured and managed (i.e., agriculture and forestry sectors) would be not efficient regarding to the transaction cost (Herold, 2008). Small sources under the minimum threshold should also be excluded in order to maximize the proportion of environmental effect to the transaction cost. Partially covering these sectors in the ETS might lead to intra-sectorial distortions, whereas allowing them to generate project-based credits can provide incentives for mitigation without generating distortions before they become eventually covered under the scheme (Garnaut, 2008).

2) Permit allocation

There’re two methods to allocate permits to covered liable entities: by free or by auction. Free allocation means entities can get permits for free while auction means entities have to buy permits. They two can be combined as well. In order to intensify the effects of cap and empower the carbon market, some schemes are integrating the mode of auction into permits’ allocation. Less than 100 per cent permits are free allocated to entities, and the rest permits under cap are released by auction, which increases the cost for entities to offset all of their emissions. Auctioning is one transparent allocation method and puts into practice the principle that the polluter should pay. Auctions are generally conducted either via static "blind" or "sealed bid" auctions, where all bidders bid once and pay the same price; or by dynamic "ascending clock" auctions where each bidder pays closer to what they are willing to pay as revealed through multiple rounds (ICAP, 2016). In addition, the mode auction has been adopted by most revised ETS as gradual substitution of free-allocation for the use of fiscal revenues from auctioning permits. The revenue from this new source amounts in total to € 3.6 billion for Member States of EU in 2013 (EC, 2016). Member States have used or planned to use € 3 billion from these revenues or the equivalent in financial value for climate and energy related purposes, primarily to support domestic investments in the low carbon economy (EC, 2016).

Free allocation includes grandfathering and benchmark. Grandfathering is one allocation method depending on the historical emissions of entities while benchmark depends on the standard performance. The benchmarks have been established on the basis of the principle of "one product = one benchmark" (EC, 2016). This means the benchmark methodology does not differentiate according to the technology or fuel used, or the size of an installation or its geographical location.

In the recent revision of the EU ETS, benchmarking is getting more votes than grandfathering. Under the mode of grandfathering, entities that emitted larger emissions than the reporting year would benefit from larger free allocation of carbon permits while entities adopt green measures in advance are put into the embarrassment with less free allocation. It runs counter to the principle of UNFCCC that green innovation and adoption should be encouraged to reduce the total emissions on the earth. Under this condition, benchmarking is proposed as one good solution for permits' allocation. For example, how much permits one entity can get from official for free depends on the average emissions of the best practices running in its sector. In this way, environmental attentions and efforts paid by the best practices in this sector are respected and take an important role to guide other entities going after.

3) Price of permits

The price of permit is influenced by broad economic, financial, and environmental issues, including (Talberg & Swoboda, 2013):

- industrial production,
- differentials in energy prices,
- increased deployment of renewables,
- permit stockpiling (affecting the quantity trading in the market),
- weather (affecting renewable output and demand for heating and cooling),
- and the supply of permits associated with target and alternative sources.

Due to the diversity of influence factors, it is difficult to give any individual reason to explain the change of price. The market price of permit can never be constant. It is fluctuating and varying from time to time. In order to limit the uncertainty brought by the price of permit on the economy growth, some scholars have investigated how quantity controls could be reconciled to improve the efficacy of price policies via the application of price bounds. The terms most concerned among them are price ceiling and price floor. Price ceiling, called also safety valve, defines a fixed price at which additional permits exceeding the cap can be acquired while price floor defines a minimum price for permit traded in the market (Pizer, 2002; Jacoby & Ellerman, 2004). Both of the two terms guarantee the economic certainty under the ETS through quantity control. Price ceiling combines the economic efficiency of carbon taxes in the form of a certain fixed price and provides the most certainty for carbon cost evaluation. Moreover, ETS participants are ensured under price ceiling to make investment into other emission abatement potentials. Price floor ensures that the price do not fall beyond a certain level and keeps the volatility of market characteristics as well by setting a baseline to the market price.

In fact, carbon market needs to be as dynamic as possible for the sake of market maximization. At the same time, it's imperative to keep the volatility of carbon market under control in order to limit its negative impacts on the whole economy to the least. Therefore, the carbon price in a certain market will not be too low or too high. On one hand, a too low carbon price would be resulted from an excessive permits' provision in the market. For example, too much permits are free allocated to entities and they sell the extra permits into the market in order to make an earning. Too much supply in the market brings cheap permits. Entities that are short of permits would in this situation prefer to buy permits from the market instead of investing into emissions abatement measures considering the emissions cost. It's also possible that entities buy large amount of permits in this stage and save them to offset the emissions in the next stages or resell them later to make earnings from the price differential. However, the permits traded in the market come from the excessive free allocation by official, which means the total emissions are not reduced at all. Hence if the emissions price drops to a low level, efforts to reduce emissions will also be reduced.

On the other hand, the much smaller supply of permits than demand derives a too high carbon price. Entities in this situation would decide to take emissions abatement measures that are more cost-effective than permits purchase. However, most of these measures will take effect in a long term like years, and in the first year entities still have to purchase permits at a high price. If the emissions cost occupies up a large proportion of the whole cost for an entity, it will prohibit the economic performance of the entity as well as the whole market competition it lies in.

From these two aspects, a joint regulation from both government control and market affection is essential to bring the superiority of ETS as one cost-effective emissions reduction instrument into full play. A proper carbon price would not only provide a degree of certainty and stability for investment in emissions reductions, but also boost the development of the emerging carbon market. And the world emissions could be really reduced in a practical and prosperous tempo.

4) MRV & enforcement

Credibility of emissions is the fundamental basis for an ETS. It is important that emissions are accurately and consistently monitored (M), reported to regulators (R), and verified (V). Common rules are necessary for ensuring the quality of the reported emissions and the credibility of the data.

Emissions can be measured by direct emissions monitoring and real time emissions are measured by a device (such as a Continuous Emissions Monitor or CEM System). Alternatively, emissions levels can be calculated using emission factors of fuels or of chemical processes (ICAP, 2016). In selecting a monitoring methodology, the improvements from greater accuracy shall be balanced against the additional costs. Monitoring and reporting of emissions shall aim for the highest achievable accuracy, unless this is technically not feasible or incurs unreasonable costs.

Emissions then need to be reported to the relevant authority on a regular basis. Accredited authorities, either government inspectors or third party experts, verify the system. Enforcement provisions help the system function by giving penalties to entities that are non-compliant. MRV together with enforcement provisions ensure that an ETS is trustworthy and effective.

## 2.2 Emission trading scheme

### 2.2.1 Overview of worldwide ETS

1) Mandatory market

The Kyoto Protocol forms the IET where ratified countries are able to trade emission permits between countries to reach their Kyoto binding targets. Countries are further allowed to construct domestic ETSs in the enterprise level to realize permits exchange between enterprises. Since the introduction of the first regional ETS for GHGs in the EU in 2005, many other ETS have emerged in North America, Asia and the Pacific region at the regional, national, and local levels (see Figure 2-3). Totally, there're 17 ETS in force, 12 jurisdictions are considering and 4 have put into schedule to implement their own domestic ETS. 2 out of 5 persons live in a jurisdiction either considering, scheduling, or operating a mandatory ETS (ICAP, 2016).

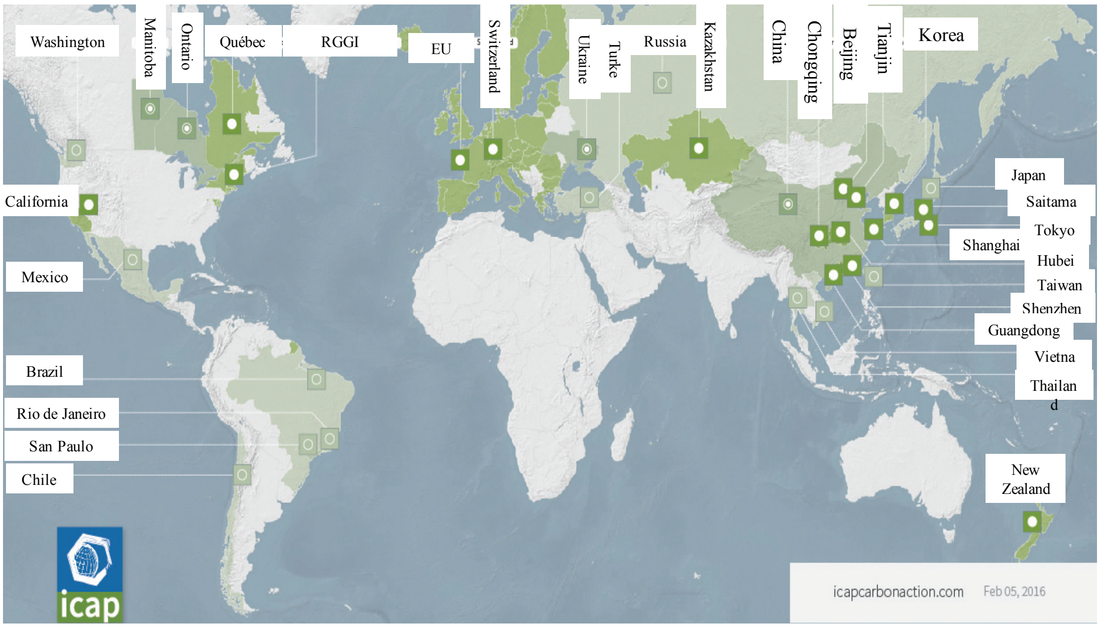


Figure 2-3 ETS map

Source: ICAP (2016)

Generally, ETSs around the world are either in the international level such as International Emission Trading (IET), in the regional level (i.e., the EU ETS, Regional Greenhouse Gas Initiative (RGGI)), in the national level (i.e., New Zealand (NZ) ETS, SWISS ETS), and in the city or provincial level such as China ETS pilots. Sovereign governments control the types of emission units that are acceptable within the ETS that they oversee. For example, the IET trades in terms of Assigned Amount Unit (AAU); the EU ETS trades primarily in European Union Allowance (EUA); the Australia ETS in Australian Unit (AU); the California cap and trade scheme in California Carbon Allowance (CCA); and the NZ scheme in New Zealand Unit (NZU).

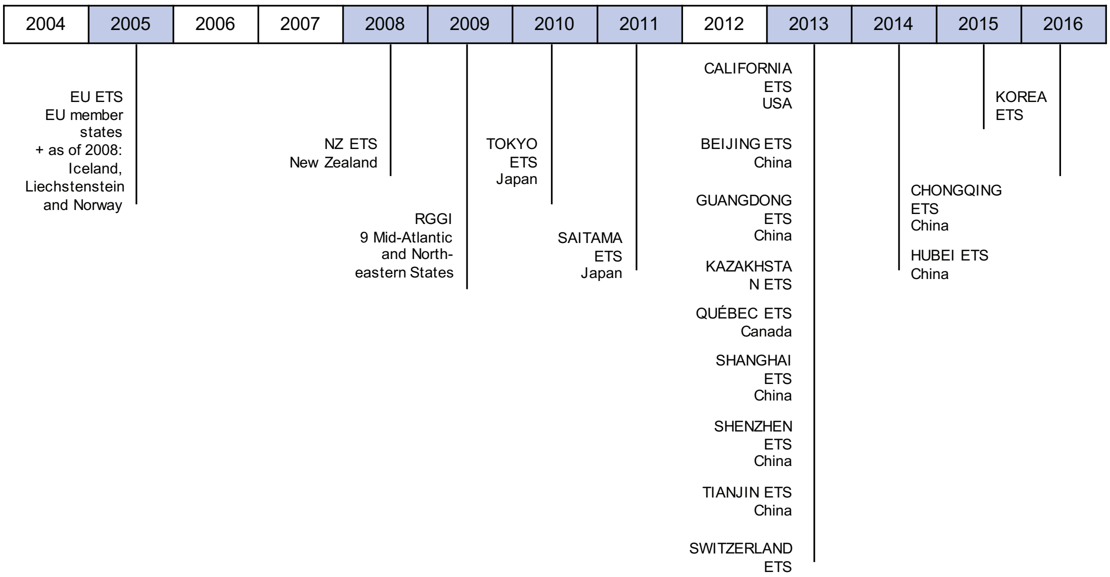


Figure 2-4 ETS in force and under implementation
Source: ICAP (2016)

Figure 2-4 shows current ETS in force and under implementation around the world. According to the emissions coverage, the EU ETS is so far the largest carbon market, followed by the aggregated China ETS pilots in terms of trading volume (ICAP, 2016).

2) Voluntary market

Most of existing ETSs are compulsive which means that the compliance of enterprises is binding to the legal system. Enterprises satisfying certain requirements are mandatory to join ETS. The voluntary carbon markets function outside of the compliance market and there are no established rules and regulations for the voluntary carbon market (CORE, 2016). They enable businesses, governments, Non-governmental organizations (NGOs), and individuals to offset their emissions by purchasing offsets in the voluntary market and the offsets are so-called VERs (Verified or Voluntary Emissions Reductions). In addition, credits created by CDM and JI projects can be used as well in the voluntary market (CORE, 2016). CDM projects generate credits so-called CER and JI projects create credits in the name of ERU.

In the voluntary market, demand is created by voluntary buyers (corporations, institutions and individuals) that might be anticipating mandatory controls, attempting to shape future trading systems, establishing baselines to gain credit for early action or hoping to gain competitive advantage through early trading experience (Kolk et al., 2006). Since these kinds of voluntary behaviors have not yet become mainstream, trading volumes in the voluntary market are much smaller compared to the compliance market. Due to the voluntary nature of the cap, usually the price of credits is also lower than CDM and other compliance market projects (CORE, 2016).

The market for carbon offsets is another form of voluntary carbon trading. A larger group of associate members have smaller direct emissions but commit to offsetting them. Several small firms and non-profits, such as Atmosfair in Germany and TerraPass in the US, purchase emission credits from a variety of sources, including official programs such as the CDM, voluntary initiatives such as CCX and other sources and sell offsets to consumers and firms who wish to reduce their carbon impact (Kolk et al., 2006).

In addition, voluntary markets can serve for micro projects currently not covered under compliance schemes and as testing field for experimentation and innovation of methodologies and technologies that will be later included in regulatory schemes (CORE, 2016).

3) International transferred mitigation

The Paris agreement opens a new era in international climate action by accelerating and intensifying the actions and investments needed for a sustainable low carbon future. It encourages public and private entities in both parties and non-parties to make voluntary efforts in GHGs reduction. It creates one mechanism, which allows international transfer of mitigation units on a base of voluntary cooperation.

Different ETS could be connected either directly or indirectly. When permits of one ETS are able to substitute the permits in another ETS, they are directly connected. When both ETS have access to the same kind of offsets or credits, they are indirectly connected. Linkage of ETS across borders provides the participating parties with a larger range of options to reduce their GHGs and thus offers efficiency gains. The full linkage among existing ETS creates a single carbon price in all participating systems and makes the cheapest mitigation options available to all participants in the linked system (ICAP, 2016). The Paris outcome thus provides new impetus for a dynamic global carbon market and the further proliferation of domestic carbon pricing systems post-2020 (UNFCCC, 2015).

### 2.2.2 The EU ETS

1) Overview

As one of the large polluters in the last decade EU takes actively part in emissions' reduction. The EU has set itself targets for reducing its GHGs progressively up to 2050 and is working successfully towards meeting them both under its own internal target in the Europe and under the Kyoto Protocol's commitment period, as shown in Tab 2-2.

Tab 2-2 The EU GHGs reduction targets

| Commitment | Target | Base year | Comments |
|---|---|---|---|
| **The Kyoto protocol 2008-2012** | 8%* | 1990 | *over-achieved |
| **The Kyoto protocol 2013-2020** | 13-18% | 1990 | |
| **The 2020 Strategy** | 20%<br>30%* | 1990 | *if other major emitting countries undertake their fair share of emissions reduction effort |
| **The 2030 Strategy** | 40% | 1990 | |
| **The 2050 Strategy** | 80-95%* | 1990 | *if other developed countries reduce their emissions by a similar degree |

Source: EC (2016)

The EU, opposing the use of emission trading to meet emissions reduction targets under the Kyoto protocol at the beginning, has constructed the first and still by far the largest multi-country, multi-sector system – the EU ETS. It accounts for about 45% of EU GHGs, 40% of EU $CO_2$, and covers all 28 EU member states, as well as other non-EU nations, Iceland, Liechtenstein and Norway, Croatia. Up to now, more than 11,000 facilities are covered by the EU ETS (EC, 2016).

With the introduction of the EU ETS, each national Kyoto target was split into a target for the ETS sectors (through the allocation of allowances linked to Kyoto units for the second trading period) and a target for emissions in the sectors not covered by the ETS. For the ETS part, cap was distributed to different sectors according to the national allocation plan (NAP) designed separately in each country.

For the non-ETS sectors, they are required to reduce emissions under an "effort sharing decision" policy through various measures. The EU ETS runs in phases (see Tab 2-3).

Tab 2-3 The EU ETS phases

| | Phase I | Phase II | Phase III |
|---|---|---|---|
| **Period** | 2005-2007 | 2008-2012 | 2013-2020 |
| **Cap setting** | Bottom up by NAP | NAP | EU-wide cap |
| **Registry** | National registry | National registry | The EU Transaction Log |
| **Participant country** | 25 EU States | 27 EU States | 28 EU States + Norway, Iceland, Liechtenstein |
| **Participant industry and threshold** | power stations and other combustion installations with >20MW thermal rated input (except hazardous or municipal waste installations), industry (various thresholds) including oil refineries, coke ovens, iron and steel plants and production of cement, glass, lime, bricks, ceramics, pulp, paper and board. | In addition to Phase one sectors, aviation was introduced in 2012 (>10,000 t CO2/year for commercial aviation; >1,000 t CO2/year for non -commercial aviation since 2013) | In addition to Phase two sectors, CCS installations, production of petrochemicals, ammonia, non-ferrous and ferrous metals, gypsum, aluminum, nitric, adipic and glyoxylic acid (various thresholds) were introduced |
| **Covered entities in number** | | | 12,000 installations |
| **GHG type** | $CO_2$ | $CO_2 + N_2O$ | $CO_2 + N_2O$ + PFCs |
| **Covered emissions in per cent of total EU emissions** | 40% | 40% | 43% |
| **Permits allocation** | 100% free: grandfather and benchmark | 90% free | Less than 50% free;<br>None for power plants;<br>Up to 80% of benchmark;<br>Free for heavy emitters;<br>Max. 10% auctioning |
| **Compliance cost (€/ton)** | 40 | 100 | 100 |
| **Banking** | No | Yes | Yes |
| **Borrowing** | No | No | No |
| **CERs restriction** | Limited | Limited | Limited |

Source: ICAP factsheet (2016)

2) Elementary design of the EU ETS in Phases

- Cap and coverage

In the fist and second phases, member states designed their own NPA and submit to the EC for the final approval (so-called bottom up). Member States decided the total amount of allowances allocating to each EU ETS installation on their territory (EC, 2016). Usually, the Commission asked for further amendments before the final approval in order to ensure that allocation allowances do not exceed projected emissions (EC, 2016). However, this decision process was time-consuming, too complex, and not transparent. In the third phase, a EU-wide cap is employed. It means "the EC gives an overall volume of GHG that can be emitted by the power plants, factories and other fixed installations covered by the EU ETS" (EC, 2016). This amount is limited by a cap on the number of emission allowances (so-called top down). Within this Europe-wide cap, companies receive or buy emission allowances as needed.

"The cap in 2013 for emissions from power stations and other fixed installations in the 28 EU Member States and the three EEA-EFTA states was set at 2,084,301,856 allowances" (ICAP, 2016). It decreases each year by 1.74% of the average annual volume of allowances in 2008-2012 during the third phase of the EU ETS (2013-2020)(EC, 2016). To achieve the target of a 40% reduction in EU GHGs below 1990 levels by 2030, the annual reduction in the cap will continue beyond 2020 and the reduction rate will need to be 2.2% per year from 2021, compared with 1.74% currently (EC, 2016). It means emissions from fixed installations need to be cut around 43% below 2005 levels by 2030 (EC, 2016).

Since January 2012, the aviation sector is mandatorily included into the EU ETS by targeting aircraft operators that depart from or arrive at the region of the EU. A separate cap at the EU level applies to the aviation sector (EC, 2016). The aviation sector gets also separate aviation allowances which are different from general allowances allocated to fixed installations. Airlines have access to both kind of allowances while the aviation allowances can not be used by fixed installations. In each year of the 2013-2020 trading period, the cap of aviation sector remains the same. "It has been provisionally set at 210,349,264 allowances per year, which is 5% below the average annual level of aviation emissions in the 2004-2006 base period" (ICAP, 2016).

The EU ETS implements mainly downstream coverage by including the energy-intensive emitters in the downstream of supply chains. Installations over the threshold of emissions are mandatory to join ET.

A limited amount of emission credits from the Kyoto Protocol's project mechanisms, CDM and JI mechanism is allowed (EC, 2016). In the second phase, businesses were allowed to buy CDM and JI credits from limited fields up to 1.4 billion tonnes of carbon dioxide equivalent ($CO_2$e) (EC, 2016).

- Permit allocation

The method of allowance allocation in the EU ETS is transferring progressively from free allocation to auctioning. In the first two phases, allowances were allocated almost for free. In 2013 over 40% of the allowances were auctioned (ICAP, 2016). Over the period 2013-2020 the proportion of auctioned allowances might take up 50%. Meanwhile, free allocation still applies to manufacturing industry until 2020 and probably beyond on the basis of ambitious benchmarks of GHGs performance. Airlines are expected to receive free allowances up to 85% of the total allowances (ICAP, 2016). Since power generators have shown their ability in passing the cost of allowances to customers in the first two trading periods, even when they get them for free, allowances are fully auctioned to them from the third trading phase (except that in the eight Member States which have joined the EU since 2004 (EC,

2016).
Member states receive auction allowances for the period 2013-2020 according to their share of verified emissions from EU ETS installations in 2005 or the average of 2005-2007 period, whichever is the highest (EC, 2016). They are requested to use at least 50% of auctioning revenues for climate and energy related purposes and report annually the quantity and use of the revenue under the Monitoring Mechanism Regulation (EC, 2016). Member States should implement certain articles of the Auctioning Regulation into their national laws so as to admit potential candidates to bid in the auctions (EC, 2016).
To advocate and develop the auction mechanism, the EC and member states consider a joint auction platform as one cost-efficient approach. There're at the moment two auction platforms in use: the European Energy Exchange (EEX) in Leipzig and the Intercontinental Exchange (ICE) Futures Europe in London. EEX is the common platform for most countries participating in the EU ETS while ICE acts only as the United Kingdom's platform. To ensure the transparency, openness, and harmonization of auction, it is governed under the EU ETS Auctioning Regulation including timing, administration and other aspects of auctioning (ICAP, 2016).

- Price of permit

The first phase of EU ETS was designed as a learning stage with only modest abatement aims. Too many allowances were allocated into the market and the allowance price was nearly zero as a result. In the second phase, emission reduction targets were designed more strictly based on the knowledge of verified emissions during phase one. However, due to the financial crisis that began in late 2008, a large and growing surplus of unused allowances (including the high imports of international credits) is resulted as production activities decreased. Allowance price fell again to the ground.
In the last two phases, government has not implemented any regulation on the price control. The price is totally decided by the market supply and demand. The EU ETS succeeds at realizing free trade across the EU, but it also builds up a surplus of emission allowances which are expected not to decline significantly during the third phase. This has led to lower carbon prices and thus a weaker incentive for companies to reduce emissions. "Such surplus could risk undermining the orderly functioning of the carbon market, and affect the ability of the ETS to meet more demanding emission reduction targets cost-effectively" (Talberg & Swoboda, 2013). Since the third phase the EC is employing short- and long-term measures to address the surplus from a level of around 2 billion allowances (EC, 2016).
As a short-term measure: "back-loading". The Commission implemented the 'back-loading' through an amendment to the EU ETS Auctioning Regulation, which entered into force on 27 February 2014 (EC, 2016). This 'back-loading' postpones the auctioning of 900 million allowances until 2019-2020 (EC, 2016). It does not reduce the overall number of allowances to be auctioned during phase 3, only the distribution of auctions over the period. "The impact assessment shows that "back-loading" can rebalance supply and demand in the short term and reduce price volatility without any significant impacts on competitiveness" (EC, 2016).
As another short-term measure: a faster reduction of the annual emissions cap. The Commission proposes in the revision for EU ETS phase 4 to reduce the overall number of allowances by 2.2% each year from 2021 onwards, compared to 1.74% currently (EC, 2016).
As a long-term measure: market stability reserve. With a market stability reserve, the current surplus of allowance can be addressed. By adjusting the supply of allowances to be auctioned, it improves the system's resilience to major shocks. The Market Stability Reserve shall be established in 2018 and the first operation shall start from 1 January 2019 with pre-defined rules (EC, 2016).

- MRV

Entities subject to the EU ETS have to register for accounts by the Union registry which is coordinated by the central administrator. In 2012, the EU ETS operations were centralized in a single Union registry operated by EC. The Union registry, ensuring the accurate accounting of all allowances issued, has replaced Member States' national registries. The single registry covers all 31 countries participating in the EU ETS (EC, 2016).

To manage all accounts, the Union registry uses one online platform – the EU Transaction Log (EUTL) as the successor of the Community Independent Transaction Log (CITL). It automatically checks, records, and authorizes all transactions that take place between accounts in the Union registry for each entity in each trading period. The information includes registration name, account type, total allowance allocation, total verified emissions, total allowance surrendered, and compliance code, and so on.

The compliance period of the EU ETS is one year, starting from May 1st, 2013 to April 30th, 2014 (EC, 2016). Entities are allocated with allowances at the beginning of this period, and their accurate emissions must be verified by an accredited verifier by 31 March of the following year (EC, 2016). They are required to surrender enough allowances one month later after the verification by 30 April of that year (EC, 2016).

For industrial installations and aircraft operators covered by the EU ETS, they have to make a delicate plan to monitor and report their emissions during the year. In order to ensure the quality of the annually reported emissions and the credibility of the data, the plan has to be composed in accordance with two Commission Regulations – the Monitoring and Reporting Regulation (MRR) and the Accreditation and Verification Regulation (AVR). The EC has published electronic templates for monitoring plans, annual emission reports, verification reports and improvement reports. A general template of the plan can promote administrative efficiency and support the mutual recognition as required by accredited verifiers.

The plan has to be approved by competent authorities designated by each Member State. Installation operators are allowed to improve and modify the plan when there're any issues around unreasonable cost and technical feasibility. Of course, competent authorities have to verify the modification.

The emissions of entities are verified by accredited verifiers designated by each Member State pursuant to the Article 18 of Directive 2003/87/EC (EC, 2016). There could be only one competent authority in each member state. The Member State needs to coordinate all of them when there's more than one authority.

### 2.2.3 China ETS

1) Overview

Being one of developing countries, China was exempted from the binding target of emissions reduction in the first Kyoto period (2008-2012). The Paris agreement at CoP 21 in 2015 encouraged all nations including China to submit INDCs. All members of international community are obliged to comply with the principle "common but differentiated responsibilities" in climate mitigation. In addition, the economy growth of China in the last decade depends mostly on the energy consumption, like coal, fuel and natural gas. As energy becomes short and is going to be used out in the future, China is getting more conscious about the problems surrounding energy security, energy efficiency and competitiveness. China has recognized the urgency to address climate change from a global level and the particular role it can play in it. For the long-term interests, addressing climate change is regarded as one of the important strategies of China's economic and social development.

As one of contributions to the international efforts addressing climate change, China commits in the

National Development and Reform Commission (NDRC) to lower $CO_2$ emissions per unit of Gross Domestic Product (GDP) by 40–45 per cent by 2020 compared to 2005 (NDRC, 2007). $CO_2$ emissions per unit of GDP had accumulatively dropped 28.56 per cent by 2013 from the levels of 2005, or a reduction of 2.5 billion tonnes of $CO_2$ emission (NDRC, 2007). However, China claimed in UNFCCC in 2014 that the peak of $CO_2$ will come around 2030.

Typically, cap and trade scheme was approved firstly by the NDRC of China in 2011 as one market instrument to approach its emissions reduction target. Supported by the 12th Five Year Plan (2011-2015) endorsed by the National People's Congress, a mandatory "cap and trade" emissions trading pilot scheme is adopted in seven provincial regions in 2013, including Beijing, Shanghai, Tianjin, Hubei, Chongqing, Guangdong, Shenzhen (see Figure 2-5).

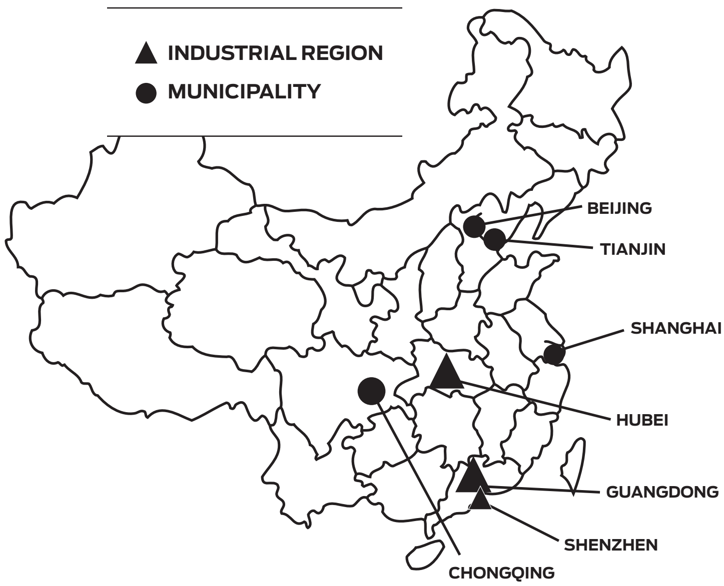


Figure 2-5 Map of China ETS pilots

Source: Han et al. (2012)

China is characteristic of its wide geographic distribution and complicated administrative regulation. These seven pilot cities are carefully selected to stand for the diverse situations of economic development and local feature. Shanghai and Guangdong are most developed cities in China while Hubei and Chongqing are relatively far behind. Together, they comprise about 25% of the country's annual GDP (Han et al., 2012). Beijing, Tianjin, Shanghai and Chongqing are four municipalities directly controlled under the central government while Hubei and Guangdong are two provinces with self-administration. Shenzhen is the capital city of Guangdong and it is subject to Guangdong's ETS as well as its own scheme. In addition, these seven pilots' locations spread geographically from north to south, from west to east. The seven pilots are constructed to learn experiences before establishing a national unified ETS during the 13th Five Year Plan (2016-2020) (see Figure 2-6).

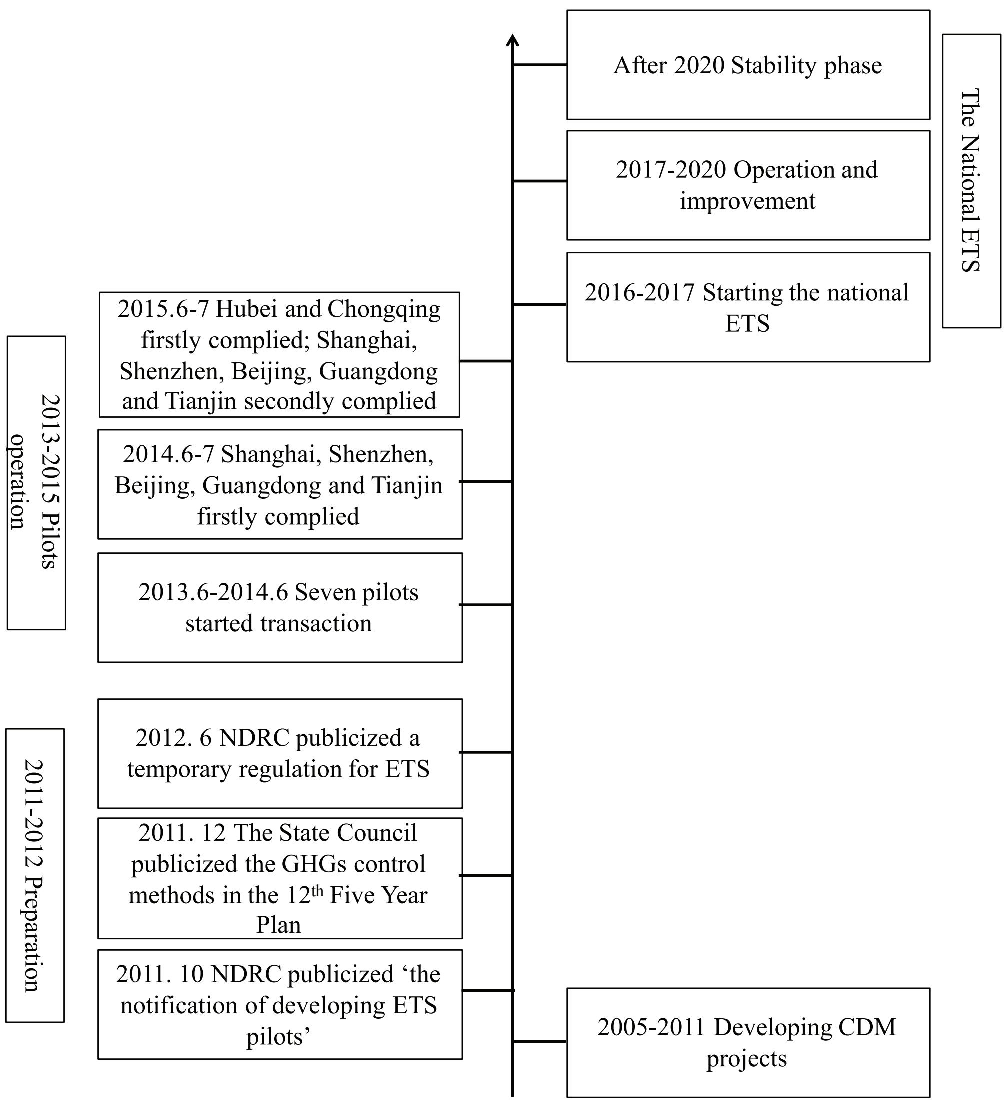


Figure 2-6 Development proceedings of China ETS
Source: Qi & Cheng (2015)

The seven pilot programs, basing on their individual policy frameworks, serves as basic foundation for a national-level and unified emissions trading market. Focusing only on carbon dioxide, the seven pilots cover roughly 40 to 60 percent of a city or province's total emissions, and apply to power and other heavy manufacturing sectors such as steel, cement, and petrochemicals (ICAP, 2016). These seven pilot schemes are collectively expected to cover 700 MtCO2e, a quantity only behind the 2.1 GtCO2e that the EU ETS covers (ICAP, 2016).

Seven pilots ETS are running under regional preparation and separate plan in order to inform policy makers about what types of programs best suit specific types of regions. Diverse regional development of pilots ETS is supposed to give the national ETS planning process as much suggestion as possible. The overview of China ETS pilots is seen in Tab 2-4.

Tab 2-4 Overview of China ETS pilots

| | Beijing | Tianjin | Shanghai | Shenzhen | Guangdong | Hubei | Chongqing |
|---|---|---|---|---|---|---|---|
| **Start date** | 2013.11 | 2013.12 | 2013.11 | 2013.6 | 2013.12 | 2014.4 | 2014.6 |
| **GHG type** | CO2 | CO2 | CO2 | CO2 | CO2 | CO2 | CO2 |
| **Cap** | 50 Mt CO2e | 160 Mt CO2e | 160 Mt CO2e | 34.78 Mt CO2e | 408 Mt CO2e | 281 Mt CO2e | 106 Mt CO2e |
| **Covered emissions** | 40% | 60% | 50% | 40% | 55% | 35% | 40% |
| **Number of covered entities** | 551 (2015) | 112 (2014) | 312 (2016) | 635 enterprises 197 public buildings (2015) | 217 (2015) | 138 (2015) | 237 (2014) |
| **Permits allocation** | Grandfather and benchmark | Grandfather and benchmark | Grandfather, benchmark, and ex-post allocation adjustment | Benchmark, Game theory, and Ex-post adjustment | Grandfather, benchmark, and auction | Grandfather, auction, and ex-post adjustment | Grandfather and ex-post adjustment |
| **Offsets and credits** | CCER 5% | CCER 10% | CCER 5% | CCER 10% | CCER 10% | CCER 10% | CCER 8% |
| **Compliance cost** | 50,000 CNY | No | CNY 50,000 (EUR 6,544) – CNY 100,000 (EUR 13,088) | CNY 100,000 (EUR 13,088) | CNY 10,000 (EUR 1,309) to CNY 50,000 (EUR 6,544) | CNY 10,000 (EUR 1,309) to CNY 3,000 (EUR 3,927) | No |
| **Banking** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Borrowing** | No | No | No | No | No | No | No |

Source: ICAP factsheet (2016)

2) Elementary design of China ETS in pilots

- Cap and coverage

ETS Pilots decide the threshold respectively to include companies (seen Tab 2-5). The targeted GHG type is only $CO_2$ for the first trial period. Different from the EU ETS, China pilots choose to include entities according to the unit of company while the EU ETS includes per unit of installation. This is because of the data availability. Company is the minimum unit for energy statistics in China. It would be convenient for the ETS administrator to manage the emissions and compliance of companies. However, including installations as the minimum unit is favorable to track the routine activities and therefore to facilitate allowance allocation and compliance management.

Tab 2-5 Threshold and the number of inclusive companies of pilots

| Pilots | Covered sectors | Threshold* |
|---|---|---|
| Beijing | Industrial and non-industrial companies and entities, including electricity providers, heating sector, cement, petrochemicals, other industrial enterprises, manufacturers and service sector.<br>With the revised inclusion threshold the transport sector will be covered as well. | Annual emission > 10,000 ton $CO_2$e |
| Tianjin | Heat and electricity production, iron and steel, petrochemicals, chemicals, exploration of oil and gas. | Annual emission > 20,000 ton $CO_2$e |

| | | |
|---|---|---|
| Shanghai | The following sectors are covered: airports, aviation, chemical fiber, chemicals, commercial, electricity, financial, hotels, iron and steel, petrochemicals, ports, non-ferrous metals, building materials, paper, railways, rubber, textiles, paper, rubber. Since 2016, local shipping is included as well. | Industry: annual emission > 20,000 ton $CO_2$e<br>Non-industry: annual emission > 10,000 ton $CO_2$e |
| Hubei | Power and heat supply, iron and steel, chemicals, petrochemicals, cement, automobile manufacturing, ferrous metals, glass, pulp and paper, food and beverage | Energy consumption > 60,000 tons coal equivalent /year |
| Guangdong | Energy, iron and steel, cement, petrochemicals. Ceramics, textiles, nonferrous metals, chemicals, pulp and paper, construction, transportation sectors may be included during the pilot phase at a later stage. | Annual emission > 20,000 ton $CO_2$e |
| Chongqing | Power, electrolytic aluminum, ferroalloys, calcium carbide, cement, caustic soda, and iron and steel | Annual emission > 20,000 ton $CO_2$e |
| Shenzhen | Power, water supply, manufacturing sectors, buildings. Since June 2015, public buses and taxis are required to measure and report their emissions and may be included during the pilot phase at a later stage. | Industry: annual emission > 3,000 ton $CO_2$e<br>Public buildings: annual emission > 20,000 m2<br>Government building: annual emission > 10,000 m2 |

*: considering both direct and indirect emissions.

Source: ICAP factsheet (2016)

The system covers both direct emissions from the power sector upstream and indirect emissions from electricity (and heat) consumption downstream. A scheme including only direct emissions would not induce a pass-through of carbon costs to end consumers via the electricity price, since the electricity price is regulated by the China central government.

The emission reduction target of China is to reduce the emission intensity (emission divided by GDP). Compared to the EU ETS with absolute emission reduction targets, the relative target is flexible and takes into account the potential of economic development. It helps control the cost when an economy is booming, and address some problems like over-allocation and price collapse when the economy is waning. But it also brings difficulty to ensure the cap in amount of total permits. Until the GDP data for that year had been published, there would be uncertainty in the market about the number of available permits. China ETS pilots usually adopt three steps to calculate the cap (Qi & Cheng, 2015):

a) Predict local economic output and emissions to transfer the relative target into absolute target
b) Account the proportion of emissions from inclusive companies in the total local emissions in a given historical period, or allocate the relative target into different industries and design benchmark in each industry
c) Calculate the local cap on the base of last two steps

In the structure of cap, China ETS pilots have also their own features. The cap is composed by three components: initial allocation allowance, emerging reserve allowance, and government reserve allowance (Qi & Cheng, 2015). Initial allowances are allocated to inclusive companies, and emerging reserve allowances are for companies join ETS in a later phase or companies that widens their business scope. Government reserve allowances are used to control the emission market. In 2014, the government

reserve allowances of Hubei ETS pilot account up 8% of the total allowances (Qi & Cheng, 2015).
In addition, borrowing of allowances from future periods are forbid in China ETS pilots while banking of allowances is allowed under certain conditions. For example, Hubei ETS pilot requires that allowances can only be banked after trading, or else unused allowances will be automatically removed (ICAP, 2016).

- Permit allocation

There're generally three modes for allowance allocation: enterprise-government discussion, multi-game, and enterprise application. In the first mode, local government carries out workshops and forums for enterprises to transfer the knowledge about emission management. They design the amount of allowance allocation together. Hubei, Shanghai, Beijing, Tianjin, and Guangdong are taking this mode. Shenzhen tries the second mode to realize the allowance allocation among the leading industries except electricity, water, and gas. Chongqing adopts the last mode where enterprises decide for the amount of allowances by themselves and submit applications to the local government.
Except Guangdong, all other six ETS pilots allocate initial allowances for inclusive companies for free (ICAP, 2016). Beijing issued free permits in 2013 to coal-fired power plants that are the main polluters in Beijing to 99.9 per cent of their average emissions over 2009 to 2012. The amount will drop to 99.5 per cent by 2015. Manufacturers received permits in 2013 equal to 98 percent of their historical emissions, falling to 94 percent in 2015. Guangdong sets 97% allowances for free and 3% for auctioning in the period 2013-2014. The proportion of auctioning is going to increase. Government reserve allowances (around 3% of total emissions) are allocated by auctioning or at a fixed price. Each pilot administrator decides the detail rule of allowance allocation. For example, Hubei ETS auctions 2.5% allowances at the beginning of a trading period in order to discover the market price and increase the market volatility. Shenzhen pilot auctions 3% allowances at the end of each trading period to satisfy companies' need before the compliance (ICAP, 2016).
For free allocation, grandfathering is the leading method while benchmark is adopted as well in some pilots together with grandfathering. Benchmark is set on the base of industry instead of product. For example, Shanghai and Guangdong set six types of benchmark for electricity generator on the base of different engines. Hubei pilot adopts grandfathering and benchmark separately at the beginning and end of a trading period.
Those that emit more than their free-allocated permits can buy additional permits, from others or use offset credits issued by the central government, known as Chinese Certified Emissions Reductions (CCERs). All pilots allow a limited use of CCERs in order not to affect the total amount of cap. On one hand, the use of CCERs cannot exceed 10% of the total free-allocated allowances a company gets in one trading period. Chongqing reduces it to 8%. Shanghai and Beijing limit it to 5% (ICAP, 2016). On the other hand, in order to motivate the local emission reduction and realize the local reduction target, some pilots require that project sources of CCERs have to come from the same province or city. Beijing and Guangdong require respectively 50% and 70% of CCERS from local production. Hubei and Chongqing require 100% (ICAP, 2016).

- Price of permit

The transaction price average from all pilots is between 24-25 yuan/ton (Qi & Cheng, 2015). Hubei market was the most stable one among others. Shenzhen focuses on the market volatility participated by a large number of companies with small scale. At the beginning of mandatory emission trading, companies cannot predict exactly their need for allowances in the future. Lack of information increases the market instability. Hubei did properly to combine the market flexibility and regulation. It set a price floor and cell to control the unreasonable price fluctuation within a proper range.

Considering the overall transaction amount (see Figure 2-7), Hubei has the biggest transaction amount and all transactions were produced consistently. However, in other pilots, companies tried to make transaction only in the last month before the compliance point. This is due to the passive participation of companies into transaction. To complete the compliance is the main incentive to perform transactions. The success of Hubei pilot lays in that it auctions allowances at the beginning of a trading period. This motivates the positivity of participants to the most extent. Secondly, allowances are allocated to companies once per year, and unused allowances are removed automatically in the next trading period. It makes sure that companies would focus on transaction from time to time.

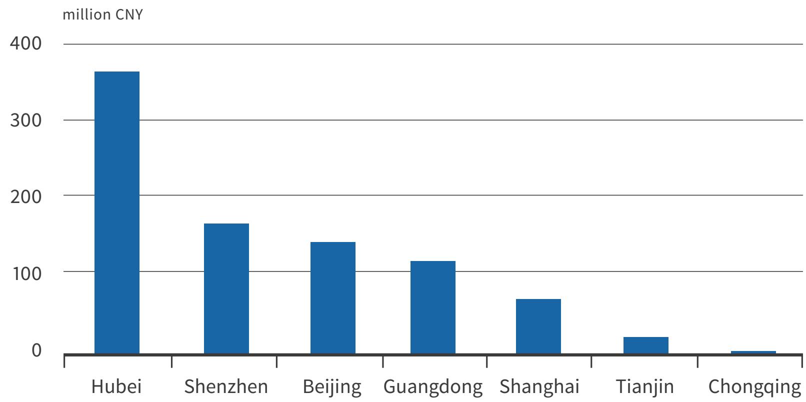


Figure 2-7 Accumulated trading volume in secondary market of various ETS pilots in 2015

Source: ICAP (2016)

Till the June 28th, 2015, there were only 12 transaction performed in Chongqing pilot. Inclusive companies themselves decide the allowance allocation. Government regulates only the total amount of allowance. It gives freedom for companies and the market while it cannot avoid ethical risks. Companies apply for much more allowances allocation than they accurately need.

- MRV

In seven pilots, local development and reform commission (LDRC) is the administrator and responsible for the implementation, arrangement, coordination, and supervision of issues related to ETS. Each pilot develops its own exchange platform and designs the rule for transaction respectively. For the verification in most pilots, government provides the full financial support and designates accredited verifiers for companies (see Tab 2-6).

Tab 2-6 Institutions involved in China ETS pilots

| Pilot | Authority | Exchange platform | Accredited verifier | Market oversight |
|---|---|---|---|---|
| Shenzhen | LDRC | Shenzhen ETS | 21* | LDRC |
| Shanghai | | Shanghai ETS | 10 | |
| Beijing | | Beijing ETS | 19 | |
| Guangdong | | Guangdong ETS | 16 | |
| Tianjin | | Tianjin ETS | 4 | |
| Hubei | | Hubei ETS | 3 | |
| Chongqing | | Chongqing ETS | 11 | |

*: Enterprises pay and choose verifiers. For the rest, verifiers are sponsored and allocated by government.

Source: Qi & Cheng (2015)

This could reduce the participation cost of companies and ensure objectivity and fairness. Shenzhen pilot adopts another mode where companies have to pay for the verification and choose accredited verifiers by themselves. Beijing did the same in 2015. This mode is also adopted by the EU ETS. It improves the positive competitiveness among verifiers and promote their professional level. All seven pilot markets are supervised by LDRC respectively. The EU ETS market is supervised by EC and administrators of Member States. Usually, the administrator of Member States is taken by the environmental department of local government. For example, Germany orders the environmental department of the federal to supervise the market.

3) Suggestions for building the national China ETS

The national China ETS is supposed to be established in the 13rd Five Year Plan period (2016-2020). Seven pilots were assumed to run from 2013 to 2015 and then would be substituted by the national ETS. Due to the long and complex preparation, the national ETS is not possible to come until 2017. Pilots might operate before the national ETS is put into practice. Pilots' operation together with the reformation of the EU ETS provides experiences for China to build its domestic ETS. This section generates some suggestions for establishing the national China ETS based on a comparison between the EU ETS and China ETS pilots in six aspects.

- Cap setting: Experiences from the EU ETS show that an integrated cap with an absolute value would not only ensure the effectiveness of ETS but also improve the efficiency. Submitting NAP and applying for approval by the EC is time-consuming and complex processes. A EU-wide cap saves labor and time. In addition, an absolute cap limits the overall amount of emissions and therefore guarantees the emission reduction effectiveness. China pilots connect the value of cap to local economic growth because China is still a developing country and emissions reduction should be compatible with the need for national economy development. Reducing emissions in the form of carbon intensity suits to the national situation of China. It is referable for the construction of the national ETS.
- Coverage scope: A broad coverage is suggested to minimize the emission reduction cost across the whole economy. UNFCCC takes the principle that climate change should be combated wherever emissions could be reduced. In addition to targeted downstream installations, the EU ETS is including or considering including more and more sectors such as aviation, shipping, etc. Rules for including these sectors are under discussion considering the cost-effectiveness and feasibility. Since electricity prices are heavily regulated in China, power plants cannot pass their carbon costs on to consumers through electricity prices. China pilots cover upstream power/heat generators and downstream emitting plants. The complicated administrative structure in China results in the particularity to tackle with planning and operation processes of establishing China ETS. Setting the coverage of the national ETS cannot afford neglecting the characteristics of the China national situation.
- Permit allocation: Permit allocation affects the outcome of an ETS as well as the economy performance. In the reformation of the EU ETS, it is transferring from free allocation to a more transparent, fair, and effective method – auction. It can also avoid market manipulation of some single big players. Auction helps administrator discover market price. Ultimately all companies need pay for every unit of emissions that they emit under a 100 per cent auction system. China pilots are running mainly under free allocation and a proportion of permits is reserved for auction for new entrants, capacity building, or market control. For the national ETS, it is reasonable to adopt free allocation at the beginning phase and integrate auction in later phases until auction

platforms and the legal binding of bidders are accomplished.

- Price control: The EU ETS realized a complete free trade in the first two phases but the price of permits came to be very low. In the third and fourth phase, certain price regulations are employed including back-loading and stability reserve. The economic gap among China provinces or cities is larger than that of EU ETS participant countries. Regional pilots experiences cannot be easily transferred into useful knowledge to benefit establishing the nation-wide ETS. Permits price in the initial stage is of big difference in different pilots region where Shenzhen has the highest price. The different price levels show it is still early days for market participants and that there is great deal of uncertainty about whether permits are scare. It's advisable to prepare price regulations for the operation of the national ETS through controlling permits allocation either in the aspect of time or volume.
- Legislation and regulation: In order to guarantee a smooth operation, the EU ETS has spent several years in establishing a relatively sound legal system before it started putting the transaction into practice. For instance, "Direction 2003/87/EC" formulates the legal status of the EU ETS as well as the attributes of permits. Meanwhile, the EU ETS also published regulations from the technical perspective to set the detailed rules for transaction such as Registry Regulation, Regulation on MRV, Allocation Decision 2011/278/EU, Guidance Documents, and Rule Books, etc. These regulations describe the method for permit allocation, emissions verification, report and monitor, market supervision, etc. Shenzhen and Beijing pilots are legislated in the form of local people's congress committee. The government decrees publish management approaches for Shanghai, Guangdong, Tianjin, Hubei and Chongqing pilots. The legally binding of local government regulations is weak. In addition, seven pilots have designed certain technical regulations such as transaction rule and MRV instruction, but they are not confirmed yet in the form of legal status. It needs further improvement especially in the method of permit allocation. To construct a national ETS, China has to prepare well for the legislation and regulation issues before the ETS finally starts.
- Institution setting: The EU ETS is generally regulated and monitored together by the EC and state members. The EC is responsible for coordination, support, and approval, meanwhile it is also supervised by state members in order to keep transparency and efficiency. The climate change department of EC forms the central administrator. The environmental department of each state member forms each sub-administrator. China pilots are both regulated and supervised by local DRCs without out any reference and coordination from another regulator. To ensure the effectiveness of the national ETS, institutions involved should be well set. At least, different institutions should complete administration and supervision.

## 2.3 Business impact and reaction

### 2.3.1 Business impact factors

After the first proposal of emission trading, lots of literature has analyzed the impacts and effects of ETS on firms' as well as industries' competitiveness in international trade. By giving a price to each ton of GHGs saved, the ETS has placed climate change on the agenda of companies' financial departments. Increased carbon cost is supposed to affect the market share of firms and industries. However, literature shows that GHGs could possibly be cut without impairing the economic performance of agents under the umbrella of ETS. The impacts of the ETS are complex and not necessarily negative. The net effect of carbon cost exposure depends upon to which extent this sector can 1) reduce its emissions, 2) get free allocation, and 3) pass cost through to products and customers (Hourcade et al., 2014).

1) Emission abatement capability of the industry

Graichen et al., (2008) investigate the impacts of the EU ETS on Germany industrial sectors' international competitiveness and they indicate that only for the sectors that reveal high value at stake and high trade intensities, market positions are likely to change under the EU ETS due to the increased production cost and high exposure to international competition. Value at stake is defined as the sum of potential direct (emission related cost) and indirect cost (electricity related cost) under the EU ETS. The direct cost contains cost for internal abatement measures and permit purchase. Due to different abatement costs in different industries, the impact of ETS on the production cost of different industries differs.

The above Figure 2-8 also shows that the exposure of industrial sectors to carbon cost as a whole would have only a small negative influence on the GDP of Germany, maximal around 2%. This illustrates in fact how emission trading works. Since emission abatement costs are different in different industries, emission trading allows the average abatement cost is minimized across all of inclusive industries. Therefore, both of the overall emissions and the impacts on the overall economy are controlled. By implementing ETS, it is expected to decrease $CO_2$ emission by 3.8% by 2020, and the maximum impact on the GDP of the EU will be roughly -0.002% (Anger & Köhler, 2010).

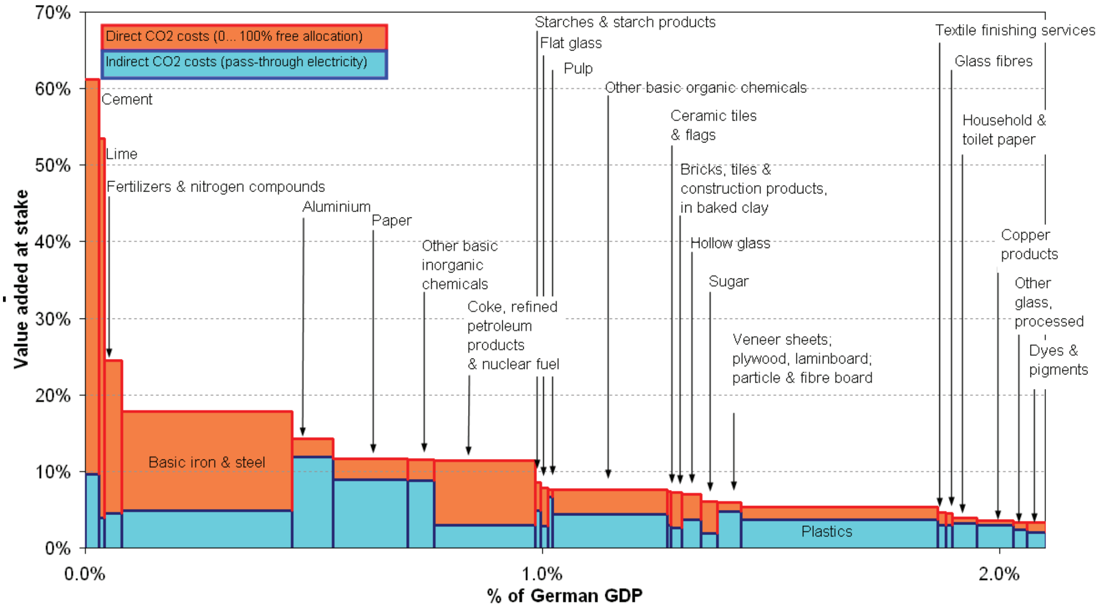


Figure 2-8 Value at stake in Germany relative to GDP

Source: Graichen et al. (2008)

2) Design of permit allocation rules

The allocation rule is another key factor affecting the impact of ETS on business competitiveness. Abrell et al. (2011) study the effectiveness of the EU ETS at firm's level by using a sample of 2101 European firms (3608 installations) covered by the ETS. They certify that the EU ETS has only a modest impact on the participating companies' performance because permits were over-allocated to industrial entities at the beginning phases (see Figure 2-9). And they find that emission reduction is significantly related to the initial allocation of permits and firms do reduce emission under the second phase of EU ETS where benchmark allocation method is adopted instead of grandfathering. A full auctioning system could help reduce emission but could also have a negative impact on the profits of participating companies.

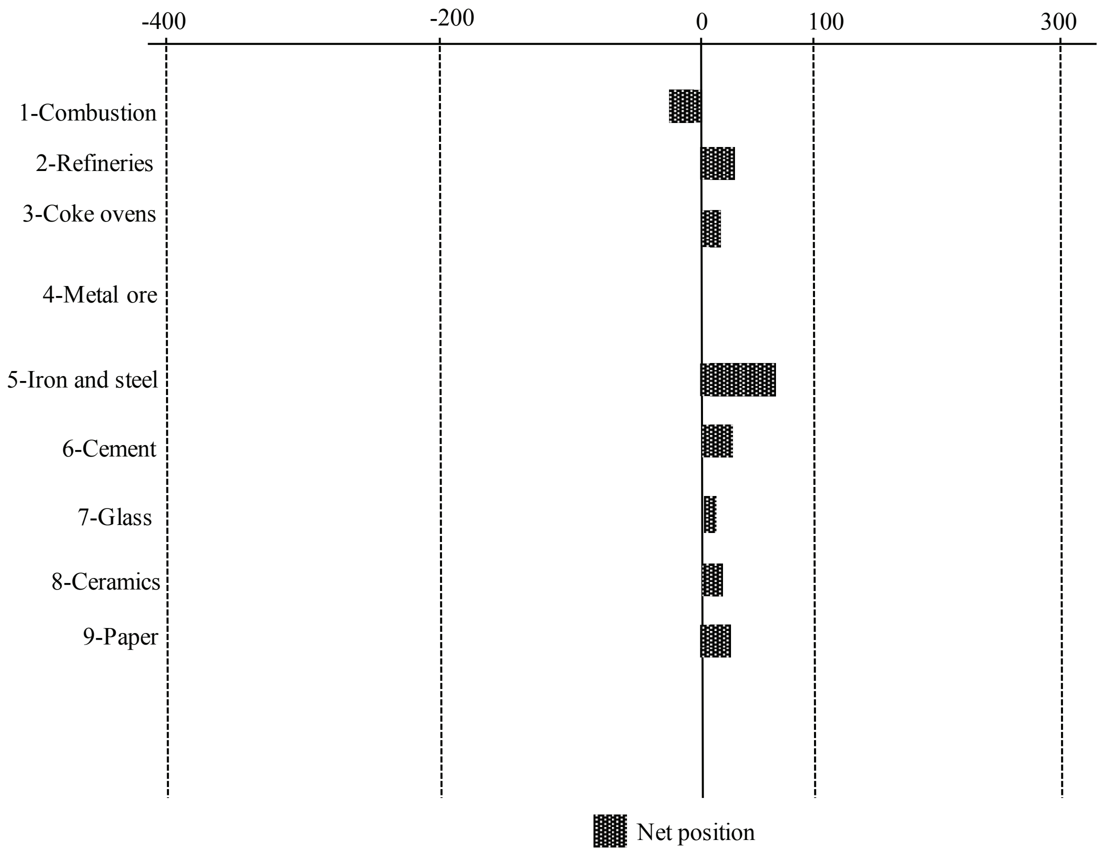


Figure 2-9 Over-allocation of EU allowances to industrial sectors
Source: Ellerman & Buchner (2008)

Despite the over-allocation of EU allowances, it is estimated that the EU ETS has still reduced EU-23 emissions by between 50 and 100 $MtCO_2$/year for 2005 and 2006, which is 2.5% to 5% less than the emissions expected in a scenario without EU ETS (Ellerman & Buchner, 2008). It is not the initial allocation that causes a source to reduce emissions but the price it must pay for its emissions, even if in opportunity cost terms (Ellerman & Buchner, 2008).

From the literature overview conducted by Graichen, et al. (2008), it shows clearly that the cost increment incurred by ETS on industrial sectors is affected by the amount of free allocation and the price of permits in the market. One of literature investigates the impact of auction proportion on the average and marginal cost of selected industries. In all scenarios of this study, it keeps the same price of allowance and assumes two values of the auction proportion: 2% and 10%. The results of all scenarios show that the average cost increase becomes bigger as the auction proportion is larger. Another literature keeps the same auction proportion in all scenarios and investigates the impact of different allowance price on the average cost increase of selected industries. The average cost increase in the scenarios with a higher allowance price is always larger than that in the scenario with a lower allowance price. In other two literatures, the average cost increase differs in selected industries though they assume the same allowance price and auction proportion for all industries. This result emphasizes again that the emission reduction capability of the industry is one key factor affecting the impact of ETS on the industrial performance.

3) The ability of cost pass-through

Demailly & Quirion (2008) quantify the impact of the EU ETS on two dimensions of competitiveness – production and profitability – for the iron and steel industry due to their high $CO_2$ intensity and exposure to international trade. Their results conclude that for this sector competitiveness losses are small, because they are more related to the implicit factor: allocation update rules and pass-through rate. Some industry is able to pass the ETS-incurred cost to its product price and customers while others are not allowed. For instance, the electricity price is regulated by the central government in China and electricity generators are not able to pass the ETS-incurred cost to the electricity price. The ability of cost pass-through depends upon factors including the industry competitiveness, national administrative characteristics, the customer relationship, and so on.

When the industry is able to pass the ETS-incurred cost through to its product price, it can even gain profit from joining ETS. For example, electricity generators tend to profit in aggregate because the pass-through of carbon costs to electricity prices increases revenues far more than it increases costs. However, higher prices generate profits from free allocation in the short term but attract imports in the long term. The more they add ETS-induced costs to their product prices, the more they risk losing market share to foreign competitions.

### 2.3.2 Compliance measures

Companies that are mandatorily included into ETS are usually confronted with two measures to comply with their emission reduction target: purchasing carbon permits and investing in emission abatement initiatives. Most often, these measures are combined in use. Besides, this section also introduces some illicit initiatives companies would take which results in carbon leakage.

1) Purchasing carbon permits

Besides giving a limit to the allowed emissions of participants, ETS also provides flexibility for targeted firms to make strategies under various compliance measures through its market price. Notably, purchasing carbon permits is a reactive measure and will not reduce carbon emissions, but will alleviate the impact of ETS on the economic performance of firms directly. Companies would usually compare the options that they have to reach the emission reduction target and make the most cost-effective strategy for emission reduction. For the mandatory target, companies have to purchase permits from compulsive ETS, or purchase credits and offsets from CDM, and JI projects. For the voluntary target, companies are allowed to purchase offsets from CDM projects or other voluntary exchange markets.

2) Green investment (GI)

Conversely, GI practices are a proactive measure as their effect on firms' performance is long term and sustainable, moving toward the goal of reducing GHGs. Sheu & Li (2013) take both permit purchase and GI measures into account to facilitate the characterization of short- and long-term competitive strategies of airlines moving toward sustainable business development in the emerging ETS context. Green investment initiatives include generally two types: technological investment and operational investment.

Technological investment means investing into green technologies which can save GHGs compared to current technologies. These initiatives contain implementing LED lighting in warehouse and buildings, importing electricity from solar and wind energy, and so on.

Operational investment is to reduce GHGs by adjusting existing operations. Sgouridis et al. (2011) separate compliances airlines under EU ETS could take into five categories: technological efficiency improvements, operational efficiency improvements, use of alternative fuels, demand shift, and carbon pricing for emission reduction. Chaabane et al. (2011) classify the compliances firms and supply chains could take in response to ETS into two categories: internal and external measures. Internal measures refer to operational adjustment within the range of individual firms (i.e. production output reduction, investment in green technologies) and supply chains (i.e. procurement, allocation, distribution, recovery management) while external measures are regarded as the market-based instruments (i.e. ETS, CDM, and JI). Benjaafar et al. (2013) find out firms could effectively reduce their carbon emissions without significantly increasing their costs by making only operational adjustments with regard to procurement, production, and inventory management, and by improving collaboration among supply chain partners. Subramanian et al. (2010) consider reducing product output to reduce GHGs.

3) Carbon leakage & fraud

ETS is becoming more and more popular in the world as an instrument to realize emissions reduction targets, but it has so far not covered all nations and sectors in the world yet. Global emission trading would ideally establish one common system for all the countries and all sectors in the world, and all participants from worldwide share a uniform carbon price. However, in reality countries or sectors are subject to asymmetric ETS and carbon pricing is only partially and unevenly applied. Countries and sectors under ETSs are given possibilities to transfer their business-related emissions to broad countries or other sectors non-covered by any environmental policies. That is so-called carbon leakage (EC, 2016). Emissions arise in wherever or from whatever else in the earth. For example, it happens when one emitter under ETS relocates its production processes to other countries free of emissions policies or when emissions go to other industries because customers choose to buy alternative but less expensive products.

In addition, some companies even make fraud to avoid the emission cost under ETS through ling about the amount of GHGs to related government administration. This happens often in the airline sector. They give false information about the sales and the reported GHGs are therefore less than accurately emitted. This situation happens when the MRV system of ETS relies on the self-reported data from companies without any effective review. It also happens when the GHGs of companies are calculated based on the sales data. Assigning specific authorities to be responsible for the MRV system of ETS would effectively reduce such illicit behaviors.

### 2.3.3 Intentions of corporates to participate in the emission trading

Pinkse (2007) uses the questionnaire data from 136 companies to analyze the intentions of companies to join emission trading. He finds that for most multinational corporation industry pressure under climate policy/regulation and product/process innovations are the main determinates.

For example, energy-related industries usually are more interested in emission trading compared to other industries because the climate policy particularly induces them to reduce emissions (Pinkse, 2007). Beyond the industry pressure, pursuit of other innovative options to cut GHGs is another important strategic factor for multinational corporation to participate in the emission market. Innovative companies are more perceptive than their competitors to changes in their environment, and therefore they are able to identify the opportunities of emission trading and develop the necessary competencies ahead of others (Pinkse, 2007).

In addition, process improvements for energy reduction combining with emission trading can bring a surplus of emission allowances which creates earnings in turn by putting into the emission market. Since the current emission market is still immature, those companies that already express a business interest in emission trading probably view process improvements as an opportunity to reap the "low hanging fruit" (Pinkse, 2007).

In addition, companies focusing on product emissions that are beyond the boarder of the own organization are likely to be more aware of the opportunities of the emissions market as well(Pinkse, 2007).

Generally, companies who are in pursuit of supply chain emissions reduction and other innovative options to cut GHGs are increasingly exploring great opportunities offered by emission trading.

## 2.4 Summary

This chapter introduced the policy background and working principle of emission trading. Especially, the Paris agreement plays one essential role in raising emission trading as the most important tool for nations, regions, and companies to reduce GHGs. It complies also to the actual status of ETS development and construction. Together there're 17 ETS in force in the world. The EU ETS, among them, is the biggest and most developed one. Although the first two phases of the EU ETS were not so effective as theoretically expected due to the over-allocation of allowances, it has revised a lot in the system design and supervision aspect based on existing experiences. Emission trading is still the main instrument employed by the EU to reach their GHGs reduction target under Kyoto protocol. However, the influence of the over-allocation of allowances in the last two phases would last for long and need long time to recover. Besides, China has established seven ETS pilots which have come into force since 2013. These ETS pilots were designed based on the China national condition and they were constructed to gain experiences for promoting the national ETS implementation. It is expected that the national ETS of China might start operating in 2017. To prepare the national ETS construction, it is advisable to consider the experiences of the EU ETS as well, especially from the regulation and legislation perspective.

As one market-based instrument, emission trading connects climate change to the economic performance of the society. On one side, by giving a price to each unit of GHGs, it has put climate change into the financial board of companies. On the other side, emission trading provides one mechanism for participants to achieve their emission reduction targets in the most cost-effective way. From a general aspect, the exchange of emitting rights among participants minimizes the overall emission reduction cost. Specifically, the impact of ETS on each targeted company would not be necessarily negative, and it depends upon several factors including the ETS allocation rules, the ability of cost pass through to customers, and the emission abatement capability.

# 3. Management of supply chain GHGs

The importance of supply chain management in achieving environmental goals is not a new idea. In 1996, Lamming & Hampson advocated the importance of environmental considerations in supply chain management. Either induced by the market pressure or in pursuit of profits, companies are managing GHGs within their own operations and extending the management to their supply chain carbon emissions. On one hand, customers and consumers are increasingly requiring the full transparency of emissions along the whole supply chain. On the other hand, the experiences of the largest corporation in the world and those of a start-up company show how companies can profitably reduce GHGs in their supply chain. Emission reduction is associated with cost reduction, new sources of revenue, improved employee motivation, enhanced public relations, and increased voice with policy makers. Therefore, it is both necessary and significant to manage emissions from the supply chain perspective. This chapter introduces the drivers, practices, and barriers of managing supply chain GHGs.

## 3.1 Supply chain GHGs

### 3.1.1 Scope 3 emissions

GHGs are a part of every phase of the value chain and every tier of the supply chain. Emissions result from the extraction of resources (which can release methane), the transportation of goods (which requires burning fossil fuels), the manufacturing of finished goods or parts (which requires energy), and finally the warehousing and storage of the product (which also requires electricity and heating) (Huang et al., 2009).

If we allocate emission sources from the economy-wide level to the supply chain of a different product or service, it is possible to show that all the emissions generated in an economy exist in producing and delivering products and services to meet the needs of the end consumer (Carbon Trust, 2006). Supply chain emissions account for around 75% of the whole emissions from an industry sector while companies' direct emissions average only 14% of their supply chain emissions prior to use and disposal across all industries (Huang et al., 2009). Mitigating climate change cannot afford neglecting the greatest climate impacts from indirect processes within the supply chains. Fundamental changes are required to the way that business delivers products and services to the end consumer.

In order to measure, account, and manage supply chain GHGs, it is necessary to get transparency of the emissions sources. The GHG protocol (2012), one non-profit foundation developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) developed two standards for government and business leaders to understand, quantify, and manage supply chain GHGs. They are either based on corporate standard (also called Scope 3) or product standard (also called product life cycle). These two standards provide the scope and boundary of supply chain GHGs. Both scope 3 (corporate emissions) and product emissions are supply chain GHGs.

The GHG protocol (2012) separates corporate emissions into 3 scopes (Figure 3-1).

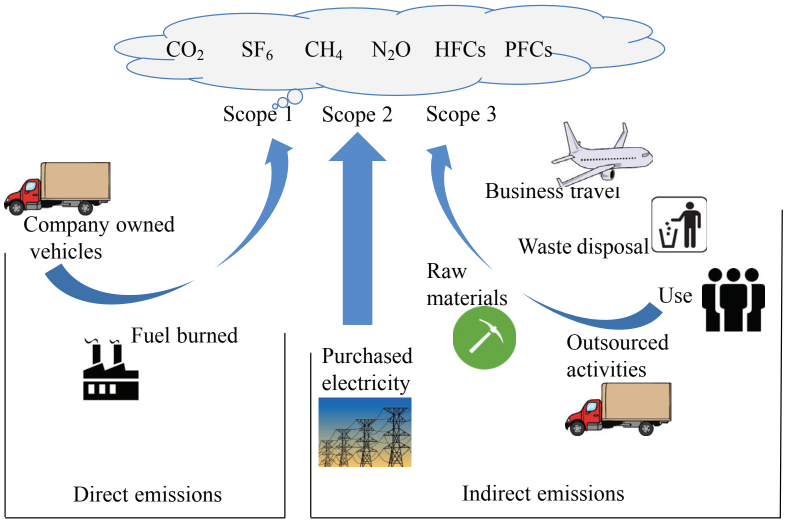


Figure 3-1 GHGs by scope

Source: GHG protocol (2010)

- Scope 1: All direct GHGs.
- Scope 2: Indirect GHGs from consumption of purchased electricity, heat or steam.
- Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. T&D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

Direct GHGs are emissions from sources that are owned or controlled by the company. Indirect GHGs are emissions that are a consequence of the activities of the company but occur at sources owned or controlled by another company.

Since Scope 3 emissions include emissions mainly coming from upstream and downstream in the supply chain outside of the boundary of individual companies, Scope 3 emissions of one company are often regarded as supply chain GHGs of the company in the empirical field (Kingsbury et al., 2012). By defining Scope 3 emissions from the corporate perspective, it intends to help organizations categorize GHGs into those that they control (e.g. Scope 1) versus those that they can influence (e.g. Scope 3). It is therefore possible to pose corporate responsibility and future regulatory risks to organizations that lead and control supply chains.

Corporate climate change strategies towards GHGs management are diverse and continually evolving. Many companies have implemented initiatives to achieve reduction on their Scope 1 and 2 emissions, such as investing into energy-efficient technologies, facilities, and low-carbon energy sources, etc. Measuring and managing these emissions is relatively straightforward as they result from activities within the company's direct control. Furthermore, the case for reduction can easily be made, as there is a clear return on investment from increasing energy efficiency. Measuring and managing Scope 3 emission, the emission from a company's full value chain, is however more challenging because of the complexity of modern day value chains. Control firms have over activities beyond their own operations, but they have only diminished access to those activities, such as the production methods of their suppliers or use habits of their customers.

However, companies seeking to reduce their GHGs often find that their direct emissions are dwarfed by the emissions in their supply chains. In fact, scope 3 emissions comprise the majority of companies' carbon footprint, often up to 80-90% of the total (Kingsbury et al., 2012). The production and transportation of goods causes approximately 45% of those emissions, and the energy consumed when people use those goods accounts for much of the remainder; energy use in buildings alone accounts for approximately 25% (IPCC, 2007). Therefore, to avert dangerous climate change will require tremendous changes in the design and operation of supply chains, defined here as encompassing the multi-stage production, transportation, use, and eventual disposal of goods, and the energy generation and transmission that supports all of those activities.

### 3.1.2 Product life cycle

The product standard set the boundary for supply chain GHGs on the base of product life cycle. The carbon footprint of a product is, under a product life cycle thinking (Figure 3-2), the carbon dioxide emitted across the supply chain for a single unit of that product.

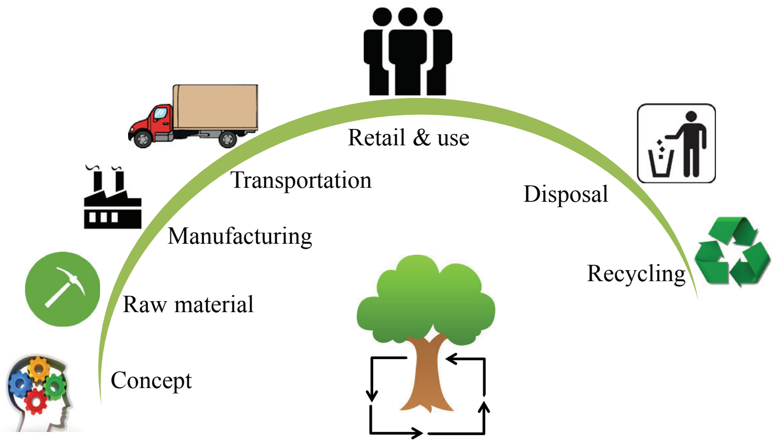


Figure 3-2 Product carbon footprint - life cycle thinking
Source: GHG protocol (2010)

Managing the carbon footprint of a product means minimizing the carbon emissions required to produce and deliver that product to the end consumer. Usually, two life cycle modes are used to set the boundary for emissions inventories: "cradle-to-gate" and "cradle-to-grave". The life cycle "cradle-to-gate" inventories include emissions from material acquisition and processing, production, distribution, and storage while the life cycle "cradle-to-grave" inventories extend to the use and end-of-life phase of the product. Emissions from the transportation between activities must be included, but companies have the choice to exclude emissions from capital goods, overhead, corporate activities, employee commute and delivery to the retail location (Carbon Trust, 2006).
For example, the carbon footprint of cola is the total net amount of carbon dioxide emitted to produce, use and dispose of a single can of cola (see Figure 3-3). The total carbon emissions are not just those due to the manufacturing processes or those due to "food miles" but should be based on all the steps in the supply chain to produce, use and dispose of or recycle the can of cola. Processes, and their emissions, do not occur in isolation but are always part of the supply chains for different products or services. Thinking about carbon emissions in this joined-up way shows the contribution that each of the steps along the supply chain make to the total carbon footprint of the product (Carbon Trust, 2006).

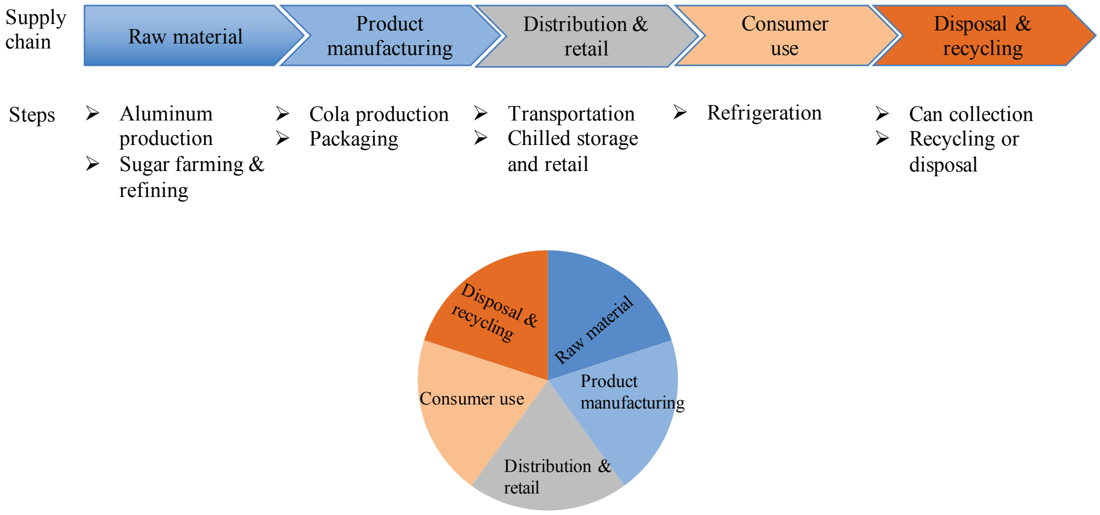


Figure 3-3 Schematic of the supply chain of a can of cola (illustrative)
Source: Carbon Trust (2006)

The Scope 3 standard applies to enterprise level inventories, which include all activities and products across the full value chain of an enterprise. The product standard focuses on a single product across its entire life cycle. Both standards enable companies to account their supply chain GHGs consistently and include them into their emission inventories. Corporates are encouraged to use both standards as complementary tools (Kingsbury et al., 2012). For external stakeholders such as customers and consumers, corporate can use product standard to assess their supply chain GHGs and provide the data on GHGs per unit of product. For stakeholders like investors, corporate could employ corporate standard to show the total corporate GHGs.

Supply chain leading organizations are increasingly attempting to manage their supply chain GHGs, starting by measuring, accounting, and reporting their supply chain GHGs. The GHG protocol is most widely adopted as one accounting tool for companies to have a better understanding of the carbon footprint of their supply chain. Users of these standards become new frontiers of carbon management in addressing climate change. According to the record of the GHG protocol, there're totally 115 corporate users except business association and business initiatives (GHG protocol, 2012).

### 3.1.3 Framework for managing supply chain GHGs

The management of supply chain GHGs is one sub-discipline emerging from green supply chain management (GSCM) and sustainable supply chain management (SSCM). GSCM and SSCM analyze environmental negative impacts of supply chain activities, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to consumers as well as end-of-life management of the product' (Srivastava, 2007). The environmental negative output contains GHGs, noises, water pollutions, etc. Since GHGs are the main cause to climate change, there's increasing need to address the problems of GHGs management. Supply chain leading organizations and governments require an understanding of supply chain GHGs and how they are managed (Long & Young, 2016). The management of supply chain GHGs, as a result, focuses only on the understanding and control of GHGs from the supply chain perspective.

Most work in this area is seen in empirical study in the form of interview (Butner et al., 2008; Kingsbury et al., 2012; EPA, 2015; Plambeck, 2012). They investigate how leading corporates from each sector manage their supply chain GHGs and try to develop benchmarks for each sector. Organizations have a central role in reducing the GHGs associated with products and services, through product choice and marketing (Bocken & Allwood, 2012). By attributing GHGs to organizations that lead and control supply chains, policy and regulation can target these organizations to affect a larger proportion of GHGs. Climate strategies of leading corporates for the management of supply chain GHGs become essential to combat climate change (Long & Young, 2016).

Kingsbury et al. (2012) investigate the supply chain carbon management in the consumer packaged goods industry by identifying drivers, quantification methods and reduction practices. They suggest five steps to measuring and managing scope 3 emissions: 1) identify business goals, 2) gain transparency, 3) identify opportunities, 4) establish partnerships, and 5) prioritize and take action.

EPA (2015) performs one case study in supplier engagement and show corporates' experiences in managing supply chain GHGs. They separate several steps for engaging suppliers: 1) choose suppliers, 2) conduct questionnaire, 3) provide training and capacity-building for suppliers, 4) expand strategic supplier engagement, and 5) set and achieve GHG reduction targets.

Carbon Trust (2006), one independent organization working in the low-carbon field, proposes one supply chain approach for carbon management. This approach covers complete supply chain for a single product developed on the base of standard life cycle analysis (LCA).

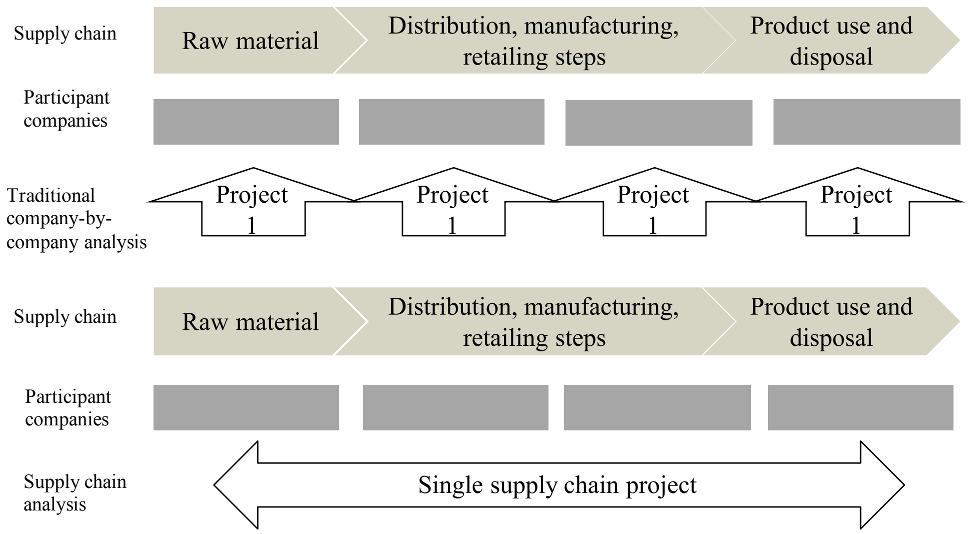


Figure 3-4 Traditional VS integrated supply chain GHGs management

Source: Carbon Trust (2006)

Compared to traditional emissions management, supply chain carbon emissions management is one holistic approach to manage emissions (Figure 3-4). Traditional emissions management focuses separately on supply chain steps restricted to companies' or sites' scope and implementing respective emission abatement measures without comparing and sequencing the cost and benefit of all initiatives. However, supply chain emissions management analyzes the whole processes across the supply chain, by 1) accounting and assessing the carbon footprint, 2) evaluating the carbon emission reduction potentials, 3) prioritizing abatement alternatives, and 4) implementing the prioritized emission reduction initiatives. This integrated approach allows creating the full carbon footprint for a product.

Based on the knowledge, research experiences, and practical investigation results, Carbon Trust provides one standard for supply chain – Carbon Trust standard for supply chain (see Figure 3-5). It is the world first independent certification for organizations that are measuring, managing, and reducing GHGs in their supply chains. The certification provides a framework for organizations to address their holistic carbon performance and tackle key inefficiencies in their supply chains, working collaboratively with suppliers to reduce their joint overall environmental impact and enhance the economic performance of both businesses.

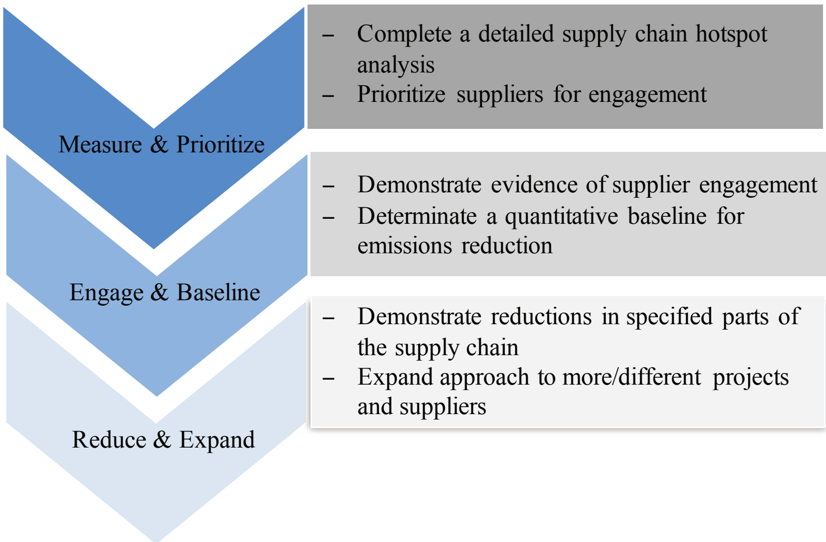


Figure 3-5 Carbon Trust supply chain standard

Source: Carbon Trust (2016)

There're different steps companies can take to limit carbon emissions concerning the trade-offs among cost, quality, service and emissions. Some measures are easy and can be implemented by individual companies' board, whilst some are complex optimizations that involve the participation of multi-companies in the supply chain. While an all-encompassing approach may have the highest potential for improvement, it also introduces more complexity, more coordination effort and more implementation time (Butner et al., 2008). "Low hanging fruit," such as point solutions for reducing carbon, may have less overall improvement potential, but can show an immediate return on investment. These efforts can even lower certain expenditures to the point of enabling additional, more integrated carbon-reducing investments. The more integrated the supply chain is, the greater control they will have over carbon emissions (see Figure 3-6).

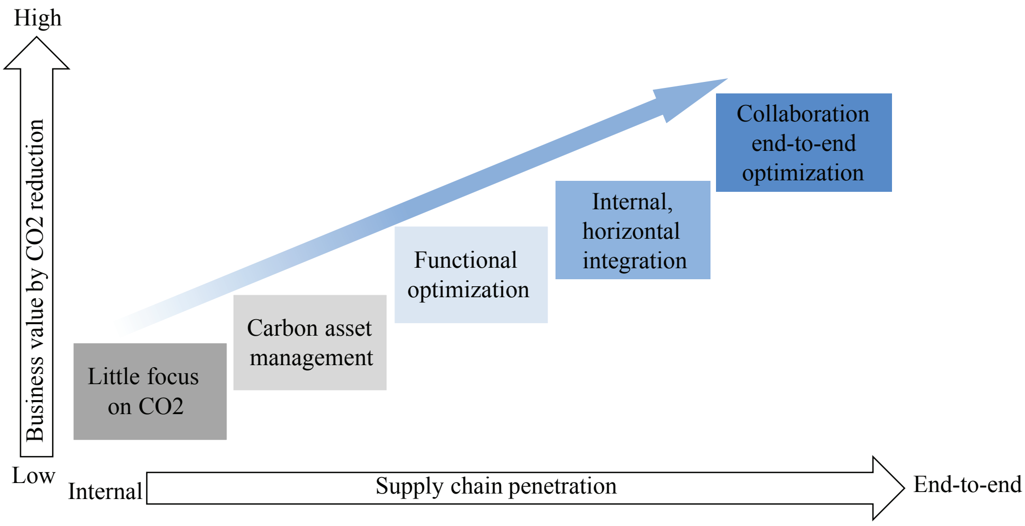


Figure 3-6 Supply chain carbon mastery model

Source: IBM (2009)

Butner et al. (2008) recommend a step-wise approach to master supply chain GHGs, and it includes five steps: 1) diagnose and assess, 2) implement asset management and realize point solutions, 3) address emissions in supply chain functions (see Figure 3-7), 4) find the optimum solution for integrating across functions, and 5) collaborate with supply chain partners to realize overall potential.

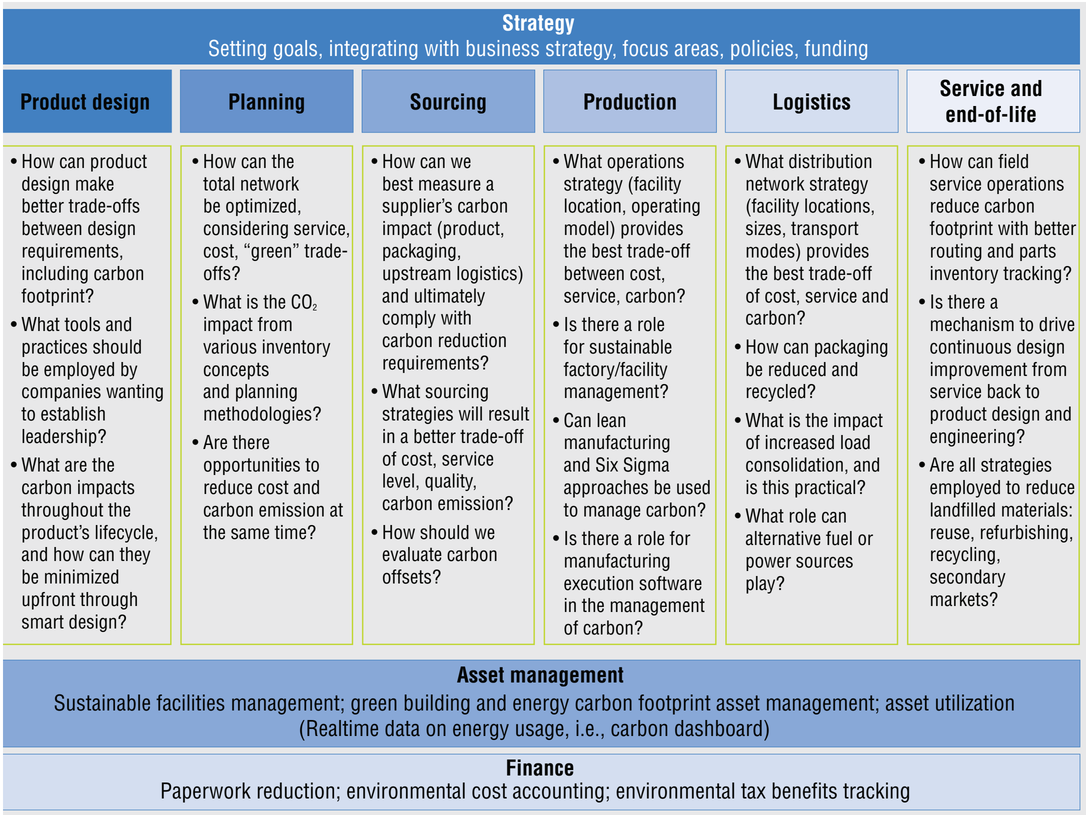


Figure 3-7 Environmental optimization potentials in supply chain function

Source: IBM (2009)

Ideally, a lifecycle carbon assessment serves to determine a comprehensive approach for reducing carbon along the supply chain. In practice, however, end-to-end lifecycle assessments are often lengthy and costly undertakings. Pragmatic approaches that focus on a few key collaborative steps among partners in the supply chain can lead to tangible results comparatively fast, and with a potentially higher return on investment than a single player can achieve.

Based on these definitions and proposals for managing supply chain GHGs from literature, this paper generates one framework for supply chain GHGs management (see Figure 3-8).

This framework provides guidelines and instructions for companies to follow in managing their supply chain GHGs starting from setting a supply chain GHGs reduction target. The target is set on the baseline year, and it could either be a relative reduction target or an absolute target. Companies need then to identify and quantify the GHGs sources in order to understand the supply chain emission map. After getting transparency of supply chain GHGs sources, companies should designate and assess emission abatement measures, i.e., evaluating the cost and benefit of each measure. By designating emission abatement measures, companies should take both internal, inter-organizational, and market-based measures at all of strategic, tactical, and operational levels.

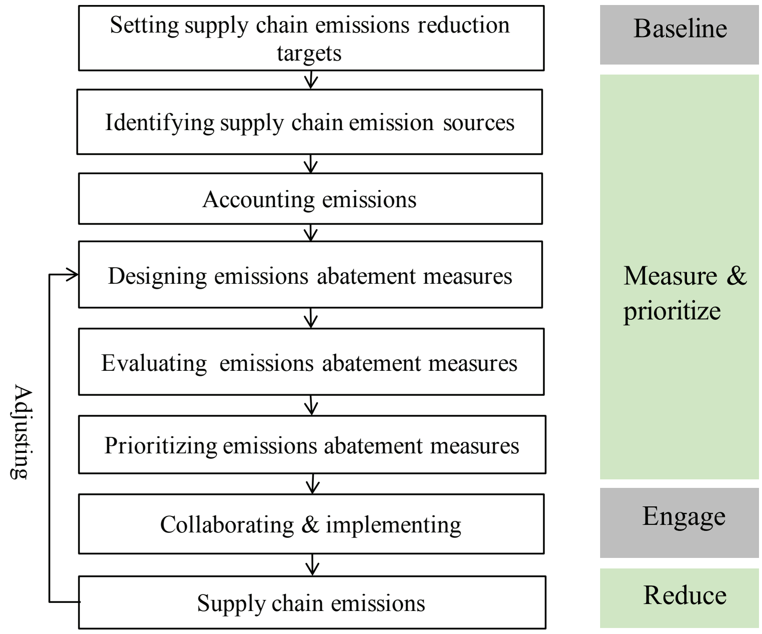


Figure 3-8 Framework for supply chain GHGs management

Emission abatement measures should be prioritized afterwards and the most cost-effective measure has the priority to be implemented. To implement measures, companies need collaborate with other supply chain partners when the measure takes place beyond the boundary of the companies. At last, the supply chain GHGs should be reevaluated and emission abatement measure should be adjusted according to the evaluation result from time to time.

## 3.2 Drivers

A growing number of leading companies are seeking ways to drive down emissions beyond their own operations by engaging into the management of supply chain GHGs. Some companies are making public commitments about measuring and reducing their supply chain GHGs. Wal-Mart, for example, announced its intent to reduce GHGs from its supply chain by 20 million metric tons in early 2011 (Rosenbloom, 2010). Companies are recognizing that leadership in addressing the challenges of global climate change means continuing to reduce their own emissions while working with their value chain partners, customers, and suppliers, to manager GHGs beyond their facilities (EPA, 2015). An overview of the drivers addressed in the area of GSCM and GSCM addressed in literature is given in Tab 3-1.

Tab 3-1 Overview of drivers for corporates to manage their supply chain GHGs

| Category | Driver | Literature |
|---|---|---|
| Internal factors | Sustainability commitment | (Jeswani, Wehrmeyer, & Mulugetta, 2008) |
| | Cost saving | (Jeswani et al., 2008) (Okereke, 2007) (Handfield et al., 1997) (Green et al., 1996) (Carter & Dresner, 2001) |
| | Corporate social responsibility | (Okereke, 2007) (Hall, 2006) |
| | Quality improvement | (Pil & Rothenberg, 2003) |
| External factors | Stakeholder demand | (Kolk et al., 2008) (Okereke, 2007) (Trowbridge, 2001) (Hall, 2006) (Zhu & Sarkis, 2006) (Carter & Dresner, |

| | | |
|---|---|---|
| | | 2001) (EPA, 2015) |
| | Competitive pressure | (Sarkis, 2003) (Lamming & Hampson, 1996) (Zhu & Sarkis, 2006) (Carter & Dresner, 2001) |
| | Energy price volatility | (Okereke, 2007) (EPA, 2015) |
| | Government regulations | (Jeswani et al., 2008) (Okereke, 2007) (Min & Galle, 2001) (Hall, 2006) (Zhu & Sarkis, 2006) (EPA, 2015) |
| | Market shifts | (Okereke, 2007) (Sullivan, 2010) (Kolk et al., 2008) (Jeswani et al., 2008) |
| | Technological change | (Okereke, 2007) |

Either induced by internal or external factors, companies are realizing that they have to reduce emissions not only within their own board, but also from their supply chains. Managing supply chain GHGs effectively can avoid damage to brand value, exposure to energy price volatility, and lack of preparedness for complying with carbon regulations (EPA, 2015). This section explains the key drivers for companies to implement supply chain GHGs management from four aspects: cost reduction, pressures from customer, competitors, and government.

### 3.2.1 Cost reduction

Contrary to usual belief that emission reduction programs would be of high cost, practical experiences tell that there exist in fact ideal emission reduction measures (so-called low hanging fruits) which could save emissions as well as cost. In 2010, "50% of carbon disclosure project (CDP) supply chain program members and 25% of their suppliers demonstrated a reduction in supply chain costs due to managing their GHGs" (Kearney, 2011). The savings of Walmart amounting to $3.5 million from transportation costs by reducing packaging has driven the engagement of their supply chain partners. Walmart encourages and supports their suppliers to find similar measures for cost and carbon savings and therefore it will benefit by receiving some of the savings' pass-through (EPA, 2015).

In addition, by looking through the supply chain to reduce GHGs, corporates are also given opportunities to get cost-savings by adjusting and optimizing their supply chain operations. "Supply chain operational adjustment has as much of an impact on the carbon footprint of a firm as the energy efficiency of individual units deployed in production or distribution" (Benjaafar et al., 2013). Coordination among multiple firms within the supply chain would very often save cost and emissions at the same time.

Last but not least, as the total carbon resource is limited (the cap is fixed and increasingly reduced), it would increase the price of high-carbon materials and services throughout the supply chain and hence affect the cost structures of products (EPA, 2015). Due to the influence of climate change on the means of production, price volatility would increase (Okereke, 2007). Managing supply chain GHGs aims ultimately to ensure that the supply chain becomes more energy efficient, especially for emissions-intensive processes and activities. By doing so, companies might avoid both the direct and indirect impact from sudden spikes of energy and fuel price on the cost.

### 3.2.2 Stakeholder demand

Increasingly, stakeholders including investors and customers are demanding the transparency of corporate and product emissions, and therefore companies have to build the capacity to understand the GHG footprint of their supply chain.

Corporate emissions become one important metrics for investors to make investing decisions. In 2010, global investors with assets totaling over $15 trillion signed a statement call for companies to build a low-carbon economy (Kingsbury et al., 2012). For business to business (B2B) companies, sustainability metrics are fast becoming incorporated into the customers' procurement decision. Corporate buyers are increasingly interested in the carbon footprint of products or services they purchase because it saves these buyers the time and money associated with footprinting each product themselves (Carbon Trust, 2006). For business-to-consumer (B2C) companies, sustainable-oriented consumers favor in products that can provide the information of embedded GHGs. Carbon Trust found that 67% of customers prefer to buy low carbon products (Kingsbury et al., 2012).

This emerging requirement put companies at risk of losing brand value and market share if they can not provide stakeholders with complete corporate emissions or product emissions. Hence, companies have to look out of their own operations, through the whole supply chain to collect and manage this data. Especially when products are assembled by small components manufactured in different regions, most of the product emissions are embedded within the processes of components' manufacturing and transportation. In this case, identifying emission reduction opportunities within the global supply chain where the bulk of components are produced is necessary to achieve one low-carbon product (EPA, 2015). Anyway, the increasing demand of emission transparency drives companies to manage GHGs from the supply chain perspective.

### 3.2.3 Environmental regulations

Legislation is identified as a key driver of pro-environmental behavior in organizations (Zhu & Sarkis, 2006). A range of regulation and policies are available to tackle with climate mitigation including carbon tax, cap and trade, eco-label, and so on. While current carbon legislation is piecemeal and often undefined, companies cannot expect this current situation to remain stagnant (Kingsbury et al., 2012). With the long trend of resisting climate change, it is not difficult to imagine that carbon emissions regulations are going to cover more and more industry firms and be much stricter in a short or long term. Existing protocol has been accounting for Scope 1 and 2 emissions. Forward-thinking companies should prepare for upcoming regulations that require them to be responsible for their Scope 3 emissions.

It becomes inevitable to cap GHGs and put a price tag on them since each ton of $CO_2$ is estimated to bring the economic damage in value of US$85 (Stern, 2006). Emission regulations are putting the environmental department of firms in a financial board by giving cost to each unit of emissions. Most recently, companies in heavy manufacturing have also started looking into the quantity of their supply chains GHGs (EPA, 2015). Impending regulation on manufacturing sector have induced companies to evaluate the relation between a carbon cost and their purchase/production cost (Bosch, 2011). Going forward, companies should expect to be charged for every unit of their carbon emissions in carbon-limited world. Taking actions before regulations come will release the impact of suffering regulation-incurred impact in advance.

Along with the development of mandatory emission trading and voluntary emission offsetting, supply chain GHGs reduction activities may entail further benefit in carbon pricing or capping schemes (EPA, 2015). In anticipation of such regulations, forward-thinking companies can preemptively decrease their carbon exposure through their supply chain to gain a competitive advantage over less forward-thinking competitors.

Suppliers' cost structure would likely be influenced by the price of GHGs which is in turn determined by legislation in various markets around the world (Bosch, 2011). For example, for energy-intensive activities such as steel and plastics manufacturing, the cost will increase noticeably with a tax on carbon and the cost change is affecting buyers' purchasing activities in downstream supply chain (Bosch, 2011). Therefore, to have a better understanding of supply chain GHGs would decrease the exposure to cost implication of carbon price.

### 3.2.4 Market competitiveness

Business firms are always confronted with the competition from counterparties in serving similar markets. Cost reduction was the first run of market competition, by reducing labor cost, material cost, producing cost, etc. However, this is not enough nowadays. Firms need to find innovative ways in developing businesses to survive from current competition and possibly win from the market competition in the future. As customer's preference is gradually changing from traditional products to low-carbon products, such innovative ways include providing green products by reducing emissions along the supply chain (Sarkis, 2003). As customers are increasingly looking for green products to satisfy the demand of energy efficiency or a sustainable lifestyle, differentiating specific products to open new markets or capture market-share in the green product market becomes the new strategy for companies (EPA, 2015).

In addition, corporates might also get competitive advantages by making commitments of reducing their corporate GHGs including scope 1, 2, and 3 emissions. A strong corporate sustainability commitment can provide investors of a company with a signal of stability as an investment (Kingsbury et al., 2012). As companies commit to reduce the corporate or product GHG footprints, they look to their supply chain partners to align their efforts with the company's sustainability goals (Jeswani et al., 2008).

## 3.3 Supply chain GHGs measurement

The adage "you can't manage what you can't measure" truly holds. When companies commit to reducing their supply chain emissions, the first step is to gain transparency into what those emissions are and where they come from. Viewing a full picture of supply chain emissions allows companies to find the most cost-effective potentials for emissions reduction along the supply chain. However, inventorying supply chain emissions is a complicated task, especially for companies with large, complex, international supply chains.

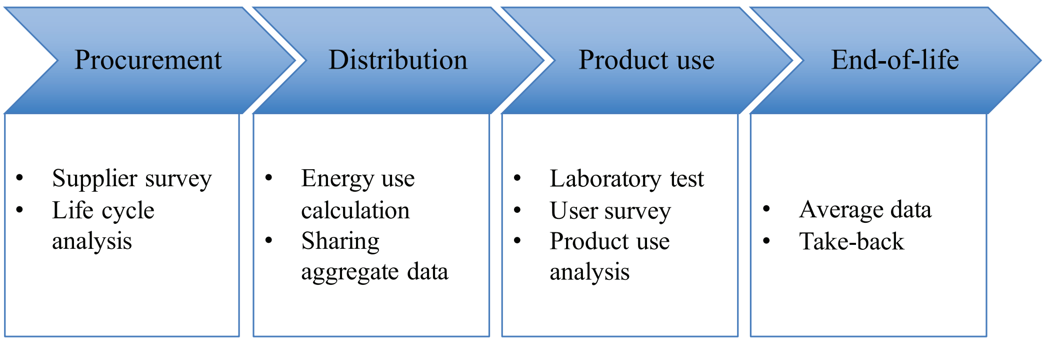


Figure 3-9 Measuring supply chain GHGs

As a result, companies have historically taken a piecemeal approach, quantifying emissions only for certain aspects of their supply chain. While there are several industry-wide or third-party based initiatives to resolve such issues, standards and protocols that tackle the measurement of GHGs, mitigation, and reporting from a supply chain perspective are still in their infancy (Boone et al., 2012). This section introduces some methods for measuring carbon emissions from four supply chain activities and processes as shown in Figure 3-9.

### 3.3.1 Upstream supply chain

Quantifying a company's upstream supply chain emissions or a product's emissions from material acquisition, processing, transportation and production requires significant data collection and analysis of activities beyond the own board of a company (Kingsbury et al., 2012). Supplier surveys and life cycle analysis are most often used in practice as complimentary methods to collect emissions data from the supply chain.

1) Supplier surveys

In practice, supplier engagement is the most direct approach to collect data from suppliers, which is most often accomplished by supplier surveys. Companies may ask their core suppliers (including tier 1, 2, and 3 if possible) to report emissions to them or to the third part such as CDP. The survey is either created by individual companies or the third parties. Beyond quantitative data on Scope 1, 2, and 3 emissions, it also requires qualitative data reflecting the supplier's carbon reduction initiatives.

Survey response rates vary widely in different industries, different relationships with suppliers. In order to increase the response, some leading companies even put environmental purchasing into the evaluation criteria for their suppliers' selection. DELL demonstrates it is possible to achieve 100% response rate by integrating the request into their overall supplier engagement initiative, leveraging contacts from their ISO 14001 program, giving suppliers advance notice, and tracking reporting (CDP, 2011). Dell distributed the survey directly to suppliers so as to affirm the importance of survey and it also inform its suppliers how the survey will affect the decision-making in the procurement processes (CDP, 2011). Besides, companies may use one standard survey or scorecard for the same supplier industry so as to save suppliers' time and cost for responding to different surveys from different producers. It avails suppliers to make a response in this way.

Despite this, collecting data by survey for companies with extensive, complex, international supply chains would be inefficient. Nevertheless, companies using this method to inventory their supply chain emissions are still confronted with the issues of data quality and completeness.

2) Life cycle analysis

Another method of measuring carbon emissions from products' supply chains is life cycle analysis (LCA). In response to the limitation of supplier survey, LCA is one methodological method to complement the data with the company's own database. "LCA is perhaps the key to understanding what makes a "green" product, and ultimately to determining environmental purchasing strategies" (Lamming & Hampson, 1996). There are mainly three approaches of LCA: process-focused LCA (conventional LCA) and economic input-output LCA (EIO-LCA).

The process LCA calculates emissions data directly from activities and processes in the supply chain and requires primary data collection (EPA, 2015). Firstly, it is necessary to set boundaries for analysis based on what data is available or deemed relevant. Secondly, the primary data of material flows is collected from all the stages within the boundary. Finally, emissions are calculated based on emission factors that are assigned to specific activities and processes in the supply chain, for example, the equivalent $CO_2$ emissions from the production of 1 kg of hot rolled steel. Generally, the calculation could be formed in the equation in below.

$$E = Wl * \delta$$

E: Emissions from the activity (ton),
$Wl$: Working load, for example, the working load of transportation could be the weight (kg) multiplying the length of distance (km),
$\delta$: Conversion factor, and they are different for different activities.
The complexity and accuracy of a conventional LCA comes with certain tradeoffs. The analysis requires significant time for completion and a high level of technical expertise.
The EIO-LCA approach uses the entire economy as the system boundary and estimates the general environmental impact from the economic transactions (Bosch, 2011). Since specific processes are not measured EIO-LCA would produce the same result for any type of vehicle while identical products made of different processes would have different LCA results under conventional LCA calculation. A comparison of these methods for supply chain GHGs measurement is listed in Tab 3-2.

Tab 3-2 Methods for measuring supply chain GHGs

| Measuring methods | | Description | Pros and Cons |
|---|---|---|---|
| Supplier survey | | Leading companies ask suppliers to report their emissions data from the upstream supply chain. | ■ Direct and easy to execute<br>■ Possible to be integrated into supplier selection criteria<br>■ Information of all supplying products<br>✓ Suppliers' agreement for involvement and data share<br>✓ Limit to upstream supply chain emissions<br>✓ Time consuming<br>✓ Uncertainty of data completeness |
| LCA | EIO-LCA | The total emissions in economy are allocated to companies according to their sales output. | ■ Low time consuming<br>✓ Reduced accuracy<br>✓ Limited to particular type of product |
| | Process-focused LCA | Emissions are calculated from supply chain activities based on emission conversion factors. | ■ High accuracy<br>✓ Limits of emission conversion data in all activities<br>✓ Time consuming |

Given detailed data for each process, conventional LCA can provide users with complete results on their carbon footprint, and therefore it applies to the users who are in pursuit of fineness and completeness of the results. In contrast, users who is interested in a general picture of the supply chain emissions can refer to EIO-LCA which provides the opportunities to identify emission "hot spots". Given these considerations, scientific researchers may perform a conventional LCA while a business may prefer the EIO-LCA or hybrid approach (Zhong & Zhong, 2013).
Therefore, a common emission measuring standard that provides technics for an accurate calculation of supply chain GHGs should be employed by ETS for all inclusive supply chains. Mandatory measuring and reporting of supply chain GHGs could be the first step before they are included into ETS.

### 3.3.2 Downstream distribution

The production and transportation of goods causes together approximately 45% of all emissions (IPCC, 2007). Global production has additionally contributed to extend the transport distance of distributing finished goods to consumers. Cutting emissions embedded in product delivery is an essential component of greening the supply chain. There are two main methods to measure transport emissions: calculating energy use and sharing aggregate data. The knowledge of a company about the transportation cost and customers' characteristics determines which method a company will choose (Kingsbury et al., 2012).

1) Energy use calculation

The first method relies on process-focused LCA. Fuel use data are firstly collected based on specific transport modes and distances. Emissions produced from each activity could be calculated by integrating the emission conversion factor of each type of fuel. Therefore, each mile driven to ship products around the globe can be attached with a carbon cost.

Since it requires full knowledge of transport modes, distances travelled and fuels used for transport to ensure the completeness and accuracy of the calculation and considering the complexity of most supply chain distribution, quantifying direct emissions associated with each delivery may be inefficient and time consuming.

2) Sharing aggregate data

The second method relies on EIO-LCA by allocating aggregate data which is likely to be more cost-effective. Most often this method applies to the calculation where distribution is outsourced to a third party such as a shipping company or a third-party logistic service provider. A third party provides transport and distribution service not for only one company but for all its customers. The total fuel use of the third party is available. The total emissions are therefore known. When possible, the total emissions could also refer to the Scope 1 and 2 emissions of the third party. Companies can then calculate their share of transport emissions based on net spending or weight occupied and distances travelled (Kingsbury et al., 2012).

Since it requires a high degree of collaboration with shipping and distribution companies, it would be challenging to measure the transport emissions from third-party logistics partners. However, gaining transparency on transport emissions can bring a desired outcome for shipping companies as well because cutting transportation emissions translates directly into cost-reduction through reduced fuel use (Kingsbury et al., 2012).

### 3.3.3 Product use phase

A large portion of Scope 3 emissions can be attributed to product use especially in the consumer-packaged goods (CPG) sector (e.g., IT products, printer, kitchen products). "Unilever has determined that 35% to 68% of the GHG footprint for all their products (not to mention 95% of their water footprint) is emitted during consumer use phase" (Kingsbury et al., 2012). Two main methods are being employed by CPG companies to estimate the GHG associated with product use.

1) User survey

User surveys gather information on consumer's habits and general use. For example, to collect emissions from using a laptop, it is necessary to collect user information such as the working length with the laptop everyday and the frequency of using the laptop. This method could raise awareness among consumers to their actual use habits since reducing emissions in user phase would directly reduce energy use and save energy cost for consumers.

However, this method would often be time consuming and suffer from selection biases and non-response issues. Different consumer has different characteristics and habits in using products. For example, the laptop for office working would usually produce more emissions than the laptop for home entertainment due to the more intensified use. The investigation group should cover as broad types of users as possible in order to avoid selection biases. Designing surveys, distributing surveys, collecting surveys, and analyzing statistics would be challenging.

2) Laboratory testing

The other method, often used during the product design phase, is laboratory testing. Similar to the process-focused LCA, it estimates the energy use and associated emission release per usage of product in a laboratory testing (Kingsbury et al., 2012).

By using this method one quickly realizes the most effective way to reduce the CO2 emitted per usage of product. The laboratory testing can simulate different combinations of usage preferences and therefore can tell that which setting is the most effective one among them in terms of emissions and energy cost. Though it can vary significantly from a real-world setting where consumers' habits affecting significantly the actual performance and resource consumption associated with a specific good, companies can influence consumers' use habits to the most extent by providing this information in the product use instruction.

### 3.3.4 Product end-of-life phase

At the end of a product's useful life, it will be recycled and reused, composted, combusted, or landfilled. Quantifying the amount of GHGs at this step is difficult for an individual company. Companies may focus only on certain sections of this phase. There're two methods available to estimate the emissions depending on a particular recycling rate or average data (Kingsbury et al., 2012).

1) Take-back program

Take-back programs could confirm the recycling rate of a certain product by giving the amount of product sold and the amount of product recycled. Since it is challenging to manage product end-of-life emissions, most companies to-date have chosen to focus on the processes and activities under their control only such as selecting recyclable or compostable materials, reducing packaging amounts, and eliminating hazardous materials from packaging (Kingsbury et al., 2012).

Emissions associated with product end-of-life include those emitted from transportation, logistics activities, combustion and landfill. Take-back program could roughly calculate the emissions related to recycling, and the rest emissions from combustion and landfill might better use average data.

2) Calculation based on the data average

Calculating emissions associated with product end-of-life phase relies mostly on the data average (e.g., aggregate emission data from combustion sites). By giving the recycling rate, either resulted by the take-back program or the local/national average data, the total tonnage of disposable materials remaining after the use phase could be quantified. Then a rough estimate could be calculated by allocating the aggregate emission data from local compost, combustion, and/or landfill sites according to the weight share of disposable materials.

## 3.4 Supply chain GHGs reduction practices

Companies can choose to act in different areas of the supply chain, based on what constitutes the majority of their supply chain emissions as well as where they have the most influence. Many opportunities may be "quick wins" besides creating competitive advantages. The management of GHGs within organizational supply chains is noted in relation to voluntary corporate action on climate change, including product development and process and supply improvement. This section introduces four fields where most companies have analyzed and implemented emissions reduction projects (as seen in Figure 3-10).

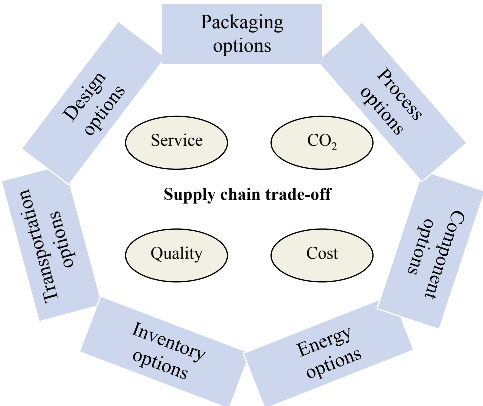


Figure 3-10 Emission reduction potentials in the supply chain
Source: Butner et al. (2008)

### 3.4.1 Product design

Emissions embedded in a product would be undeniably affected by product design which starts from choosing raw materials, selecting production technics, to determining disposing methods. Product design as the beginning phase of supply chain is one essential supply chain GHGs source. Since companies can often get control of this area, product design offers opportunities to create emissions reduction programs including energy-efficient product design and package design.

1) Green product development

There are many methods in designing a carbon-efficient product. Changing and reducing resources and materials that go into final products are common practices for companies to address supply chain GHGs. This method can take direct effects on GHGs reduction by decreasing the use of energy needed during manufacturing.

Other methods include enhancing the recyclability of the resources, decreasing the size and volume of the product, utilizing recycled materials, and simplifying the structure of the product components so that it is easier to be recycled when discarded. By doing so, companies can realize GHGs reduction directly or indirectly throughout the supply chain, from the phases of production, transportation, handling, warehousing, recycling, and use etc. For example, P&G's Tide Coldwater product line is designed to deliver the same amount of cleaning ability, at cold washing temperatures. It saves energy and money for consumers when switching loads to load (Kingsbury et al., 2012).

2) Package design

Another source of carbon management in the product design phase is packaging design. Despite preventing products from damages in the supply chain, packaging contributes to the overall carbon footprint of a product that occurs through shipping and handling. Many companies are targeting packaging improvements as an initial step to address supply chain GHGs, as enhancing packaging efficiency and efficacy are direct without affecting the features of product (Kingsbury et al., 2012). For example, changing packaging materials would possibly lighten the overall packaged product; incorporating recyclable materials into packaging promotes more environmentally friendly discards of packages. Since the amount of GHGs from transportation and logistics activities are related to the weight and distance of processed goods, the same amount of lighter packaged goods could reduce GHGs from goods delivery. Recyclable packages allow multiple turns of use and reduce GHGs by avoiding manufacturing extra packages. Philips switched to recyclable packaging for its Essence toothbrush (reducing cardboard amount from 160g to 140g and plastic amounts from 60g to 2g) gaining both environmental and cost-savings benefits (Kingsbury et al., 2012).

### 3.4.2 Supplier engagement

Indeed, approximately 85% of all industrial energy use occurs in basic material manufacturing (IPCC, 2007). Engaging suppliers is the most common way for companies to increase transparency in their supply chain GHGs, beginning often by collecting emission data from suppliers by survey (Kingsbury et al., 2012). The survey could either be individually designed by the focal company or standardized by a third-party institution. Companies will analyze the reported data and make decisions on the further supplier engagement in supply chain GHGs reduction. Depending on the relationships with the supplier, companies can choose between changing suppliers, compelling suppliers, collaborating with suppliers, and collaborating with industrial partners to force suppliers.

1) Supplier's selection

Given multiple alternative suppliers, a high leverage over any single supplier enables the company to select and deselect suppliers based on suppliers' reported data (Kingsbury et al., 2012). If the company (e.g., PepsiCo, Intel, Kimberly-Clark) has supplier relationships where it is the major customer for some of their strategic suppliers, it is able to compel those suppliers to improve their GHG management (EPA, 2015). In the case of complex supply chains, companies might focus on core suppliers who have great influences on economy or on emissions. By doing so, it attracts attention from the upper level of management and thus improves suppliers' environmental performance.

As a common practice, companies could put environmental initiatives as one critical element into supplier selection criteria or supplier scorecard to rate suppliers. For example, suppliers have to measure and report their carbon emissions directly to companies or to other third party organization such as CDP. Such report could include either quantitative data of emissions or qualitative data describing suppliers' engagement in emissions reduction such as setting emissions reduction targets, implementing emissions reduction projects, and tracking progress, etc. Companies could put a weight for each green criterion and make decisions according to the final results of evaluation.

Walmart and Procter & Gamble (P&G) have started implementing the supplier sustainability scorecards. Walmart is adjusting its overall procurement practices by shifting the order quantity to greener suppliers (Plambeck, 2012). For example, Walmart allocates private brands business among tier-1 suppliers by using the information that suppliers provide on emissions and emission reduction efforts. P&G used the sustainability scorecard to rate targeted suppliers according to the tracked information on energy use, water use, waste disposal, and GHGs on a year-to-year basis (Plambeck, 2012).

2) Collaboration with suppliers

Alternatively, if a company (e.g., IBM) whose spend does not constitute a significant portion of a supplier's revenue, has less leverage or influence over its suppliers, it may choose a joint carbon management approach to implement emission reduction program (Kingsbury et al., 2012). This joint approach could be reflected by cost share/financial support, technical support, contract extension, or any other joint efforts.

Some initiatives suppliers take could not only reduce emissions but also save cost. In this case, it would give suppliers motivation to do so. In other cases, suppliers would probably hesitate to do so due to the increasing cost incurred by emissions reduction. The cost would also partially be passed through to the companies who are asking for emission abatement. In this case, the companies could adopt efforts like extending contract length and volume to strengthen the motive of suppliers in emission reduction and get rid of cost pass-through. For example, "Walmart will typically commit to purchase a larger quantity over a longer period of time, as opposed to paying a higher price per unit" (Plambeck, 2012).

In addition, companies can provide environmental training programs to suppliers, introducing energy efficient technologies to suppliers, and informing suppliers other emissions reduction measures, etc. Such initiatives could not only improve the awareness of suppliers about their own GHGs, but also provide suppliers technic support to realize their GHGs reduction. "Training and capacity building for supplier are critical components of a customer-supplier relationship built around the goal of managing GHGs" (Kingsbury et al., 2012). Companies can also create standing team to provide technical assistance to suppliers. For example, through global sustainability summit, on-site training sessions, and webcasts, PepsiCo provides training resources which can be shared by suppliers as suppliers' own capacity (EPA, 2015).

3) Collaboration with industrial partners or third parties

If a company has only a little influence on its suppliers, the company may partner with other companies that working with the same suppliers to increase their collective impact based on shared influence (Kingsbury et al., 2012). This is the case when a company composes only a small part of its supplier in terms of purchasing capacity. For example, the dying process in the apparel supply chain of Walmart creates substantially negative environmental outputs, but even dominant buyers such as Walmart, Nike, and Levi-Strauss typically account for only a small fraction of the business for a dye house. Therefore, Walmart is beginning to collaborate with other multinational buyers to jointly motivate suppliers to improve their environmental performance (Plambeck, 2012).

In addition, some third parties that have interests and expertise in reducing GHGs have designed standardized GHGs reduction programs such as EPA's ENERGY STAR, SmartWay, and Green Suppliers Network. Employing the standardized programs by collaborating with third parties can build supplier capacity in managing GHGs and improving energy and fuel efficiency (EPA, 2015). The success of Walmart's sustainability strategy stems from the collaboration with third parties as well. Starting in 2005, environmental nonprofit organizations, academics, suppliers and other stakeholders are invited to scrutinize the environmental impacts of its extended supply chain and offer suggestions for performance improvement (Plambeck, 2012). "The Environmental Defense Fund and Business for Social Responsibility, for example, are working with 200 of Walmart's highest-impact suppliers in China to reduce their energy intensity by 20% by 2012 (relative to a 2007 baseline)" (Plambeck, 2012). These nonprofit organizations primarily provide information – helping suppliers to see how to improve their energy efficiency.

### 3.4.3 Green logistics and transportation

Transportation sector takes up 20% emissions in all industry emissions, becoming the second emission sources after manufacturing industry (IPCC, 2007). Academic researchers and practitioners have made lots of efforts in this area to reduce GHGs. Generally, this section provides some main approaches adopted so far in both practical and theoretical areas in reducing GHGs from logistics and transportation activities.

1) Multi-mode transportation

Carbon intensity (expressed as $gCO_2$ per tonne-km) varies widely between transport modes (Figure 3-11). Shifting freight from modes with relatively higher carbon intensities, such as air and road, to those with much lower carbon emissions, such as rail and water-borne services, can substantially decarbonize freight transport operations.

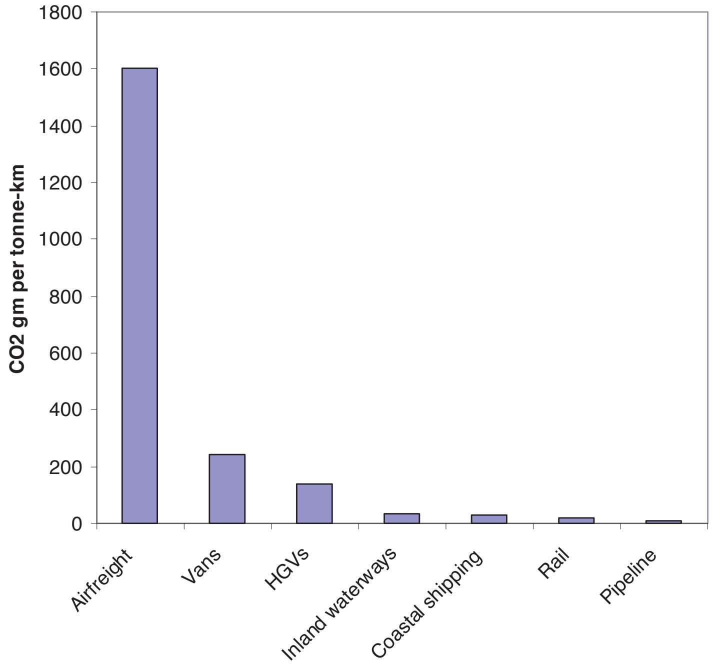


Figure 3-11 Variations in the carbon intensity of freight transport modes
Source: McKinnon (2010)

However, different transportation modes are characteristics of different service levels such as delivery time and safety. Transferring from transportation modes with high carbon intensity to transportation modes with relatively low carbon intensity would probably put companies at risk of failing in fulfilling customers' need. A proper combination of different transportation modes would be the best solution in the economy stepping from the traditional market to the low emission market. For example, given one route, a truck-shipping-truck transportation program would not only reduce emissions but also save cost compared to a truck-only program.

But this multi-mode transportation has certain limits. Firstly, the availability of ocean, inland-river, or rail tracks is the prerequisite. Without such facilities, it is impossible to realize a multi-mode transportation and especially it should be achieved within a certain expenditure of cost and time. Secondly, a freight village or logistics center is needed to provide the transferring. The cost of building new logistics center or detouring through an existing center should be assessed.

2) Ship consolidation

Gucwa & Schäfer (2013) found that transportation load per vehicle is the key variable affecting energy efficiency for ships, trucks, and rail (and the second most important factor for air, behind stage length). Their empirical analysis show energy efficiency increases as that load increases. However, as just-in-time concept and other zero-inventory policies develop, transportation is completed in smaller loads with higher frequency to improve customer service level and reduce the bullwhip effect on inventory along supply chain. Although these initiatives often reduce inventory and realize a high service level, it also increases the cost and carbon emissions incurred by transportation (see Figure 3-12).

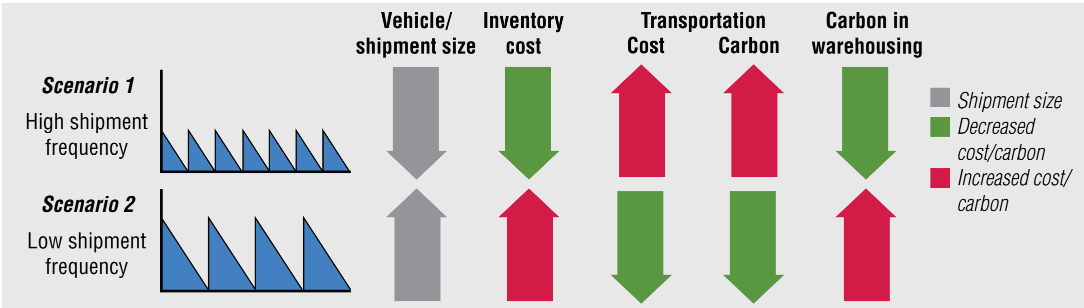


Figure 3-12 Carbon's impact on shipment scenarios
Source: Butner et al. (2008)

Vehicle loading can be improved with a broad range of measures. These include ship consolidation (McKinnon A. C., 2005), back-loading improvement (McKinnon & Ge, 2006), the use of space-efficient handling and packaging systems (Kearney, 2011), and the adoption of specific delivery timetables. Improving the loading of vehicles reduces energy consumption and carbon emissions by reducing the amount of traffic needed to move a given quantity of freight. To reach high levels of vehicle loading, firms can not only batch multiple types of products or components from its own business, but also share vehicle capacity with other companies to achieve large shipment sizes and full vehicles.

By pooling shipments from multiple firms, third-party logistics service providers have the potential to achieve fuller loads and therefore increase the loading of vehicles. Kelloggs and Kimberly-Clark have saved jointly around 430,000 vehicle-kms per annum by working with TDG, their logistics service provider in the UK (McKinnon A. C., 2010). They coordinate their transport due to similarly low density products and complementary transport demands. Besides reducing the costs and emissions associated with transport, collaborating with third-party logistics service providers might enable firms to mitigate the bullwhip effect through making more frequent and smaller orders.

3) Supply chain network optimization

As global economy rapidly develops, companies are increasingly sourcing from abroad. Sourcing from distant but energy-efficient suppliers would bring reduction in production-related $CO_2$, however, the benefit could possibly be dwarfed by the long freight hauls (see Figure 3-13). Local sourcing and decentralized distribution would reduce freight transport costs but increase the aggregate emissions from construction by building many local production facilities. Moreover, local sourcing might increase the inventory and production capacity to meet variable local demand.

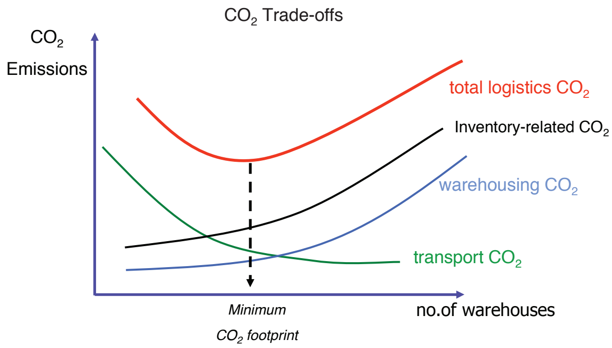


Figure 3-13 Optimizing the number of warehouses in logistics system with respect to $CO_2$ emissions
Source: McKinnon (2010)

To determine the net carbon impact it is necessary to conduct a logistical trade-off analysis under different supply chain configurations, similar to those applied in the economic optimization of logistics systems, but now recalibrated with respect to CO2 emissions (Wang et al., 2011; Tseng & Hung, 2014; Pishvaee & Razmi, 2012; Sheu et al., 2005). By scrutinizing the entire supply chain, Walmart can identify opportunities to rationalize the supply chain to reduce costs and emissions (Plambeck, 2012).

4) Freight village

Freight Village (FV) initially emerged in Japan called "Distribution Park", which largely developed in Europe generally named "Freight Village" (Wu & Haasis, 2011). To date, most common "FV" is understood as distribution center (DC), transport node, logistics center/platform, and distribution park etc. "A FV is a special intermodal hub (nodal point) in the transportation system connected to transportation, logistics and distribution in established geographical coverage, and it includes different logistics facilities, where separate operators are providing number of services," (Rimienė & Grundey, 2007). Activities that occur at FVs are related to transshipment, handling, and administrative operations, storage and goods distribution (Ballis & Mavrotas, 2007).

Most of the GHGs reduction initiatives in transportation have to be completed with the functions provided by a FV. Multi-mode transportation needs nodes where transshipment can be implemented. FVs are regarded as the principal component of the logistics system where the transshipment of goods from one mode to the other takes place (Tsamboulas & Kapros, 2003). Shipment consolidation takes place in the position where such logistics services are available. Besides providing logistics services such as handling, storing, loading and unloading, etc., a FV takes one essential role in optimizing the supply chain network.

In addition, the concept of FV plays an important role in pursuing a sustainable logistics industry since FVs are able to deal with the environmental problems and economic limitations related to long-distance and regional freight traffic (Wu & Haasis, 2011).

5) Decarbonizing warehousing

Decarbonizing warehouses would benefit from decarbonizing electricity generation because warehouses are mainly electrically operated. Keeping the lights on incur fixed emissions even when underutilized. Warehouses with a controlled temperature create emissions along with inventory. Carbon reduction measures that can be applied to individual warehouses include good insulation, airtight construction, using energy-efficient lighting systems, using daylight, etc. "The warehouse developer Prologis has designed a prototype distribution center and achieved a 69 per cent reduction in operational carbon and energy compared with a typical UK warehouse" (McKinnon A. , 2010).

It is also possible to install wind turbines and solar panels to generate renewable energy locally. In

addition, as the refrigerant gases used in temperature-controlled warehouses can have a global warming potential that is thousands of times higher than that of $CO_2$, to minimize the leakage of these gases from refrigeration systems across the supply chain is another way to reduce warehouse emissions (McKinnon A. C., 2010).
Last but not least, another GHGs source in warehouses are the handling equipment. To improve the energy efficiency of the equipment would contribute in decarbonizing warehouses.

#### 3.4.4 Consumer engagement

Consumer education often plays a big role in a successful supply chain GHGs reduction strategy (Kingsbury et al., 2012). "Providing consumers with information on a product's proper use and disposal options has become another benchmark in measuring a company's commitment to reduce its GHGs" (Kingsbury et al., 2012). Some strategies companies take to educate consumers are introduced in following.

1) Labeling product

Multiple carbon labeling schemes are being developed by organizations such as Carbon Trust and Carbon Fund, and governments such as those in France and the state of California. Since few companies are currently reporting product footprints, the company that is labeling products can attract the green market. Consumers are able to compare the carbon footprint of two similar products from the same company and learn why they are different. In the future, it might be possible for consumers to compare similar products from different companies when companies adopt the same standard to account supply chain GHGs. This is the ultimate situation where companies are competing with each other in providing low-carbon products.
Walmart has the highest associated supply chain GHGs in apparel product, approximately half of those emissions occurring in the customer use phase – i.e., washing and drying (Kingsbury et al., 2012). Changing labeling on clothes from "hot water wash" to "cold water wash" will substantially reduce emissions along with electricity use.

2) Sales and marketing

When a company's sales shift from higher to lower-carbon products, total supply chain GHGs are reduced (Kingsbury et al., 2012). The sales and marketing departments can market low-carbon products aggressively with the use of product-level carbon footprint. Given the carbon footprint data of similar products, it is possible to use them directly in marketing initiatives, through either environmental product declarations or carbon certification and labeling. As a result, it reduces GHGs through promoting the low-carbon products over others.

## 3.5 Barriers

The corporate sector is becoming more sophisticated in its treatment of climate change by moving beyond assessing the GHG impact of their own operations and toward a more comprehensive assessment of their GHG impacts along their value chain – both in the products they buy from suppliers (upstream) and in the products they sell to customers (downstream) (GHG Protocol, 2010). However, a survey of executives found that less than a quarter has acted (Brickman & Ungerman, 2008). Current engagement with this area of supply chain management is restricted to accounting and reporting (Ihlen, 2009).

Managing emissions from the supply chain involves participation from multi-firms along the supply chain and it is especially difficult with complex, international supply chains. Barriers addressed in literature are listed in Tab 3-3. This section explains some key barriers for companies to manage their supply chain GHGs and these barriers could be seen through all sectors and industries.

Tab 3-3 Overview of barriers for corporates to manage their supply chain GHGs

| Category | Barrier | Literature |
|---|---|---|
| Internal | High cost and lack of financial resource | (Jeswani et al., 2008) (Lee, 2012) (Sullivan, 2010) (Walker et al., 2008) |
| | Lack of awareness | (Jeswani et al., 2008) (Lee, 2012) (Sullivan, 2010) |
| | Supply chain collaboration | (Zhu & Sarkis, 2006) (Wycherley, 1999) |
| External | Absence of regulations and policies | (Jeswani et al., 2008) (Okereke, 2007) (Lee, 2012) (Sullivan, 2010) |
| | Low-availability of technology and lack of expertise | (Jeswani et al., 2008) (Lee, 2012) (Sullivan, 2010) |

### 3.5.1 Lack of awareness

To combat climate change, corporates and individual consumers need to have a common awareness that GHGs have to be reduced from the worldwide scope and they can take an essential role to reach this objective. Although this consciousness is raised somehow along with the international climate actions, it becomes dwarfed in front of profit and cost in the business world and in individual decisions as well.

Although there exist some low hanging fruits for companies to take at the early stage of emission management, the cost of abatement measures differs in different companies. Emission abatement-incurred costs are more significant for Small and Medium-sized Entrepreneurs (SMEs) which have generally less resources available and thus are more vulnerable (Hervani et al., 2005).

"Costs can function as a barrier especially if people act with the fixed trade-off in mind of ecology versus economy" (Porter & Van der Linde, 1996). Thinking in this way, companies might prefer to quit in GHGs reduction projects without even trying to seek for possible abatement measures, although there could in fact still exist some ideal measures or some measures bringing long-term benefits. In a weak global economy, performance and cost are still the primary considerations for business customers and end consumers. An investigation in US firms revealed that cost concerns are the most serious obstacle for customers to take green purchasing practices (Min & Galle, 2001). The management of supply chain GHGs might be inhibited by the consumer desire for lower prices (Orsato, 2006).

"The business gains of sustainability-based differentiating will only increase as more customers, investors, NGOs and the media take an interest in comprehensive corporate and product carbon footprints" (Kingsbury et al., 2012).

### 3.5.2 Shortage of professional knowledge

The shortage of sustainability professionals composes the major barrier to the pursuit of profitable energy-efficiency projects, particularly in China, i.e., lack of people with the right information and required expertise necessary to undertake those projects (Zhu & Sarkis, 2006). Although some big companies such as Walmart and IBM have started managing their supply chain GHGs, there's still no standard for companies in each industry and sector to follow. How to set emissions reduction boundaries and feasible targets? What kind of emissions abatement measures can be adopted in the supply chain? How to involve company employee into SCCM? More questions remain to be answered.

It is difficult and time-consuming to develop appropriate metrics and labels for each type of products. Companies must choose their approach based on the type of data availability, the cost and time of data collection, and their business goals. However, this would in turn result in the incomparability between different suppliers' carbon emissions. It means, even when supplier footprints are available, these data cannot be easily compared due to differences in the methodologies, boundaries, and data quality provided by suppliers inventorying their emissions.

Standards developed by some private institution have enhanced the voluntary accounting and reporting of supply chain GHGs, but they cannot act as any guidance or instructions for companies to reduce supply chain GHGs. Practical GHGs reduction ideas and projects have to be incorporated and implemented in corporate strategic, tactical, and operational levels.

Full knowledge of environmental impacts on supply chain performance is needed. As aforementioned, the trade-off in the supply chain are no longer just about cost, service, and quality – but cost, service, quality, and carbon emissions. Some mathematical optimization models from the field of operational research might be referred for advice. Although common optimization models are applied, there's no fixed pattern for all supply chains to reduce emissions and cost while increasing quality and service. Since different companies have different internal strategies and market orientation, the best practice from other experienced companies have to be adjusted before application. To reach the balance of this trade-off, companies have to look into their own specific network and find the best solution.

### 3.5.3 Supply chain collaboration

Managing supply chain GHGs needs participation of multi-firms in the supply chain (Boone et al., 2012). In order to capture full supply chain emissions, corporates ask their suppliers at all tiers of the supply chain through survey to measure their Scope 1 and 2 emissions and report this data back, and this is a daunting task to accomplish in complex, multi-tier international supply chains. Survey response rates vary widely, with the Electronics Industry Citizenship Coalition (EICC) reporting a 26% response rate to its 2009 supplier survey compared to IKEA reporting a 70% response rate in 2010 (Kingsbury et al., 2012). In addition, measurement of third-party transport emissions can be a challenging task and requires a high degree of collaboration with shipping and distribution companies.

Even if firms agree on how to report emissions, there're challenges in assigning reduction targets for each supply chain partner, and if any, sharing the benefits of joint sustainability programs (Boone et al., 2012; Benjaafar et al., 2013). For example, cutting transportation emissions translates directly into cost-reduction through reduced fuel use. Supply chain partners need to agree on proper mechanisms for the responsibility assignment as well as the profit allocation. In reality, a leading company, so-called the focal company often acts the beginning of supply chain GHGs management (Long & Young, 2016). These allocation mechanisms are essential to ensure the active participation of its supply chain partners into emissions abatement programs.

### 3.5.4 Lack of policy and regulation

"Though the potential for companies to profitably reduce emissions is substantial, without effective climate policy it is insufficient to avert dangerous climate change" (Plambeck, 2012). As population and consumption continue to grow, even firms do everything right (i.e., reduce the carbon-intensity and energy-intensity of their operations to the maximum extent) the overall emissions are likely to remain high (Plambeck, 2012). Without effective climate policy, it is difficult to imagine a huge reduction in all emissions associated with the business worldwide in the near future, despite the substantial emissions reduction achieved with leading companies' strategies.

"The environmental impacts of life-cycle products could be best managed through goal-oriented and market-based mechanisms like cap and trade that provide flexibility in choosing compliance levers to the targeted firms or industries" (Gupta & Palsule-Desai, 2011). "With such policy, it is conceivable that companies like Walmart or its suppliers or customers might be allowed to sell offset credits for emissions reductions that are measurable and additional (not profitable without the offset credit)" (Plambeck, 2012).

However, policies for carbon emissions control so far are either industry/sector-oriented or geographical-restricted. No policy is designated to target supply chain GHGs from material extraction, production, and transportation as a whole. The UK government is required to introduce mandatory GHG reporting in contrast to voluntary corporate reporting through organizational sustainability reports. A consultation was launched outlining several options, including the inclusion of supply chain (scope 3) GHGs. However, there were excluded from new reporting requirements, which cover only scope 1 and 2 (Defra, 2011). Policies that induce companies to internalize the social cost of carbon such as cap and trade are needed to avert dangerous climate change (Plambeck, 2012).

## 3.6 Summary

This chapter introduced the concept, drivers, practices, and barriers of supply chain GHGs management. Combating climate change cannot afford neglecting the contribution of supply chain GHGs management. Supply chain GHGs management is accurately one branch of GSCM but it narrows the focus only on GHGs along the supply chain. This supply chain approach has the potential to find significant emissions reduction opportunities and large financial benefits. It can help individual companies to understand the carbon emissions across their supply chains and allow them to prioritize areas where further reduction in emissions can be achieved. Managing supply chain GHGs effectively can avoid damage to brand value, exposure to energy price volatility and lack of preparedness for complying with carbon regulations.

Supply chain GHGs management practices are so far only related to voluntary actions of companies. For example, reporting Scope 3 emissions to registries such as the CDP has been optional and there has been no inventory standard. Private and public institutions have designed some tools for supply chain GHGs management, but it is still in an infancy stage. In addition, supply chain GHGs management requires a close collaboration among supply chain partners by sharing data and information. Without proper regulations and technic supports, it is difficult to make a great progress from the current status.

# 4. Supply chain emission trading programs

To combat climate change cannot neglect the contribution from corporate communities in GHGs reduction. The awareness of leading companies on environment would influence how they manage their supply chains and do business. Regulating these companies might be more cost-effective to result in a rapid and broad scale of GHGs reduction from current atmosphere. Emission trading is becoming the focal point of environmental policies in worldwide nations to reach the newly agreed Paris emission reduction goals. Corporates from every corner of the world are motivated to take voluntary measures of GHGs reduction and these reduced GHGs units could be transferred among corporates. This chapter provides a thorough literature review of previous work in addressing emission trading in the context of supply chain. In addition, it proposes several programs for supply chain GHGs management under emission trading, including supply chain permit program, supply chain credit program and supply chain offset program. Furthermore, one case from the company HP is analyzed to verify and compare the cost-effectiveness of each program.

## 4.1 Literature review – employing emission trading in the context of supply chain

### 4.1.1 Literature review

Although there's so far no policy explicitly targeted on supply chain GHGs, researchers have started analyzing the impacts of different economic policies such as carbon tax, cap, cap and trade, etc. on supply chain performance in terms of supply chain cost and emissions. This section reviews the nascent academic literature from the field of operations and supply chain management that explicitly internalizes the social cost of GHGs.

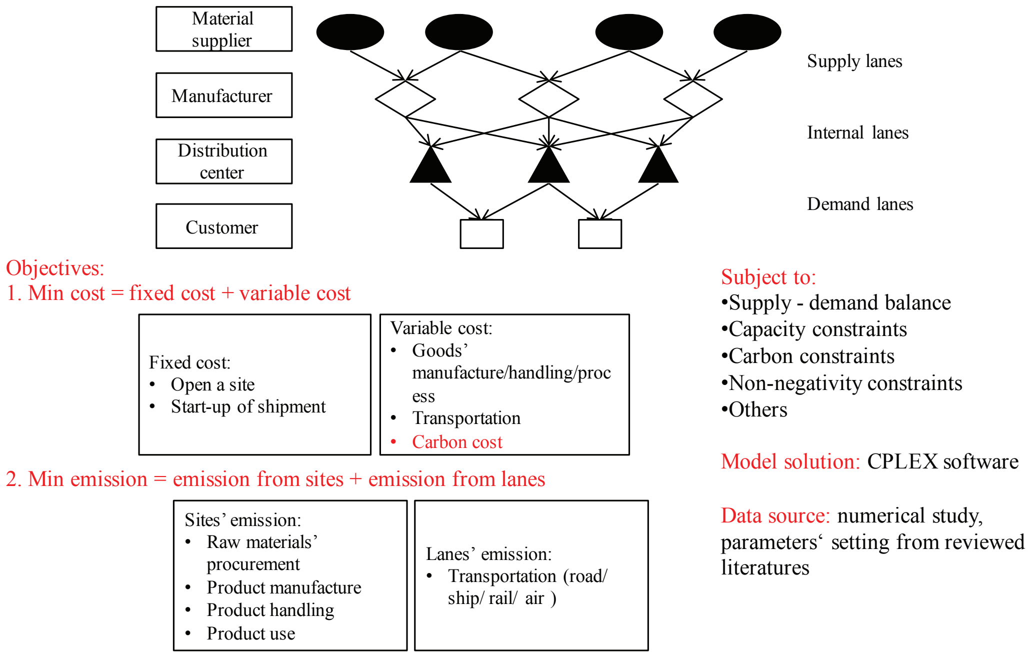


Figure 4-1 Mathematical model used in literature

Most literatures address the extent to which carbon-pricing policies will reduce emissions by optimizing supply chains from strategic, tactical, and operational level. The method is either to design a supply chain through choosing transport modes, production facilities, processes, and materials (Figure 4-1), or to decide an optimal inventory-order level to minimize the total cost of meeting demand from multiple regions. Both methods could easily incorporate the cost associated with GHGs to suggest how best supply chains can be reconfigured to account for climate concerns. This section introduces some selected literature in detail as followed.

Ramudhin et al. (2010) employ a mixed integer mathematical model formulation for the carbon caped-supply chain network design. The supply chain under consideration is regulated under a cap, and it has to purchase extra permits from the emission market with a certain price when its whole emissions exceed the cap. GHGs are limited to $CO_2$ emissions due to production and transportation activities. This model is applied in the case of a steel product manufacturer and the optimal solution indicates a cost breakdown where emission cost takes up 6% and transportation cost takes up 40% of the total logistics cost. Beside, this paper employs goal programming to determine the best trade-offs between two conflicting objectives: minimizing total logistics cost and minimizing total carbon emission. It provides decision makers with the ability to evaluate different strategic decision alternatives, such as supplier and subcontractor selection, product allocation, capacity utilization, and transportation configuration, by illustrating their impacts on carbon emission and logistics cost. Using the model, supply chain managers are able to view the overall GHG footprint of supply chain operations.

Based on the work of Ramudhin et al. (2010), Chaabane et al. (2011) apply the same model to address sustainable supply chain design problems where technology acquisition is considered in the design phase. In this study, emission is also limited to $CO_2$ caused by production and transportation activities. Emission factors are different according to different technologies adopted in production and different transportation modes. They consider environmental regulations in the form of GHGs cap, and a wide choice of compliance options including internal strategic mechanism (e.g., supplier and sub-contractor selection, technology acquisition, transportation configuration) and external mechanism (i.e., ETS). This work introduces the definition of average abatement cost according to the results in scenarios of cost minimization and emission minimization. It is the average cost of reducing one tone of $CO_2$ from the current situations and equals to differentiation of emission divided by differentiation of cost from two scenarios. The proposed approach helps supply chain managers to evaluate the average abatement cost as a function of carbon emissions reduction targets.

Chaabane et al. (2012) extend the model presented in Ramudhin et al. (2010) by considering LCA principles in addition to the traditional material balance constraints at each node in the closed-loop SC (CLSC). It also distinguishes between solid and liquid wastes, as well as gaseous emission due to various production processes and transportation systems. This framework is used to evaluate the tradeoffs between economic and environmental objectives under various cost and operating strategies in the aluminum industry. The results show that ETS must be strengthened and harmonized at the global level in order to drive a meaningful environmental strategy. Moreover, this model demonstrates that efficient carbon management strategies will help decision makers to achieve sustainability objectives in a cost-effective manner.

Bing et al. (2015) use integer programing approach to model a reverse supply chain network problem for household plastic waste where ETS is functioned as a policy instrument for controlling emissions. The case considered in this paper collects and sort household plastic waste from Europe sites, and transports them to China via seaway, and finally deliveries to China customers. The wastes are either processed in Europe plants under the EU ETS or in China plants regulated by the China ETS. A cap is set on the total amount of GHG that can be emitted by all re-processors in zone Europe and zone China and Trade can only happen between re-processors within the same zone. The network is optimized by allocating intermediate reprocessing plants from Europe to China under emission trading restrictions. Chinese processors have 10% less processing cost than European processors. Re-processors in China and Europe have the possibility of achieving the economies of scale and reduce the emission per kg of plastic waste processed. Optimization results show that global relocation of re-processors leads to both a reduction of total costs and total transportation emissions. ETS applied to re-processors further helps reduce emission from both re-processing and transportation sectors.

Fahimnia et al. (2013) determine a unified optimization model for a CLSC in the tactical-operational level in which emissions from both nodes and links are taken into account. The CLSC in this model is composed of manufacturing plants, warehouses, recycling centers, and disposal centers. In each plant, they assume different machine centers work there on different products in different efficiency of cost and emission. Moreover, different transportation modes are considered to take responsibility of freight move. They apply this model to an Australian company running textile products under carbon pricing policies (at a fixed carbon price at the first three years). Numerical results show that with carbon price increases, carbon emissions from all of production, forward distribution, reverse logistics, and transportation decrease and cost from all increases. Manufacturing emissions account for the most of all emissions, with forward supply chain emissions, reverse supply chain emissions, and transportation emissions as followed. From a sensitive analysis, it also certifies that when carbon price increases, reverse supply chain would realize a larger emission improvement and induce a higher cost than forward supply chain. Findings indicate that firms need to consider on which operations and which level of scope of the carbon pricing do affect when they design and determine their carbon footprint. In addition, government may need to subside the reverse SC-induced carbon cost in order to reduce supply chain carbon footprint.

Abdallah et al. (2010) develop a mixed integer programming (MIP) for the carbon-sensitive supply chain that minimizes emission through the supply chain by taking into consideration green procurement. Emissions are considered from raw materials, shipping, plant, and DC. Greener raw material from a greener supplier calls for higher price while it contributes to lower supply chain emission. Authors generalize three scenarios in the model considering zero emission cost, 100$ carbon cost, and minimum emission. They use the model to find the best supply chain layout as well as capacity. In addition, LCA is employed to compare the derived three optimal supply chain sets in one case company responsible for assembly and distribution of PC. The result shows that greener supply chains, where the embedded emission in the procured materials dominate the total emission, tend to be decentralized with smaller facilities because emission from transportation are reduced. What's more, this paper indicates that heavy manufacturing industries should focus on greening their supply chain by greening their internal activities and transportation through investment into green technologies. And end-use product supply chains should shift to focus more on green procurement, where suppliers are not only chosen based on prices and quality but also their environmental footprint.

Diabat & Simchi-Levi (2009) formulate a MIP to optimize a carbon capped- supply chain network. Accurately it solves a two-level multi-commodity facility location problem where emission from production plants, warehouse, and transportation are taken into account. Especially, the amount of emission from warehouses is proportional to the volume of warehouses and the emission amount from plants is proportional to the power consumption of these plants. Experimental analysis result show that as the cap increases the total cost (fixed cost and distribution cost) decreases and the cost saving comes mainly from fixed location cost. Distribution cost may increase as the cap is raised due to a large size of solution space for the integer programming equations.

Jaber et al. (2013) develop a mathematical programming problem by considering emission trading, carbon penalty, and carbon tax, as a joint production-inventory policy, in a two-level (vendor–retailor) supply chain model. Firms choose the manufacturing rate by minimizing the total supply chain cost including production-inventory induced cost and different carbon policies induced emission cost. GHGs are assumed from manufacturing processes and are a function of vendor's production rate. A coordination mechanism is presented by introducing a coordination multiplier. Numerical study results show that the total supply chain cost is a concave function of the production rate. Other productions rates lower or higher than the optimal rate would increase supply chain cost as well as emission cost. In addition, a policy that considers a combination of carbon tax and emission penalty is found to be the most effective one, as the optimal solution generated is usually associated with low emission. Moreover, the results indicate that coordination between vendor and retailer saves supply chain cost up to 8% without significantly increasing the emission amount/cost. The reduction is in inventory-related cost. The developed model could be found useful by mangers who wish to jointly minimize the inventory-related GHGs of their supply chains when penalties for exceeding emission limits are considered.

Benjaafar et al. (2013) address SC emission concerns by adjusting operational decisions with regard to procurement, production, and inventory management, and by improving collaboration among supply chain partners. Through the application of simple lot-sizing models under various scenarios, they find out firms could effectively reduce their carbon emission without significantly increasing their costs by making only operational adjustments and by collaborating with other members of their supply chain. Besides, they show that the presence of emission regulation, especially cap and trade, can significantly increase the value of supply chain collaboration. The most important is, imposing supply chain-wide emission cap is more cost-effective than individual cap installation on each firm and it also increases the value of collaboration. Moreover, it could increase the cost and emission of those firms left out from collaboration.

According to Chen et al. (2011) imposing even a small tax on GHGs will motivate changes in procurement, inventory management, and the size and location of production facilities that significantly reduce emissions. They consider three classic models of operations management. First, in the "economic order quantity" model, a firm has a constant rate of demand and chooses an order quantity and frequency. Its objective is to minimize the average cost rate, including a fixed cost per order, a cost per unit ordered, and a holding cost per unit inventory per unit time. In the second, "newsvendor" model, a firm chooses a quantity (which may represent manufacturing capacity or an inventory level) to meet uncertain demand. The objective is to minimize expected cost, assuming a constant per unit cost for both overage (when the chosen quantity exceeds demand) and underage (when demand exceeds the chosen quantity). In the third, "facility location" model, the firm chooses the number of production facilities to serve demands that are uniformly distributed over some geographical region. The firm incurs a fixed cost to open a production facility, and a transport cost per unit of product per unit distance from the nearest facility to the demand. In all three models, the objective function (cost) is remarkably flat for a wide range of the decision variables around the optimal solution. However, emissions are sensitive to the decision variable, which implies that emissions can be substantially reduced at little cost. Hence even a small carbon tax should substantially reduce emissions associated with such operations.

Zakeri et al. (2015) apply the mixed integer-linear programming (MILP) to optimize forward supply chain design under two regulations：carbon tax and emission trading, and compare these two policies given implications from supply chain performance. Results tell that both policies could influence supply chain costs or emission reduction. Carbon trading scheme appears to result in better supply chain performance in terms of emission generation, cost and service level, while a carbon tax may be more worthwhile from an uncertainty perspective.

Jin et al. (2014) investigate the impacts of three carbon policies: carbon emission tax, inflexible cap, and cap-and-trade on a major retailer (i.e., Wal-Mart) in terms of supply chain design and transportation modes choice (truck, rail, or waterway). In this paper, the retailer is assumed to be in charge of carbon emission from the whole supply chain nodes and processes, for example manufacturing emission from sources and transportation emission from freight distribution. Experimental results indicate that supply chain setting under cap-and-trade scheme derives the best supply chain performance among others. Sensitivity analysis shows that all policies could influence supply chain emission and cost, and to choose policy parameters is critical to the effectiveness of a carbon policy.

Drake et al. (2015) develop a two-stage, stochastic model to analyze the impact of two regulations: cap and trade and emission tax on firms from heavy industry. They take two alternative technologies as compliance strategies into consideration and choose the capacity for each technology as well as decide production quantities through comparing the technology shares, expected profit, expected emission, and expected production under two regimes. Results indicate expected profits are greater and expected emissions are lower under cap and trade, while expected production is greater under an emission tax.

Long & Young (2015) explore several intervention options to enhance the management of supply chain GHGs in the UK by collecting data from individuals within supply chain leading organizations attempting to manage supply chain GHGs. Several intervention options are created from interview. As a result, economic regulations are prioritized among others. They are supply chain GHG taxation scheme, supply chain GHG trading scheme and supply chain GHG credit scheme. Supply chain GHG taxation scheme and supply chain GHG trading scheme are connecting of tax liabilities to supply chain GHGs, or their inclusion in cap and trade scheme. A supply chain GHG credit scheme means the leading organizations work with suppliers to reduce their GHGs can get credits that could be in turn used as additional permits in existing ETS, e.g., the EU ETS.

### 4.1.2 Findings from literature

Selected literature is summarized in this section (Tab 4-1). Main findings from literature review are listed as followed.

Tab 4-1 Overview of selected literature

| | Authors | Field | Methods | Contributions |
|---|---|---|---|---|
| 1 | Jaber et al. (2013) | Production – inventory management | Mathematical programming | The vendor is subjective to ETS and considers only production emission. It introduces two compliances: manufacturing rate and coordination multiplier, and linking them with total supply chain cost. |
| 2 | Ramudhin et | SC | MIP and goal | It provides decision makers with the ability to evaluate |

| | | | | |
|---|---|---|---|---|
| | al. (2008) | network design (SCND) | programming | different strategic decision alternatives, such as supplier and subcontractor selection, product allocation, capacity utilization, and transportation configuration, by illustrating their impacts on carbon emission and logistics cost. Emission is limited to production and transportation activities. |
| 3 | Chaabane et al. (2011) | SCND | MILP | The proposed approach helps supply chain managers to evaluate the average abatement cost (technology acquisition) as a function of carbon emission reduction targets. Emission is limited to production and transportation activities. |
| 4 | Bing et al. (2015) | Reverse global SC design | Integer programming | It considers re-processors' allocation under two different ETSs in two countries in a reverse supply chain. Emission are considered from only re-processing. |
| 5 | Fahimnia et al. (2013) | CLSC | Mathematical programming | It takes reverse logistics into account and indicates that reverse logistics should be subsidized in order to reduce the whole SC carbon footprint. Emission are considered from manufacturing, transportation, warehousing, recycling, and disposal. |
| 6 | Chaabane et al. (2012) | CLSC | MILP-LCA | It takes reverse logistics into account, and distinguishes between solid, liquid wastes, and gaseous emission due to various production processes and transportation systems. |
| 7 | Abdallah et al. (2012) | Green procurement | MIP-LCA | Emission is considered from raw materials, shipping, assembly, and warehousing. Greener supply chains tend to be decentralized with smaller facilities because emission from transportation is reduced. |
| 8 | Zakeri et al. (2014) | SCND | MILP | It conducts a comparative analysis between impacts of carbon tax and emission trading on the supply chain performance. |
| 9 | Jin et al. (2014) | SCND | MILP | It performs impacts analysis of carbon pricing policies on a major retailer (i.e., Wal-Mart) in terms of supply chain design and transportation modes choice. Emission is assumed to come from production and transportation. |
| 10 | Dranke et al. (2010) | SCND | A two-stage, stochastic model | It takes two alternative technologies as compliance strategies into consideration. |
| 11 | Benjaafar et al. (2013) | Procurement, production, and inventory management | Lot sizing model | It employs ETS on all of supply chain nodes with a single cap or separate caps. Firms could effectively reduce their carbon emission without significantly increasing their costs by making only operational adjustments and by collaborating with other members of their supply chain. |

1) Forecast of future policies on supply chain GHGs reduction

As supply chain GHGs account for the biggest proportion in all industries and reserve huge potentials for cost saving and emission reduction for companies, it is both necessary and significant to reduce emissions from the supply chain perspective (Huang et al., 2009). Economic instruments are regarded as the most cost-effective policy to control supply chain GHGs in the future. Since carbon resources are limited for the whole society, it is inevitable to cap the overall emissions and put a price tag for each unit of carbon emissions (IBM, 2009). Emissions could originally be reduced at a negative cost. The employment of economic instruments gives companies one incentive to reach those low hanging fruits. Researchers suggest that companies in pursuit of green strategies to manage their emissions could leverage economic policies (Lee K. H., 2011). It also provides forward-thinking companies the opportunity to create markets for green products (Pinkse, 2007).

Economic instruments are also called carbon pricing polices by giving a cost for each unit of carbon emissions. Hot topics discussed are around cap and trade, cap, carbon tax, cap and penalty, and so on. Given proper settings for parameters, all of them are effective to realize emissions reduction. But cap and trade would bring the least supply chain economic loss/ biggest earn while reduce the same amount of GHGs (Zakeri et al., 2015; (Jin et al., 2014; Drak et al., 2015).

In addition, companies should expect a tight cap and a high carbon price in the future (Gupta & Palsule-Desai, 2011). Only in this way, emissions could be effectively reduced. Sensitive analysis from literature shows that as the cap decreases, supply chain emissions decrease (Fahimnia et al., 2013). A high carbon price is effective to induce companies to invest into green practices. As ETS is becoming mature, a market-based price will be properly high. If not, government intervention will be allowed to control the price. The later companies begin to take actions; the worse punishment they will encounter.

2) Economic policy as one complement to other emission reduction measures

From the political perspective, economic instrument (i.e., emission trading) should be employed in line with other emission reduction measures such as investing into energy-efficient technologies (Talberg & Swoboda, 2013). Each policy has its advantages and disadvantages. It is a long way ahead before emission trading could be adopted to target every emission source from the worldwide scope. Since emissions reduction is impending, a complex combination of policies is expected. Standing from companies, they should also take economic trading policy only as a complementary compliance in addition to strategic, tactical, and operational abatement measures.

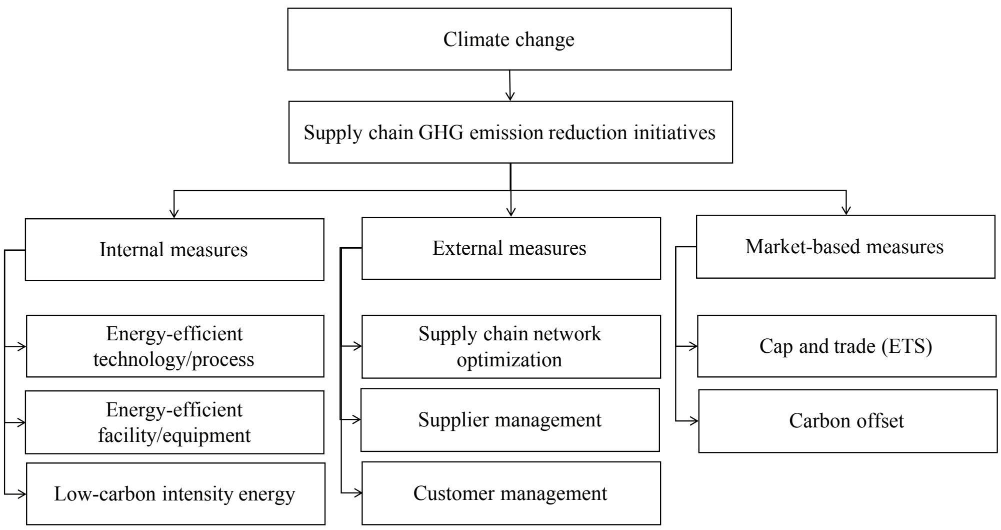


Figure 4-2 Compliance options for supply chain companies

Source: Adapted from Chaabane et al. (2011)

Companies that act early in controlling their supply chain GHGs will stand beneficial from economic policies, especially emission trading. Before supply chain GHGs is included into ETS, companies would better identify emissions abatement measures from both internal and external environment (Figure 4-2), and incorporate those measures into the supply chain management from strategic, tactical, and operational levels. For one company under a regulation which limits the overall amount of GHGs, it faces to three kinds of compliance options: reducing direct GHGs with internal measures, reducing indirect GHGs with external measures, and mitigate GHGs with market-based instruments (Chaabane et al., 2011). These three measures should be used as complementary methods to reach the GHGs reduction goal.

3) Application of emission trading to different supply chain scopes

According to the research scope, literature addressing emission trading in the context of supply chain could be generally categorized into three groups: upstream supply chain, downstream supply chain, reverse supply chain and CLSC. Literature focusing upstream supply chain denotes GHGs from the procurement, production, and inbound transportation and logistics (Benjaafar et al., 2013; (Abdallah et al., 2010; Jaber et al., 2013). Downstream supply chain research analyzes the GHGs generated from processes and activities involved in production, outbound logistics and transportation, and product distribution (Jin et al., 2014; Ramudhin et al., 2010). Reverse supply chain research studies GHGs from recovery and recycle processes (Bing et al., 2015). Studies on CLSC contain all (Fahimnia et al., 2013; Chaabane et al., 2012). Therefore, by focusing on the GHGs produced from the selected scope of supply chain, it is possible to incorporate the cost of GHGs into account for supply chain design, and the addition of GHG costs into the decision process for supply chain can change the optimal configuration of the supply chain network (Elhedhli & Merrick, 2012).

4) Assumption for supply chain structure

Most literature makes the common assumption that there's one key actor responsible for the whole supply chain GHGs. Emission trading and other regulations are targeted on this key actor. This actor is able to make strategic, tactical, and operational decisions within its own boundary and influence the decision-making of other supply chain partners as well. For example, the retailor in the downstream supply chain can influence the energy-efficient technology choice of manufacturers in the upstream supply chain (Jin et al., 2014). As the same, the retailor is also able to decide the transportation route of transportation companies, warehouse's location and capacity, and so on.

The assumption would be the real case when the supply chain is owned and operated by one single big company or supply chain partners obey the central management from the supply chain manager. Supply chain partners might work in such a close collaboration when all of them agree to reduce the GHGs embedded in the final product under a certain level (Benjaafar et al., 2013). Anyway, the whole supply chain GHGs are taken as a whole under the emission trading regulation. A limit is given to the overall supply chain GHGs, and the goal are reached by adjusting supply chain operations, choosing technologies, buying/selling permits, etc.

Taking supply chain GHGs as one unit is one holistic/supply chain approach. Applying the holistic approach and using linear programming can achieve the optimal outcome in a mathematical model whose requirements are represented by linear relationships. With this approach, it is possible to incorporate the cost of GHGs related to strategic, tactical, and operational decisions and optimize the supply chain based on trade-offs between cost and emissions in the supply chain. It also provides insights for policy-makers on the price and cap regulation.

#### 4.1.3 Research remained to be done

1) Assigning responsibility of GHGs

Based on the integrate supply chain, most literature do not allocate GHGs among supply chain partner, and the responsibility of reducing GHGs is neither assigned. They address the supply chain GHGs from only the process point of view. Benjaafar et al. (2013), as one except, assume that supply chain partners are responsible for their individual GHGs created from their separate business activities. For example, the supplier is responsible for the GHGs from material production, storing, and delivery to producers, and the producer is responsible for the GHGs from product manufacturing, warehousing, and transport to customers. Noting that multiple companies compose supply chains in real most often with individual business interests, it would provide insights for the practice if the supply chain is treated as a composition of different supply chain partners, i.e., from the stakeholder point of view.

2) Prioritizing emission abatement measures

One important step as aforementioned in the framework of supply chain GHGs management is to prioritize emissions abatement measures. This is typically essential for managing supply chain GHGs in practice. Companies need to know what are emissions reduction potentials firstly and then implement them according to their prioritization. However, this is neglected by applying optimization models where only the optimal set of emissions reduction measures is given. It would improve the knowledge of supply chain companies for GHGs management by giving the effect of each abatement measure on cost and emissions.

3) Concept/framework is needed

As a whole, literatures linked with supply chain GHGs management are mainly contributed by mathematical research via certain mathematical models. With such models, it is possible to footprint supply chain GHGs, to analyze the impacts of carbon policies on supply chain performance in terms of emissions and cost, and to compare carbon policies associated with their supply chain impacts. Their results show that by adjusting supply chain operations, it is possible to reduce supply chain GHGs without increasing too much supply chain cost (Benjaafar et al., 2013). That is, emission trading is cost-effective in managing supply chain GHGs, given proper parameter's set and supply chain collaboration. Besides, emission trading could result in the best supply chain performance compared to other carbon policies (Zakeri et al., 2015).

But there're so far neither concepts in this area nor user-friendly frameworks for companies in practice. A concept should be raised to describe such initiative and provide inspirations for researchers in the future. The framework should inform companies the processes that they can follow to manager their supply chain GHGs under emission trading.

4) Other ways of employing emission trading in the context of supply chain

Literature generally assume only one method for employing emission trading in the context of supply chain, and any other ways to combine these two fields remain to be explored. For example, importing the concept of credits/offsets would probably create an interesting implication for supply chain GHGs management. Only one literature is found in proposing other mechanisms. Long and Yong (2015) propose one supply chain credit scheme. Supply chain leading organizations who conduct work within a supplier to reduce GHGs would gain credits, which could be used to offset linked tax liabilities or as additional credits within existing emission trading schemes. They assert this scheme would be the most possible one to manage supply chain GHGs. However, they do not address how emission trading could be applied in the context of supply chain from the qualitative aspect and what kind of problems it would come across in the application.

Based on this work, there are still lots of questions that remain to be answered. For instance, how to incorporate this scheme into the existing emission trading system? How is responsibility of supply chain GHGs allocated among supply chain partners? How much is the transaction cost involved in this scheme? What are incentives for companies to participate? Would it change the variability of existing market? Little work has been done in this area.

5) Need for supply chain collaboration mechanism

Optimization models assume that supply chain partners work together or one focal company owns and operates the whole supply chain. They do not elaborate how do supply chain partners coordinate with each other. The collaboration method could be technical support, knowledge forum, cost/benefit sharing, and long-term contract, etc. Collaboration is the most important reason that results in the cost-effectiveness of employing emission trading in the context of supply chain. It is significant to assert the collaboration mechanism in supply chain partners under emission trading.

## 4.2 Supply chain emission trading programs

### 4.2.1 Conceptual framework

The Paris Agreement requires common efforts from entities at all levels of the economy to join in a mechanism that allows emission reduction units being international transferred. This mechanism bases on the principle that reducing emissions wherever in the globe is contributing to the overall climate combat. In the future, connecting emission trading with international cooperation will play an essential role in reducing the overall cost of emission neutralization. Emission reduction and trading beyond national boundary would finally result in the most cost-effective way of emission mitigation. Corporates from every corner of the world are motivated to take voluntary measures of GHGs reduction and these reduced GHGs units could be transferred among corporates. As global trading is increasingly extending the supply chain to reach every corner of the world, companies in the supply chain cannot only work together for business benefit but also for GHGs reduction. The mechanism proposed in the Paris agreement introduces flexibility for the company to meet its GHGs reduction target by reducing GHGs in the supply chain and transferring the reduced units along the supply chain.

With this policy background in mind, this paper suggests the concept – supply chain emission trading. Supply chain emission trading is one idea is to apply the knowledge of emission trading in the context of supply chain so as to realize the supply chain GHGs control in a cost-effective way. Emissions are produced along the supply chain and should be reduced with a common effort of supply chain partners. For each supply chain partner, there exist a range of emission abatement measures with different abatement cost. By applying the idea of emission trading in the supply chain, it means each unit of reduced GHGs has a certain economic value and can be transferred between supply chain partners, and in existing emission markets as well.

Allowing GHGs reduction units to be transferred between supply chain companies would not only reduce the overall supply chain GHGs but also improve the supply chain competitiveness. Compared to the supply chain without access to emission trading, emission reduction goals could be achieved by a more cost-effective way in the supply chain with access to emission trading. This would decrease the relative cost of mitigation measures, and reduce difficulties in obtaining direct benefits from GHGs reduction within supply chain partners (Long & Young, 2015). In addition, since the emission reduced units are from the same supply chain rather than from other entities outside of the supply chain, the total supply chain GHGs are reduced, i.e., the emissions embedded in the corporate or products are reduced. Therefore, the supply chain competitiveness is enhanced as the customer market shifts to green products and stakeholders demand for low corporate emissions. Furthermore, targeting supply chain GHGs into environmental policy would avoid emission leakage effectively. Companies usually might relocate their production or logistics facilities from one ETS-regulated nation to other nations in order to escape the economic cost incurred by ETS. Supply chain emission trading takes supply chain GHGs spreading over geographical countries as one unit, account, and regulate GHGs from all supply chain processes wherever supply chain partners are located.

This section proposes three programs/mechanisms that explicitly address how emission trading could be employed to affect supply chain GHGs management. A work breakdown structure (WBS) is employed to clarify the relationship between different programs (Figure 4-3). Detailed descriptions and the cost-benefit analysis of each program are performed in the following.

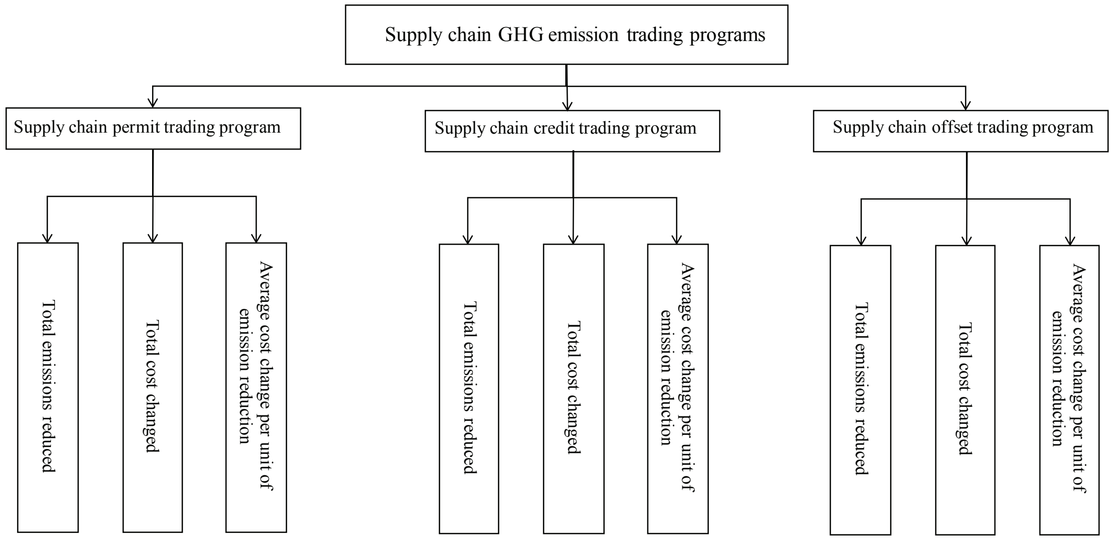


Figure 4-3 WBS chart of supply chain emission trading programs

### 4.2.2 Supply chain permit trading program

1) Working principle

This paper gives the name – supply chain permit trading to this program and generates the working principle of this program from reviewing the efforts of literature (Figure 4-4).

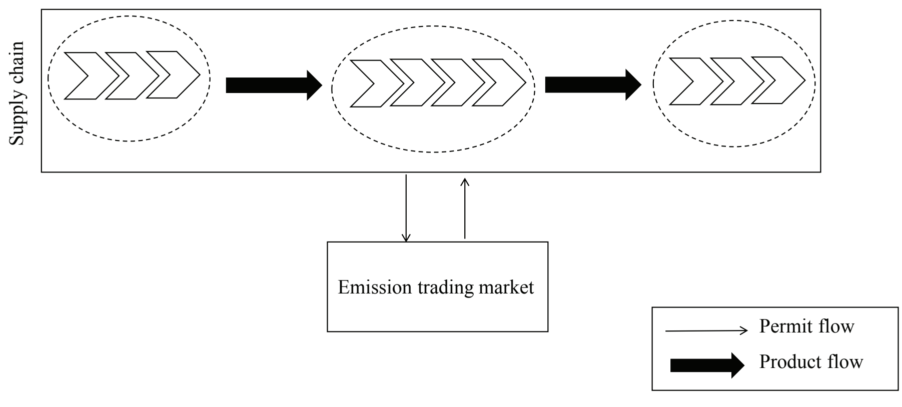


Figure 4-4 Supply chain permit trading program (illustrative)

This program is most often addressed in literature from the mathematical point of view (Abdallah et al., 2010; Chaabane et al., 2012; Fahimnia et al., 2013). Supply chain permit trading program means that the supply chain GHGs are included into ETS as same as a single unit. In fact, ETS right now covers only individual companies (e.g., China pilots ETS) and installations (e.g., the EU ETS). Supply chain permit trading is including the supply chain into ETS. It means, entities covered by ETS could not only be single firms and installation, but also supply chains. Selected supply chain GHGs as a whole are subject to a certain limit (so-called cap) due to governmental regulations. Selected supply chain denotes the area research or government regulation focuses, e.g., upstream supply chain, downstream supply chain, reverse supply chain or CLSC.

It takes into account the GHGs from all supply chain activities and processes in the selected scope. Permits under this limit are allocated to supply chains for free, or for certain auction cost. One permit is the right to emit one ton of $CO_2e$. Supply chains have to surrender permits in equivalent to their accurate GHGs at end of a certain period. Supply chain GHGs have to be reduced under the regulated cap by emission abatement measures within the range of the selected supply chain. If not, the supply chain representative have to purchase emission permits from existing emission trading markets to cover the emissions exceeding the cap. Extra units reduced by emission abatement measures could be sold as permits to other organizations in trading markets. Emitting rights (i.e., permits) are exchanged between the supply chain representative and existing emission markets.

In other words, this program appoints that supply chain work as a single company to perform emission abatement measures and to trade emission permits in current trading markets. Hence, one focal company (i.e., the representative of supply chain) coordinate actions among supply chain members, for example, calculating emissions amount from all supply chain partners, arranging emission abatement alternatives (e.g., technological investment, operational adjustment), making decisions for emission permits buy/sell, and negotiating with policy makers, and so on (Long & Young, 2015). It applies to the situation that the focal company owns and operates the whole supply chain and the focal company is subject to emission trading. It is also possible when the emissions reduction target is voluntary and the objective for the supply chain is to eventually certify that the end product has a carbon footprint that does not exceed a certain threshold. Some options are seen in literature to assign the focal organization among supply chain partners.

- The largest company or the one with the most power among the supply chain.
- Actor downstream in the supply chain where the goods are consumed.
- Actor upstream in the supply chain where the goods are produced.

The largest company within the supply chain would probably pursue green strategies and therefore have incentives to manage supply chain GHGs. The one with the most power affects actions of other supply chain partners and the supply chain performance to the most. Hence, they could be targeted mandatorily as focal companies in the emission trading policy to manage their supply chain GHGs. Actors downstream in the supply chain are dealing with end products and are facing to customers. They could have an overview of supply chain GHGs and guide customers to choose green products. Assigning these actors as focal organizations could benefit in managing GHGs from the overall supply chain perspective and in affecting the market preference as well. Actors upstream in the supply chain are always the largest emitters. It could be possible to save larger amount of emissions by spending less. Since emission trading scheme is so far mainly targeted on these actors, it would be one possible way to internalize their Scope 3 emissions into the cap. By doing this, actors upstream are responsible for the supply chain GHGs. Companies included in emission trading are responsible for their scope 3 emissions. This could be a start for targeting supply chain emissions into emission trading.

This concept bases on a high level of supply chain integration that is also the core in the area of green supply chain management. Supply chain integration requires close collaboration among partners in sharing data, compromising in benefit/cost transfer, managing and developing knowledge, and so on. Apparently, involving supply chain into emission trading scheme would come up with several problems and challenges compared to targeting individual companies. In spite of these, supply chain still represents necessities and advantages in terms of emissions regulation compared to regulating the companies that make up the supply chains separately.

- For the ecology, supply chain represents a larger amount of emissions than single companies. Therefore,c it is of priority to target supply chain GHGs into carbon policy.
- For the business, it is more cost-effective to reduce supply chain emissions as a whole than to reduce emissions separately within the boundary of individual companies because lack of collaboration among multiple firms within the supply chain can increase the overall carbon footprint (Long & Young, 2015). Doing so increases the value of supply chain collaboration as well.
- For the administration, regulating the supply chain as one single unit would save human work and cost compared to managing individual companies separately.

2) Framework for cost-benefit analysis

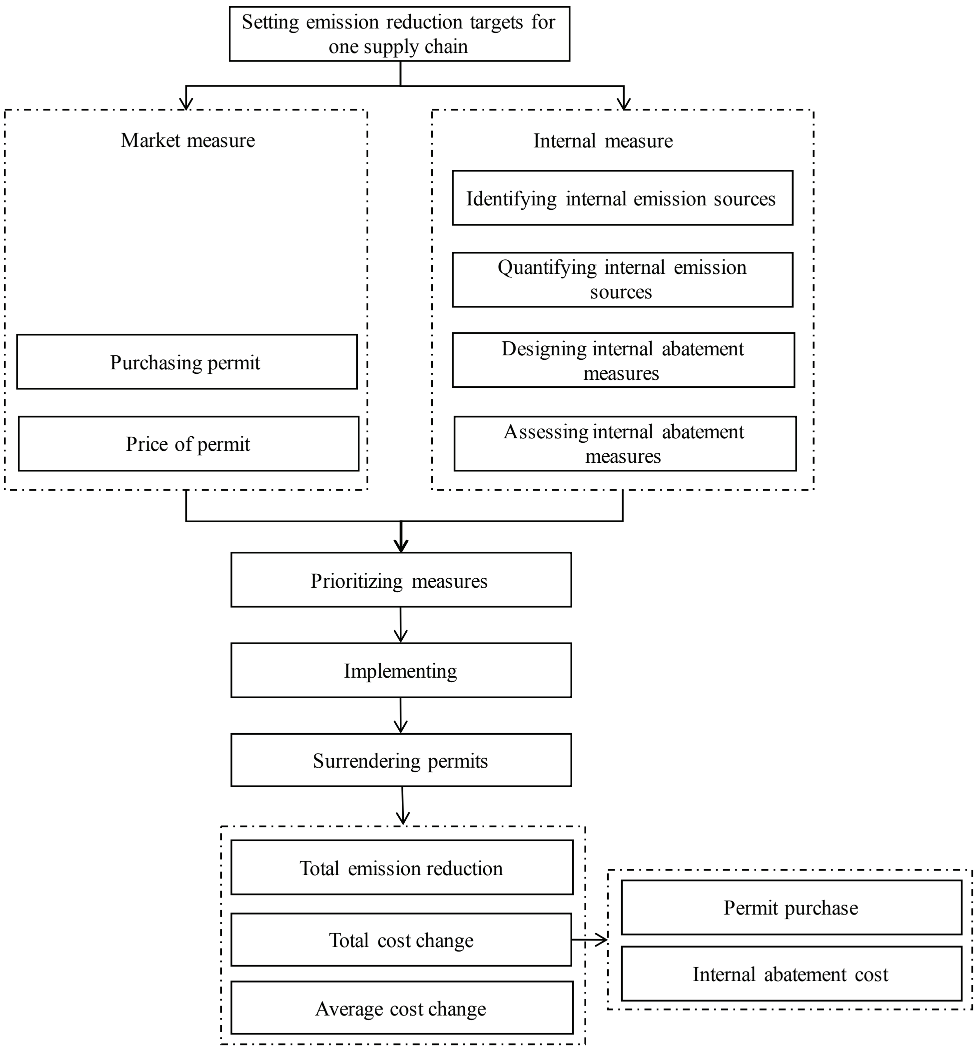


Figure 4-5 Framework for supply chain permit trading program

This section proposes one framework for performing the cost-benefit analysis of the supply chain permit trading program (Figure 4-5). The supply chain is subject to a common GHGs reduction target. Supply chain partners in this program have to closely work together.

Firstly, they have to find where are emissions reduction potentials throughout the supply chain by understanding the supply chain emission map. Since this program this the supply chain as one single unit, emission abatement measures are searched from the whole range of supply chain. For example, emission reduction potentials could lie in manufacturing processes by choosing different technologies, or in logistics service providers by transferring transportation mode to low carbon intensity mode. Note that internal measures in this program mean abatement measures within the range of the supply chain, they are different from internal measures in other programs which are addressed in later sections.

Secondly, both cost change and benefit (i.e., GHGs reduction) of each measure have to be calculated. Measures can be categorized by their effectiveness in reducing costs and emissions (Figure 4-6). Ideal measures reduce both, while ecological and economic measures reduce emissions or costs respectively. Inefficient measures should be avoided at all times. The focus of this study is on ecological and ideal measures with positive emissions reductions. The cost change of an emission abatement measure could be either positive (named ecological measures) or negative (named ideal measures).

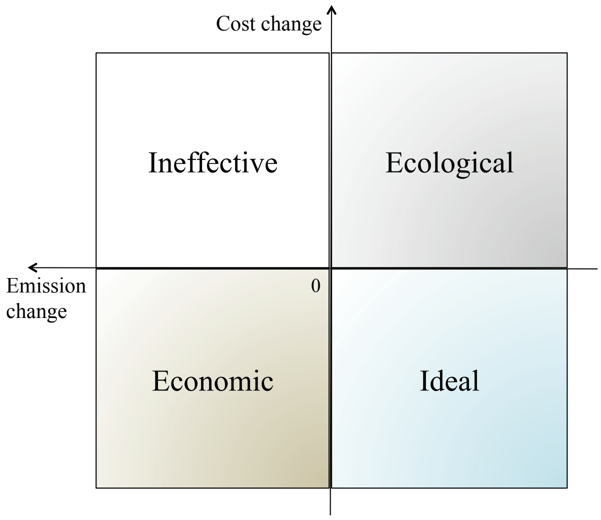


Figure 4-6 Categorization of emission reduction measures
Source: Gross et al. (2013)

Thirdly, these identified emission abatement measures should be prioritized according to the cost and benefit of each measure. Companies should implement ideal measures as soon as possible cause it will not only bring GHGs reduction but also economic benefit. Purchasing permits is regarded here as one of emission abatement measures though it does reduce GHGs in the supply chain for real. Purchasing permits would consume and retire the permits saved by other projects wherever in the world. Since the GHGs are really removed from the atmosphere around the earth, emission abatement measure must have taken place anywhere. The cost and benefit of purchasing permits is the price of permit per unit. Each emission abatement measure except purchasing permits is regarded as one emission reduction project.

Fourthly, companies implement emission reduction measures according to their priority. Given the cost and benefit of each abatement measure, it is known that which is the best cost-effective one. For example, when the price of permits is lower than other abatement measures, supply chain companies would choose to purchase permits from existing emission market to reach the supply chain GHGs reduction target, and vice verse.

At last, the supply chain surrenders enough permits to related government administrative at the end of a compliance period. The cost and benefit of this program could be easily calculated as a result.

3) Mathematical model (A)

According to the framework above, the cost and benefit analysis of the supply chain permit trading program is formulated in following.

Cost parameters:

| Name | Definition | Units |
|---|---|---|
| $E$ | The accurate amount of emissions emitted by the company without taking any emissions abatement measures | ton $CO_2$ |
| $cap$ | The emissions limit enforced by government regulation | ton $CO_2$ |
| $p$ | The price of permit per unit | €/ton $CO_2$ |
| $c_t$ | The cost involved in joining emission trading, for registration, monitoring, and verification | € |
| $e_i$ | The amount of emission units reduced by the emission reduction project $i$, each unit is equal to one unit of permit, $i = 1, 2 \ldots L$ | ton $CO_2$ |
| $c_{pi}$ | The cost change to operate the project $i$, either positive (i.e., cost increment) or negative (i.e., cost saving), $i = 1, 2 \ldots L$ | € |
| $c_e$ | The emission cost, it could be either positive (buying permits) or negative (selling permits) | € |
| $L$ | Total amount of internal emission reduction projects within the supply chain | / |

Decision variables:

| | |
|---|---|
| $a_i$ | $\begin{cases} 0, \text{the project i is not adopted} \\ 1, \text{the project i is adopted} \end{cases}, \ i = 1, 2 \ldots L$ |
| $e^+$ | The amount of GHG permits the firm buys |
| $e^-$ | The amount of GHG permits the firm sells |

Objective:

Minimize

$$\sum_{i=1}^{L} a_i c_{pi} + c_e + c_t \tag{1}$$

$$c_e = (e^+ - e^-) * p$$

Subject to:

$$E - \sum_{i=1}^{L} a_i e_i + e^- \leq cap + e^+ \tag{2}$$

$$Q \geq e^+, e^- \geq 0, \text{upper and down bounds on the amount of permits} \tag{3}$$

The objective function (1) minimizes the total cost change composed of investing into emission reduction projects, emissions cost, and permit trading cost. Restriction (2) indicates that the total amount of permits has to be more than actual emissions. The allocated permits under the cap, the emission units reduced by internal emission reduction projects, and the permits exchanged from the market compose the total permits. Restriction (3) limits the amount of permits with which the supply chain is allowed to exchange in the market. Given such a restriction, it makes sure that the supply chain has to reduce GHGs from its own operation to a certain extent. This restriction also obeys with the actual practice from most of ETS worldwide (e.g., the EU ETS).

Note that the carbon permits bought serve to realize the effective cap on emissions, although it is costly to do so, while the carbon permits sold represent a new source of revenue. Let $p_{ci}$ denote the average cost change per unit of GHGs reduced in each project and $p_{ci} = \frac{c_{pi}}{e_i}$, $i = 1, 2 \ldots L$. The solution of this problem could be formulated in following.

$$a_i = \begin{cases} 0, p_{ci} \geq p \\ 1, p_{ci} < p \end{cases}, \; i = 1, 2 \ldots L$$

In order to minimize the overall cost change, the supply chain would implement internal emission abatement projects rather than purchasing permits when the average cost change of abatement measure is lower than the price of permits. Vice verse. And saved emissions from internal projects could be sold to the market for a earning after the supply chain GHGs reduction target is achieved.

In the above formulation, we have assumed that the market price of permits is fixed. However, under cap and trade without price control, price would be subject to volatility. This volatility could be assumed away if it is primarily of a short-term nature and if the long-term trend can be reliably forecast (a predictable increase or decrease in price can be easily incorporated into the model) (Benjaafar et al., 2013). It can also be assumed away if the firm employs financial options, such as those commonly used in the procurement of commodities, which guarantee the firm the option to buy or sell at a specified price (Benjaafar et al., 2013). Therefore, we assume that price is relatively stable over the firm's planning horizon.

### 4.2.3 Supply chain credit trading program

1) Working principle

Long & Young (2015) have proposed one supplier credit scheme where the leading company in the supply chain can work with its suppliers to reduce GHGs and get credits which can be in turn used as additional permits in existing emission trading markets. Based on this work, this paper suggests one supply chain credit trading program where the leading company can not only work with its suppliers but also with other supply chain partners. The working principle of supply chain credit trading program is illustrated in Figure 4-7. A detailed description of this program is introduced as followed.

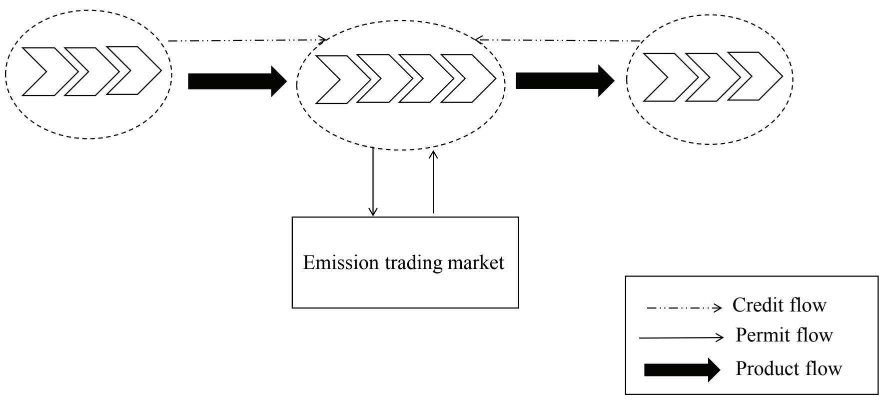


Figure 4-7 Supply chain credit trading program (illustrative)

In the supply chain credit program, one leading supply chain company (i.e., the focal company) is subject to ETS and allowed to invest into credit projects within the range of its own supply chain. The leading company is able to get credits by reducing GHGs within the supply chain scope and the credits can be in turn used as additional permits in existing emission trading markets. Each unit of credit equals to each unit of permit in terms of emitting rights, i.e., one ton of CO2e.

There're so far mainly three types of credit project: CDM, JI, and voluntary emission reduction project. CDM projects in developing countries can be further divided into three modes: single mode, bilateral mode, and multilateral mode. Single model refers to the independent implementation of CDM projects by developing countries, then selling the CERs in the market. Bilateral model means developing and Annex I countries cooperate and develop CDM projects together or all invested by Annex I countries, and Annex I countries get the CERs. Multilateral mode denotes that several Annex I countries establish a foundation to invest in the CDM projects, and the CERs are owned by the Foundation.

The supply chain credit trading program employs the knowledge of bilateral CDM projects in the context of supply chain and combines it to the concept of cap and trade. Assuming the leading company (i.e., located in an Annex I country under the Kyoto Protocol) in the supply chain is the developer of a credit project and the project is located in the supplier which lies in a developing country, this project is then one CDM project. In the supply chain credit trading program, the leading company invests into the credit project and therefore this project is a bilateral CDM project. The cost component of developing and operating a CDM project is given in Tab 4-2. In other cases, the project is either a JI project or a voluntary emission reduction project which creates VERs.

Tab 4-2 Cost components of a CDM project

| *Cost to develop a CDM project* |
| --- |
| Project screening |
| Develop/select methodology and estimate the emissions reduction |
| Prepare relevant technical documents |
| Permission of the host, consultation from stakeholders, environmental impact assessment |
| CER purchase agreement |
| DOE approval of the project |
| Registration fee |
| Monitoring |
| Verification and certification costs |
| Adaptation costs (2% of the total CERs) |

Source: Shi et al. (2013)

In this program, the supply chain GHGs reduction target is issued to the focal company which is already subject to ETS. All emissions saved from the range of supply chain could be used as additional credits for the company in existing emission trading scheme. This approach would be advantageous where government wishes supply chain leading organizations to exert their influence, power, and expertise to the benefit of less able suppliers (Long & Young, 2015).

2) Framework for cost-benefit analysis

In this program, a GHGs reduction target is given to the focal company which is already subject to ETS. The company will follow the framework steps as shown in Figure 4-8.

Firstly, the focal company reviews all internal GHGs sources within its own boundary, and it also looks for external GHGs sources in the supply chain beyond its operation, e.g., GHGs sources within its suppliers and customers.

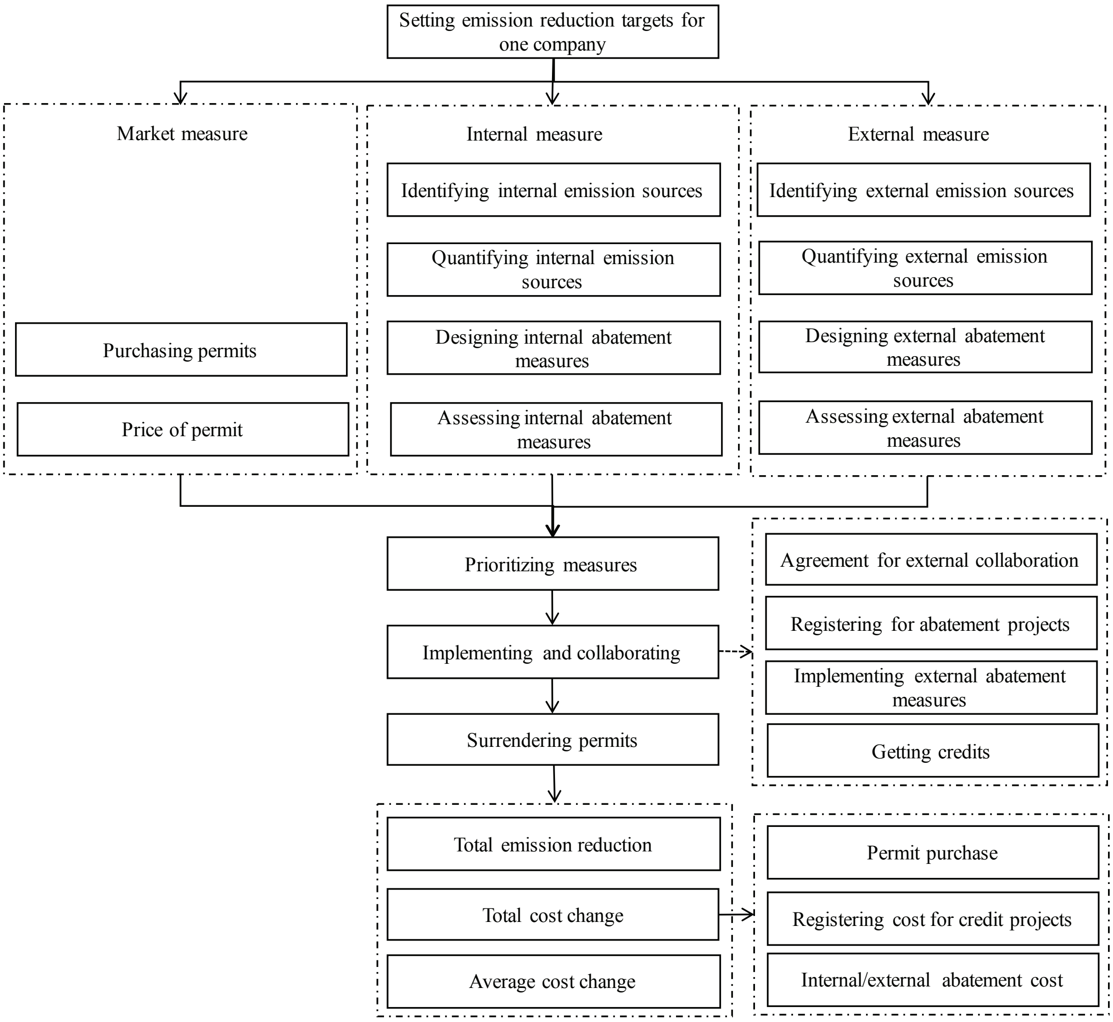


Figure 4-8 Framework of supply chain credit trading program

Secondly, after understanding the supply chain GHGs map, the focal company has to get the knowledge of potential emission abatement measures about their cost and benefit. The company study on internal emission abatement measures within its own operation and external emission abatement measures within other supply chain partners as well. Purchasing permits is taken as one market-based measure which cannot reduce but mitigate GHGs of this company.

Thirdly, abatement measures are prioritized according to the cost and benefit of each measure.

Fourthly, the focal company starts implementing emission abatement measures, as each abatement measure is one emission reduction project (except purchasing permits). For the abatement measures taking place in other supply chain partners (i.e., external emission abatement measures), the focal company has to register them as credit projects (e.g., CDM, JI projects) by corresponding authority and pay for the registration and administrative fee. The company need agree with related supply chain partners on the project issues. For example, they have to confirm the tasks and responsibilities of each party in developing this project.

At last, the focal company develops emission reduction projects together with its supply chain partners and gets the credits which have to be verified by the corresponding authority. At the end of the compliance period, the focal company surrenders enough permits including credits to related government administrative.

3) Mathematical model (B)

Suppose there are different emissions reduction projects available for companies to perform with supply chain partners, companies can get credits called CER from those projects. The cost and benefit analysis of this program can be formulated and calculated in the following. Cost parameters and decision variables are set down as same as those in the supply chain permit trading program, and some more parameters in the supply chain credit trading programs are added:

| Name | Definition | Units |
|---|---|---|
| $c_{ri}$ | The administrative cost of external project i, including registration, monitoring, and verification cost, etc. $\mathrm{i} = 1, 2 \ldots \mathrm{N}$ | € |
| $c_{ci}$ | The total cost change of developing external project i, including administrative cost and operational cost change. $\mathrm{i} = 1, 2 \ldots \mathrm{N}$ | € |
| $M$ | Total amount of internal emission reduction projects within the focal company | / |
| $N$ | Total amount of external emission reduction projects within other supply chain partners | / |

Minimize

$$\sum_{i=1}^{M} a_i c_{pi} + \sum_{i=1}^{N} a_i c_{ci} + c_e + c_t \tag{4}$$

$$\mathrm{c_{ci}} = \mathrm{c_{ri}} + \mathrm{c_{pi}},\ \mathrm{i} = 1, 2 \ldots \mathrm{N}$$

Subject to (2) (3) (5) (6)

$$L = M + N \tag{5}$$

$$\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{a_i e_i} \leq \mathrm{R}, \text{ An upper bound on the amount of credit} \tag{6}$$

The objective function (4) minimizes the sum of internal abatement cost, external credit cost, emissions cost, and permit trading cost. This function differentiates itself from function (1) on the emission reduction project cost. In the supply chain credit trading program, emission reduction projects located beyond the focal company are regarded as credit projects and the focal company has to pay for extra administrative fee for these credit projects. When the emission reduction projects are located within the focal company, the administrative fee is zero because the focal company doesn't have to register these internal projects as credit projects by authorities. Restriction (5) means that the emission reduction projects within the supply chain are composed of the internal emission reduction projects within the focal company and external emission reduction projects beyond the focal company. Restriction (6) indicates that the focal company is allowed to develop credit projects up to a certain level, and it ensures that the focal company has to invest into internal abatement measures within its own operation. Restriction (6) is valuable when government regulations are designed to require the focal company to focus on its own operation for GHGs reduction.

Considering only the internal emission reduction projects, the results of model (A) are still applicable to the model (B). In addition, let $p'_{ci}$ denote the average cost change per unit of carbon credit produced in external project $i$ and $p'_{ci} = \frac{c_{ci}}{e_i}$, $i = 1, 2 \ldots N$. The solution of this problem could be formulated in following.

$$a_i = \begin{cases} 0, p'_{ci} \geq p \\ 1, p'_{ci} < p \end{cases},\ i = 1, 2 \ldots N$$

It means that, when the cost change of credit is less than the price of permit, the company should invest into credit programs to reduce GHGs instead of purchasing permits from markets and vice verse. Besides, companies can also sell extra credits into emission trading market by doing so. Given the mandatory responsibility to cut GHGs, companies will invest into credit projects on the precondition that getting credits costs less than reducing GHGs through internal and market measures.

### 4.2.4 Supply chain offset trading program

1) Working principle

The supply chain credit trading program describes one extreme situation in practice where the focal company takes care of everything of GHGs reduction. However, in reality, the focal company would most often require its supply chain partners to reduce GHGs independently and the focal company doesn't participate. To depict this situation, this paper proposes additionally the supply chain offset program. The working principle is illustrated in Figure 4-9.

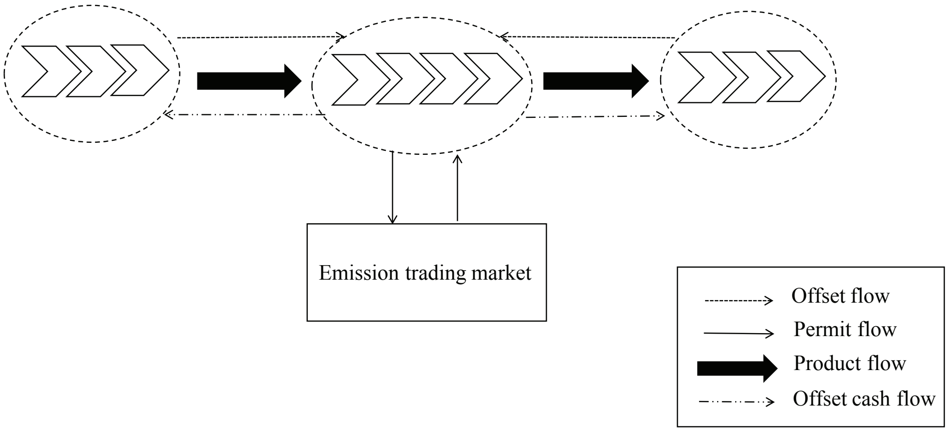


Figure 4-9 Supply chain offset trading program (illustrative)

Basically, supply chain partners invest into emission reduction projects on their own and they could sell reduced emissions as offsets to the focal company. The focal company can use offsets as additional permits in existing emission trading markets. One unit of offset equals to one unit of permit in terms of emitting rights. The sell-buy mechanism gives incentives to supply chain partners to join this program. For example, suppliers, logistics service providers (LSPs) and terminals could make earnings by selling emission credits and manufacturers could meet emissions reduction targets in a more cost-effective way.

This program incorporates the concept of single mode of CDM project into cap and trade. While supply chain partners are developing emission reduction projects independently and selling offsets to the focal company and other buyers, this kind of exchange is similar with the single mode of CDM project. In this program, the focal company plays a role of offset buyer and corresponding supply chain partners are offset project developers responsible for registering, operating, and verifying the offset projects. Therefore, supply chain partners have to pay for the administrative fee of offset projects.

2) Framework for cost-benefit analysis

In this program, the focal company is subject to ETS. The framework for performing the cost-benefit analysis of the supply chain offset trading program is given in Figure 4-10.

Firstly, the focal company has to identify internal GHGs sources within its own boundary, design internal abatement measures, and assess the cost and benefit of each internal emission abatement measure.

Secondly, given the cost and benefit of each internal emission abatement measure, the focal company can prioritize internal measures, purchasing permits, and purchasing offsets according to their average cost. In this step, the focal company doesn't have to review all GHGs abatement potentials within the range of supply chain as the other two programs. It is the supply chain partners that are responsible for developing emission reduction projects (i.e., offset projects) in the supply chain offset program.

Thirdly, the focal company makes decision and implement internal emission abatement projects and purchase permits and offsets. At the end of the compliance period, the focal company surrenders enough permits to related government authorities, given that the offsets could be used as same as permits in existing ETS.

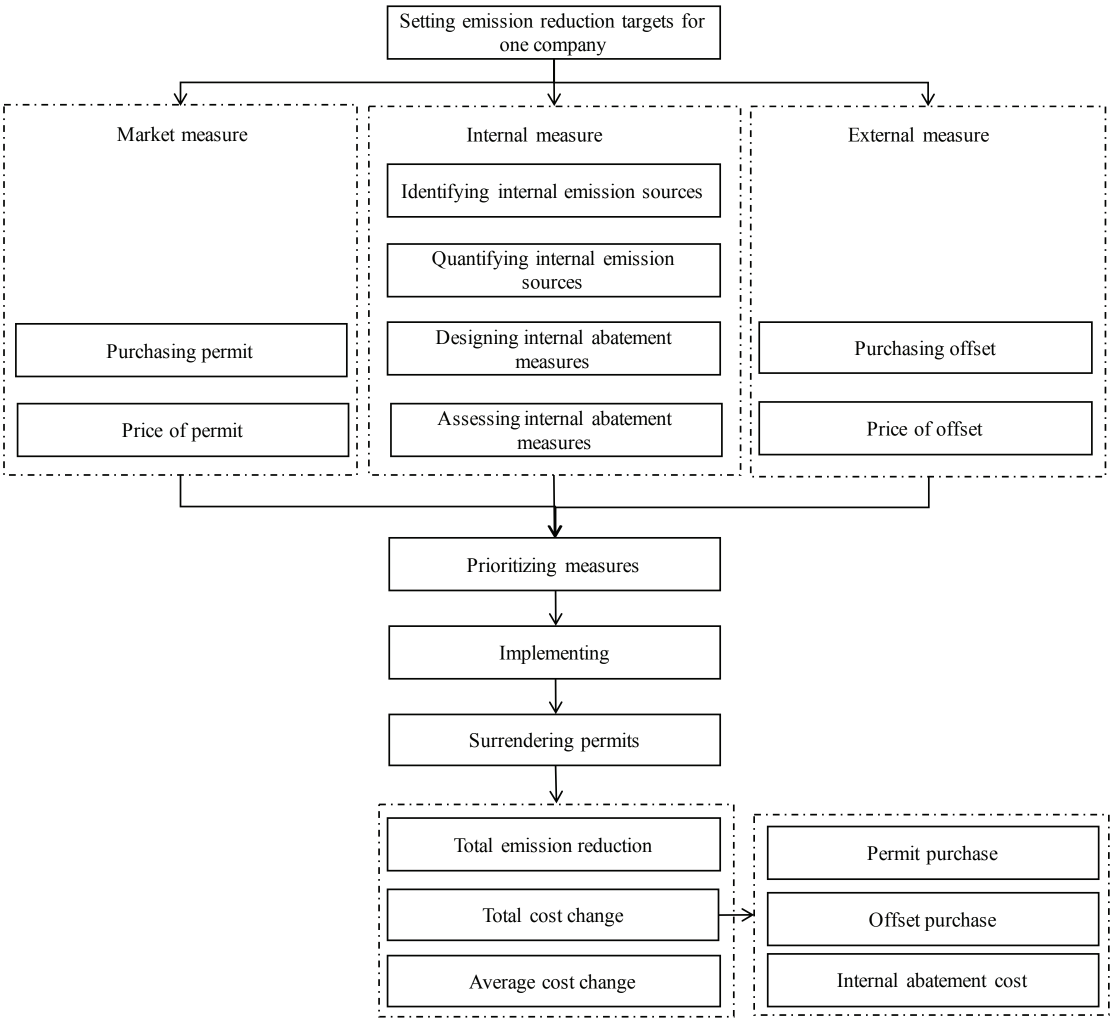


Figure 4-10 Framework of supply chain offset trading program

At last, the cost and benefit analysis could be performed for this program where the cost components include internal emission abatement cost, permits purchasing cost, and offsets purchasing cost. The offsets purchasing cost for the focal company relies on the price of offsets per unit. Theoretically, the price of offsets is decided by the offset seller and influenced by the demand and supply of offset market. In practice, the price could be negotiated between two trade parties over the counter (OTC).

3) Mathematical model (C)

The mathematical problem faced by the focal company could be formulated in following. The definition of parameters and variables are as same as the supply chain permit program and supply chain credit program. One more parameter is added.

| Name | Definition | Units |
|---|---|---|
| $p_{oi}$ | The price of offset per unit created by external project i, $i = 1, 2 \dots N$ | € |

Minimize

$$\sum_{i=1}^{M} a_i c_{pi} + \sum_{i=1}^{N} a_i p_{oi} + c_e + c_t \tag{7}$$

Subject to (2)(3)(5)(6)(8)

$$E - \sum_{i=1}^{L} a_i e_i + e^- = cap + e^+ \tag{8}$$

Objective (7) is to minimize the total cost composed of internal abatement cost, offset purchasing cost, emissions cost, and permit trading cost. The offset purchasing cost could be different from the external credit cost in objective (4). Restriction (8) denotes that the focal company in this program holds permits in equivalent to their actual amount of GHGs. Assuming out the secondary exchange of offsets and offset banking, the focal company is not allowed to sell the offsets again to the emission market for a earning. All offsets the company buys from its supply chain partners have to be used and retired in ETS. Supposing ideal and ecological internal abatement measures are adopted based on the results of model (A), the focal company will make decisions between permits purchase and offset purchase upon the price differences in following.

$$a_i = \begin{cases} 0, p_{oi} \geq p \\ 1, p_{oi} < p \end{cases}, \; i = 1, 2 \dots N$$

It means that the focal company would choose to buy offsets from external projects that cost averagely less than purchasing permits. Supply chain companies could make earnings by selling offsets to others at a higher price than the cost. But they have to confirm that the price of offsets is lower than the price of permits, or else they would lose market competitiveness to the permits trading. Therefore, the offset project $i$ is profitable for the project developer only when $c_{ci} < p_{oi} < p$ is satisfied. Some specific situations about the change of $p_{oi}$, $i = 1, 2 \dots N$ are discussed in following.

a) $0 < c_{ci} < p_{oi} < p$, $c_{ci} < 0 < p_{oi} < p$, Win-win situation

In this situation, the offset programs are profitable for both buyers and sellers. Buyers can save cost compared to purchasing permits and sellers can make earnings by setting the price higher than the cost. This is the most ideal situation and it only happens when the offset developers can perform projects with low cost or even negative cost. Possible projects could be combining transportation modes, and so on. Therefore, the offset program helps supply chain companies identify and reach the "low hanging fruits".

b) $c_{ci} < p_{oi} < 0 < p$, Win-win situation (0-100% benefit pass-through)

The emission abatement cost change is negative (i.e., ideal measures) and the project developer cannot only reduce GHGs but also save cost. Part of the cost saving (0-100%) could be passed through to offset buyers under a certain kind of collaboration. This is also a win-win case since both the offset seller and buyer make earnings. In order to get the benefit pass-through, offset buyers often need collaborate with offset sellers in developing emission abatement projects, such as providing technic support, or make cooperative contracts like extending the contract term.

c) $0 < p_{oi} < c_{ci} < p,\ or\ 0 < p_{oi} < p < c_{ci}$ Collaboration situation

The focal company in supply chain buys offsets from its partners with a lower price than the cost. It could be understood as supply chain collaboration in emissions reduction where the supply chain partners share partial cost responsibility with the focal company. This would be the case when the focal company leverages its power on its supply chain partners to do so or it makes other compensation for the supply chain partners such as extending the contract term or enlarging the contract volume.

d) $p_{oi} < c_{ci} < 0 < p$ Collaboration situation (more than 100% benefit pass-through)

This would usually be a rare case in reality when the offset sellers even would like to take a positive cost change and pass all the benefits got from ideal emission abatement measures through to the offset buyers. A strong connection between these two trade parties is the prerequisite for this case.

e) $c_{ci} = p_{oi} < p$

This case is almost like the supply chain credit trading program. The focal company takes all the financial responsibilities (either positive or negative cost) for developing credit projects. The only difference is that in the supply chain offset program, the offset seller is responsible for registering, operating, and verifying the projects while it is the focal company that takes care of such administrative issues in the supply chain credit trading program. This would like to be the real case compared to the supply chain credit program because it requires no participation from the focal company in this case.

f) $p_{oi} = 0 < p$

The price of offsets is zero in this case, and it means that supply chain partners develop offset programs and provide offsets to the focal company for free. This extreme case applies to the situation that the focal company has enough bargaining power to ask its partners to do so. It would also apply to a certain contract conducted between the company and its partners. For example, when the focal company gets free offsets from its partners, it guarantees in turn a long-term contract with these partners or a large order for a long term.

This section has performed a conceptual study on supply chain GHGs management through proposing three supply chain emission trading programs. These programs are different and applicable to different situations. The supply chain permit trading program takes the supply chain as a single unit and doesn't provide any benefit allocation mechanism for the supply chain collaboration considering the supply chain is composed of multiple supply chin partners. Instead, the supply chain credit program and supply chain permit trading program explicit the collaboration modes separately. The responsibility and benefit assignment between the focal company and other supply chain partners is different in two programs. The supply chain credit trading program provides only one mode for supply chain GHGs management where the focal company takes all the responsibilities while the supply chain offset program provides many options for the supply chain collaboration via the price setting of offsets. A case study from HP is going to be carried out to analyze the cost-effectiveness of each program in following.

## 4.3 Case study

### 4.3.1 Setting parameters and assumptions

1) Overview of HP

In 2008, HP became the first major IT Company in measuring and publishing aggregated supply chain GHGs. HP's goal, a first for the IT industry, is to drive a 20 percent decrease of GHGs intensity in its first-tier manufacturing and product transportation by 2020, compared to 2010 (Figure 4-11). HP calculates intensity as its suppliers' GHGs divided by HP's annual revenue. This method normalizes performance based on business productivity. Besides, HP also set a 20 percent and 40 percent decrease of emissions intensity separately on its own operation and products use.

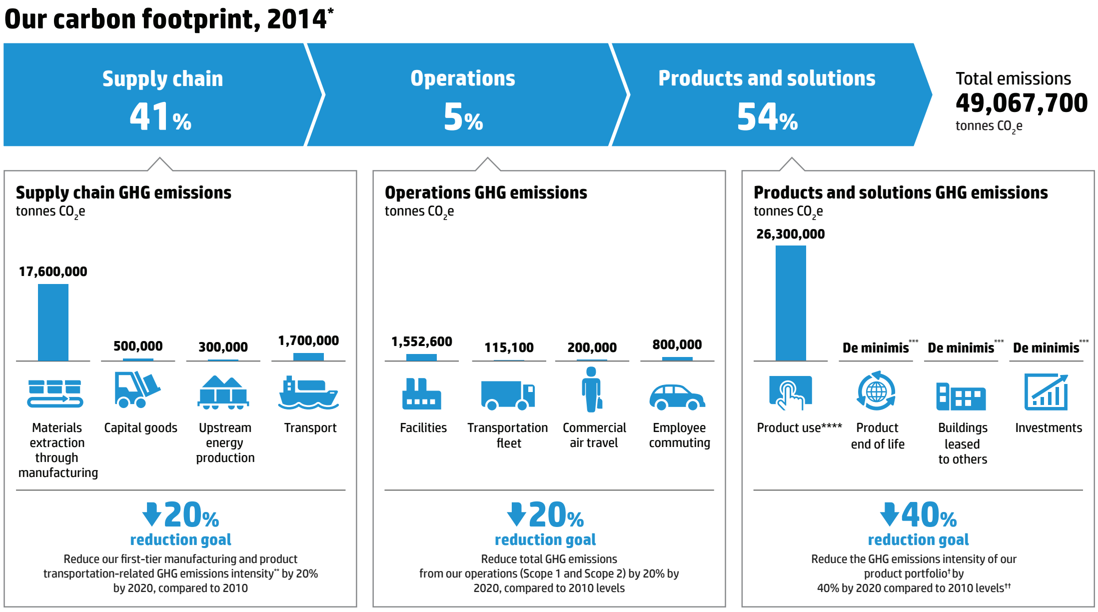


Figure 4-11 HP – supply chain GHGs footprint and reduction goals

Source: HP (2014)

The GHGs reduction goal will be driven through a variety of HP-led activities, including:

a) Abatement initiatives for HP operation

- Energy efficiency initiatives, e.g., installing LED lighting fixtures in HP data center facilities, replacing energy-intensive infrared humidification systems with ultrasonic alternatives at data centers, and replacing aging building management systems at sites, etc.
- Smart building design, e.g., increasing the use of sustainable building standards such as LEED when feasible, LED lighting, lighting controls, advanced cooling systems, and smart building software, etc.
- Renewable energy installation, e.g., using renewable energy sources, such as solar power at HP facilities, looking for self-generation technologies such as fuel cells, purchasing renewable energy from outside providers, etc.

b) Abatement initiatives for HP's product suppliers

- Provide suppliers with support tools and guidance on GHGs reduction
- Expanding Energy Efficiency Program (EEP) to more manufacturing suppliers
- Instituting specific emissions reduction initiatives with suppliers for GHG intensive operations, e.g., LCD panel manufacturing
- Requiring and monitoring suppliers' energy-saving action plan

c) Abatement initiatives for HP's transportation suppliers

- More efficient supply chain network
- Less environmentally impactful modes of transport
- Efficient product transportation providers
- Enhancing logistics through innovative packaging

In this case, HP is the focal company in its supply chain and it takes the proactive role in reducing the supply chain GHGs. Its supply chain partners are first tier manufacturers and transportation service providers. According to the emission reduction plan of HP, it requires suppliers to have voluntary emissions reduction targets and invests in joint projects together with transportation service providers to reduce transportation GHGs. In both activities, the supply chain emission trading program could align to HP's emissions reduction goals. This paper takes HP's emissions reduction targets as the example to explore the processes and effects of supply chain emission trading programs. HP is chosen as the case in this paper because it has published its supply chain GHGs footprint and reduction goals for years in its annual sustainable report. With the data availability, it is also feasible to choose any other cases for the quantitative analysis. The next sections are going to use the case of HP to verify and compare the model (A) (B) (C) by quantifying the cost change and supply chain GHGs reduction in each program.

2) Setting GHGs reduction targets

According to the sustainable report of HP, the reduction rate of emission intensity (emissions divided by the net revenue) for both supply chain partners and HP internal operation is 20% till 2020, compared to the base year 2010. In order to be consistent with annual emissions reduction projects, the targets are averagely divided into annual target and that is 2%. Due to the data availability, this paper assumes that 2013 is the base year. The net revenue of the year 2013 and 2014 are separately $ 112,298 million (HP, 2013) and $ 111,454 million (HP, 2014). Therefore, in 2014, product suppliers and transportation suppliers have to reduce 3% emissions compared to 2013. HP has to reduce 3% emissions till 2014 from its internal operation compared to the year 2013. Given the amount of GHGs in 2013 from HP product and transportation suppliers and HP operation (HP, 2013), the GHGs reduction targets for each supply chain partner and the whole supply chain till 2014 are listed in Tab 4-3.

Tab 4-3 Emission reduction targets in 2014

| | **t $CO_2$e** |
|---|---|
| **The total GHGs reduction target for HP suppliers** | 632,961 |
| **The total GHGs reduction target for HP operation** | 93,082.5 |
| **The GHGs reduction target for the whole supply chain** | 726,043.5 |

Source: HP (2014)

3) Identifying and assessing emissions abatement measures

Since it is not possible to get the cost data from HP for each emissions reduction project. Instead, this paper adopts cost and emissions data from one report released by 4 flow company (Gross et al., 2013). This report focuses on the core fields of logistics with the classic domains of transportation, transsphipment and warehousing. The measures serve as concrete and representative examples of the three levels of logistics: strategic, tactical and operational. Examples of measures from green logistics were explored concerning their ratio of implementation cost to effective emission reductions. The result of this study shows clearly the cost and emissions change of each measure. Based on the results of this study, the effects of different supply chain emission trading programs on cost and emissions are explored and compared in the next section.

The measures were grouped into four categories. This paper introduces concisely the main work about how to measure the cost and emissions change resulted by each measure, and the cost-benefit of each measure in reducing GHGs and saving cost is given in Figure 4-12. Detailed information could be found in the original report (Gross et al., 2013).

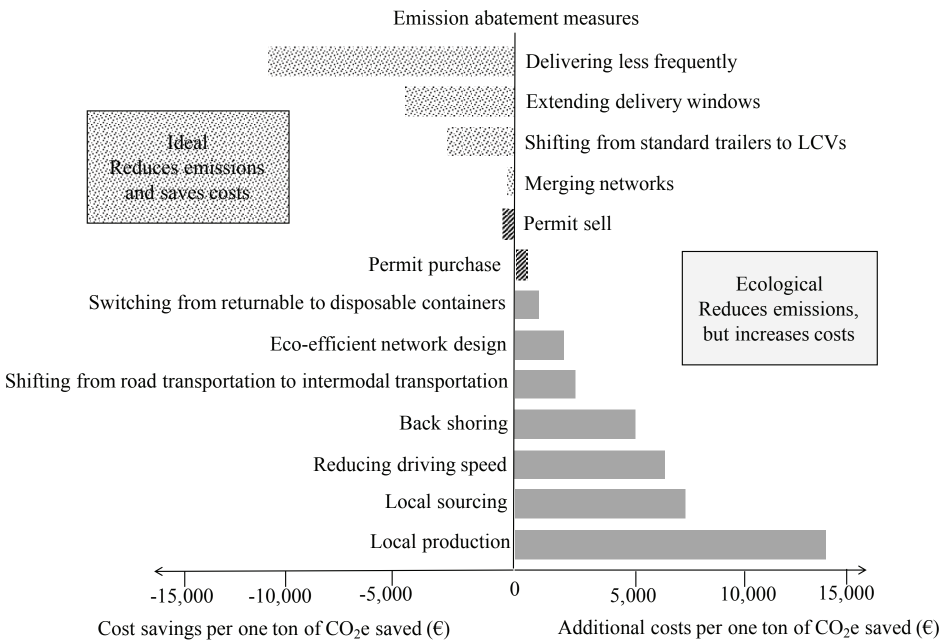


Figure 4-12 Cost and benefit of emission reduction projects

Source: Gross et al. (2013)

a) Designing networks differently

- Eco-efficient network design

The number of hubs and their position are determined by either minimizing transportation cost (scenario – cost-efficient network) or minimizing emissions (scenario – eco-efficient network). For both networks, the optimal configuration is that six hubs serve ten production plants spread across Europe. In the cost-efficient network, material flow from suppliers to production plants is consolidated to maximize truck utilization. In the eco-efficient network, material flow is decentralized and suppliers are allocated to the closest hub to minimize the total transportation distance. This study takes into account costs and emissions for transportation, handling of material, stock, floor space, and energy consumption for lighting and heating of the hubs.

- Merging networks

Independent automotive suppliers share joint hub networks in inbound logistics. This collaborative approach allows a better utilization of shipments from hubs to assembly plants, and therefore the reduction of transportation cost and emissions. The economic and ecological advantages are not distributed equally among the partners, but each partner was much better off than in the baseline scenario.

b) Relocating production

- Back shoring

Growing international competition has led companies to relocate working processes to low-wage countries thereby increasing transportation distances in their logistics network. In this case, offshore processes are brought back to a high-wage country (scenario – back shoring) and to a nearby medium-wage country (scenario – near shoring) to realize emission saving potential.

- Local production

Moving the production plant closer to the main clients is associated with shorter distance of distribution and higher labor cost. This study considers transportation costs for sourcing and distribution, inventory carrying cost, and production cost to calculate the cost-to-emissions ratio of plant relocation correlated to transportation emissions. Emissions from production are not considered since the energy mix in the plant was considered to be constant.

- Local sourcing

In the initial scenario, a plant in Southern Germany sources standard parts in Poland at an average distance of 1,000 km. Two additional scenarios are constructed where suppliers were situated at an average distance of 50 km and 200 km from the plant. A sensitivity analysis is performed to explore the effect distance has on the price per reduced ton of $CO_2$e.

c) Rethinking trucks and boxes

- Shifting from road transportation to intermodal transportation / Shifting from standard trailers to longer combination vehicles (LCV)

Shifting from carbon intensive transportation modes (e.g., road and air) to low carbon transportation modes (e.g., rail, ship) is widely advocated by academic researchers. However, limitations of intermodal transportation are overlooked. It results in additional cost from handling, carrying inventory, etc. This study finds out that the effects of these measures depend on the location of load as well as the delivery distance of goods. In terms of emissions, intermodal transportation outperformed standard trailers only on long-distance hauls and on relations with short pre-haul distances between the load facility and the hub location, provided the volume of goods shipped was high enough.

- Switching from returnable to disposable containers

Contrary to popular belief, this study finds that returnable containers are ecologically uncompetitive compared to disposable containers. Returnable containers are environmentally advantageous only for short distances when they are foldable and contain very heavy goods. This results in a high-weight, low-volume utilization of the truck. In addition, the production of returnable containers emits five or more times as much $CO_2$e per kg of container material than disposable containers.

d) Considering routing and time restrictions

- Reducing driving speed

Besides the baseline scenario with 70 km/h, two alternative scenarios are proposed with separate speed of 60 km/h and 50 km/h. Delivery routes are also changed depending on reduced driving speed. As a whole, reducing driving speeds led to an increase in the number of runs and kilometers driven in total, which was outweighed by the reduced emissions per kilometer. Labor costs were the main driver of the cost increase. Driving speeds between 50 km/h and 60 km/h reduced emissions by almost 4% compared to the baseline scenario of 70 km/h. However, it comes at a very high price. While a driving speed of 60 km/h led to 6% higher costs, a driving speed of 50 km/h resulted in an increase of up to 15%.

- Delivering less frequently

Different deliver patterns are analyzed including maximum number of delivery days, minimum number of delivery days, and most frequent pattern. For each pattern, shipment size for each customer is also adjusted according to the delivery frequency. With less trips needed to deliver goods, a reduced number of delivery days led to a decrease in handling and driving time. This contributes significantly to the total reduction of costs, especially in a high wage country such as Germany.

- Extending delivery windows

Scenarios are performed by extending the length of delivery windows on the base of baseline scenario including plus 30 minutes, 60 minutes, 90 minutes, and 120 minutes. Extended time windows enable the combination of more customers into one delivery trip, resulting in less distance traveled and a higher utilization of trucks.

4) Allocating emission abatement measures

In order to verify the effectiveness of each program and compare them according to the total cost change and GHGs reduction, this paper assumes HP and its suppliers (product suppliers and transportation service suppliers) would employ the aforementioned measures as examples. Each abatement measure is regarded as one emissions reduction project. HP and its suppliers are separately responsible for certain projects. It means, they are projects operators and take responsibility of the cost and administration fee, etc. The ratio of cost to emissions for measures in each category can be compared to the price of 1 t of $CO_2e$ at an emissions exchange to find the most economic way to reduce emissions. The effects of different abatement measures on cost and emissions change are listed in Tab 4-4.

Tab 4-4 Emission reduction projects allocation in supply chain

| Project operator | Emission abatement projects | Average cost change[1] (€/t $CO_2e$) | Cost change per year[1] (€) | Emission change per year[1] (t $CO_2e$) |
|---|---|---|---|---|
| HP | Eco-efficient network design | 2,427 | 23,056,000 | -9,500 |
| | Backshoring[2] | 5,003 | 6,754,000 | -1,350 |
| | Local production | 13,228 | 13,228,000 | -1,000 |
| | Local sourcing[3] | 7,500 | / | / |
| HP' product suppliers | Merging networks | -245 | -906,000 | -3,700 |
| HP' transportation suppliers | Shifting from road transportation to intermodal transportation | 2,705 | 3,000,000 | -1,109 |
| | Shifting from standard trailers to longer combination vehicles (LCV) | -2,054 | -924,000 | -450 |
| | Switching from returnable to disposable containers[4] | 1,000 | / | / |
| | Reducing driving speed[5] | 6,330 | 2,025,000 | -320 |
| | Delivering less frequently[6] | -4,496 | -10,000,000 | -2,250 |
| | Extending delivery windows[7] | -3,245 | -4,543,000 | -1,400 |

[1]: The data is roughly read from the figures in the report; minus "-" means emissions/cost is reduced.

[2]: The data is selected from scenario A – near shoring.

[3]: Data for local sourcing is missing from the original report.

[4]: The data is not considered in this paper.

[5]: The data is selected from scenario A – 60km/h.

[6]: The data is selected from scenario B – minimum number of delivery days.

[7]: the data is selected from scenario D – + 120 min.

Source: Gross et al. (2013)

5) Assumptions

To perform this numerical analysis, several assumptions are defined.

- These emission abatement projects can be implemented simultaneously without any interaction on the effectiveness.
- All projects are assumed to be effective in one year.
- The price of permit is 30 euro per unit for all baseline scenarios.
- The penalty for each unit of emissions that failing to meet the emissions reduction target is 100 euro.
- The cost for investing into credit projects including registration, monitor, and verification is assumed as 1,000 euro per project.

These assumptions are defined without hurting the validity of these supply chain emission trading programs. The intention of using this example should be noted.

a) Firstly, some of these measures have similarity and might not be implemented at the same time for one company, but it is possible to apply them to different plant locations of the company. In addition, implementing different abatement measures simultaneously would probably somehow dwarf the effectiveness of them. The final effectiveness is not the simple sum of the effectiveness of different abatement measures as shown in this example. But there should be abatement measures that are unrelated to each other. For example, adopting one green technology in production plant will not influence the effect of transferring transportation mode. For practical application, companies should take this into account when they are investigating the cost and benefit of each abatement measure. In this example, such kind of interaction is assumed out for similarity.

b) Secondly, authors intend to take these measures as one example to show how emission trading could be employed in the context of supply chain and what kind of effects can it bring. In our example, the set of emission abatement measures is small (nine abatement measures being considered) and the span of average abatement cost is large (from -4,496 to 13,228 euro per tone $CO_2e$). A different set of abatement measures would result in different cost, benefit, and average cost on the company and supply chain. In practice, supply chain companies must have a much larger set of abatement measures than those analyzed in this paper. The cost of different abatement measures could be either positive or negative. Despite of a larger and more diversified set of emissions abatement measures in practice, companies are able to follow the processes proposed in this example to manage their supply chain carbon emissions. The results of the sensitive analysis from the case study also provide some common features which could be taken into account by companies and policy makers.

c) In addition, the assumption for the price of permit, penalty, and CDM cost could be easily adjusted by sensitive analysis in order to observe the influences of them on the final result.

d) Furthermore, with the availability of the example, it provides opportunities for authors to compare the effects of different programs on emissions and cost. Since this paper keeps same assumptions consistently in all scenarios in different programs, the results are comparable. The result of the comparison is general for all supply chain emission trading programs; whatever abatement measures are included there.

e) Last but not least, the case analysis also provides one standpoint for authors to explore the challenges involved in each program.

### 4.3.2 Measuring cost-benefit of each program

a) Supply chain permit trading program

The emissions reduction target is allocated to the supply chain as a whole. The targeted companies would follow the decision processes as shown in Figure 4-13.

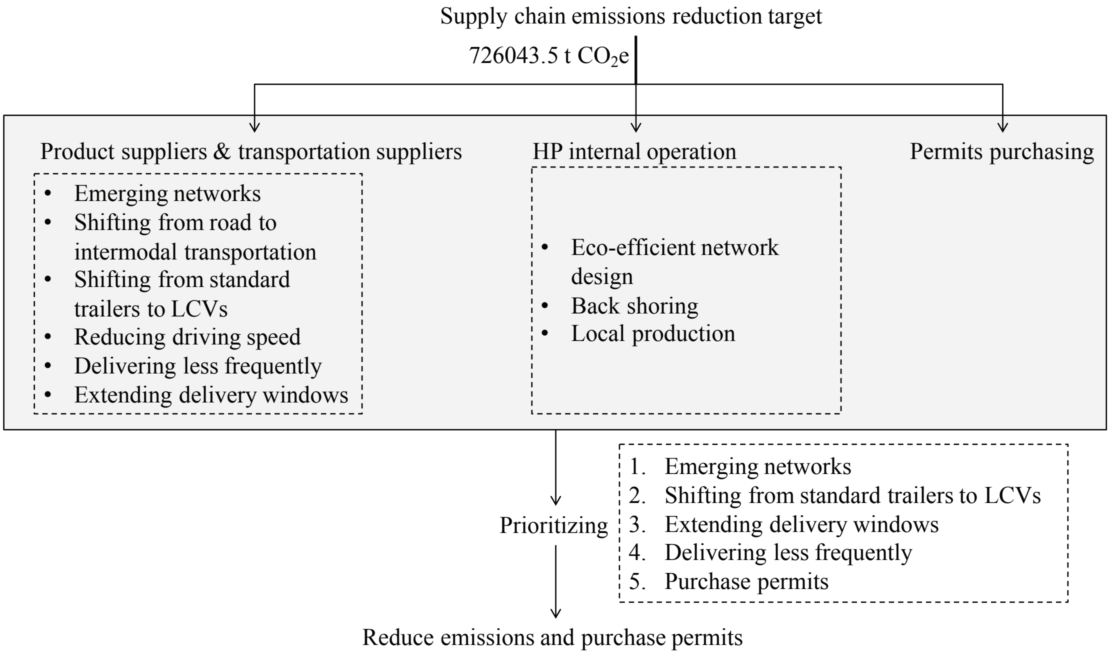


Figure 4-13 Decision processes of supply chain permit trading program

The total emissions reduction target is the sum of target on HP's suppliers and target on HP internal operation. Emission abatement measures are prioritized according to the average abatement cost (from negative to positive, from small to big). The calculation processes of the basic scenario program (a1) are listed in Tab 4-5.

Tab 4-5 Supply chain permit trading – cap and trade (a1)

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for all supply chain partners as a whole** | | | -726,043.5 | |
| **Emission abatement measures** | Merging networks | -245 | -3,700 | -906,000 |
| | Shifting from standard trailers to LCV | -2,054 | -450 | -924,000 |
| | Delivering less frequently | -4,496 | -2,250 | -10,000,000 |
| | Extending delivery windows | -3,245 | -1,400 | -4,543,000 |
| | Permit purchase | 30 | -718,243.5 | 21,547,305 |
| **The final emissions change (sum)** | | | -726,043.5 | |
| **The final cost change (sum)** | | | | 5,174,305 |
| **Average cost change** | | 7.126 | | |

Source: Own calculations

Supply chain companies in this program would choose the ideal measures at the first and for the rest target they would compare the permit price to the average abatement cost of other measures. If the price of permits is lower, then they would purchase permits from the emission market and vice verse.

When the supply chain is not subject to emission trading, it has to employ self-reduction measures to meet its emissions reduction target. If the target is not satisfied, the company has to accept the penalty. The calculation processes of this scenario program (a2) are presented in Tab 4-6.

Tab 4-6 Supply chain permit trading – cap and penalty (a2)

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for all supply chain partners** | | | -726,043.5 | |
| **Emission abatement measures** | Merging networks | -245 | -3,700 | -906,000 |
| | Shifting from standard trailers to LCV | -2,054 | -450 | -924,000 |
| | Delivering less frequently | -4,496 | -2,250 | -10,000,000 |
| | Extending delivery windows | -3,245 | -1,400 | -4,543,000 |
| **Penalty** | | 100 | -718,243.5 | 71,824,350 |
| **The final emissions change (sum)** | | | -726,043.5 | |
| **The final cost change (sum)** | | | | 55,451,350 |
| **Average cost change** | | 76.375 | | |

Source: Own calculations

It could be seen that the difference between cap and penalty and cap and trade is that in cap and penalty, companies are punished at a fixed price while in cap and trade, the price of permit is fluctuating. Given baseline parameters, the above result shows that employing emission trading could be more cost-effective than cap and penalty for reducing supply chain GHGs when the price of permit is lower than the fixed penalty. The cost-effectiveness becomes small when the price of permit increases. In order to improve the green investment of supply chain companies, government could regulate the penalty level per unit of emissions. When it is high enough, companies would transfer to internal abatement measures. In the same principle, proper interventions of government in the price of permit are recommended.

In addition, in both cases the cost increases much for supply chain companies. How should the cost increment be allocated to each supply chain partner remains to be solved in practice. Since HP's suppliers implement all the ideal measures, should HP itself take all of the increased cost? Should HP's suppliers also be responsible for the total increased cost as well? If ETS is going to include supply chain GHGs, these questions have to be addressed at the first.

If the emissions reduction targets are separately allocated to HP suppliers and HP operation, the cost-benefit calculation processes of scenario (a3) and scenario (a4) are separately presented in Tab 4-7 and Tab 4-8.

Tab 4-7 HP permit trading – cap and trade (a3)

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for HP only** | | | -93,082.5 | |
| **Emission abatement measures** | Permit purchase | 30 | -93,082.5 | 2,792,475 |
| **The final emissions change (sum)** | | | -93,082.5 | |
| **The final cost change (sum)** | | | | 2,792,475 |
| **Average cost change** | | 30 | | |

Source: Own calculations

Tab 4-8 HP's suppliers permit trading – cap and trade (a4)

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for HP's suppliers only** | | | -632,961 | |
| **Emission abatement measures** | Merging networks | -245 | -3,700 | -906,000 |
| | Shifting from standard trailers to LCV | -2,054 | -450 | -924,000 |
| | Delivering less frequently | -4,496 | -2,250 | -10,000,000 |
| | Extending delivery windows | -3,245 | -1,400 | -4,543,000 |
| | Permit purchase | 30 | -625161 | 18,754,830 |
| **The final emissions change (sum)** | | | -632,961 | |
| **The final cost change (sum)** | | | | 2,381,830 |
| **Average cost change** | | 3.763 | | |

Source: Own calculations

From the above two tables, the results show that both joint- and separate- employment will bring the same cost change and same emission reduction from the level of supply chain. But employing emission trading separately on supply chain partners would reduce the average cost for HP internal while increase the average cost for HP. This is because HP supplier is more cost-effective than HP internal in emission reduction. Distributing the cost change between supply chain partners should take the method of supply chain collaboration into account.

b) Supply chain credit trading program

In this program, the emissions reduction target is allocated only to HP internal operation. The targeted companies could follow the decision processes shown in Figure 4-14.

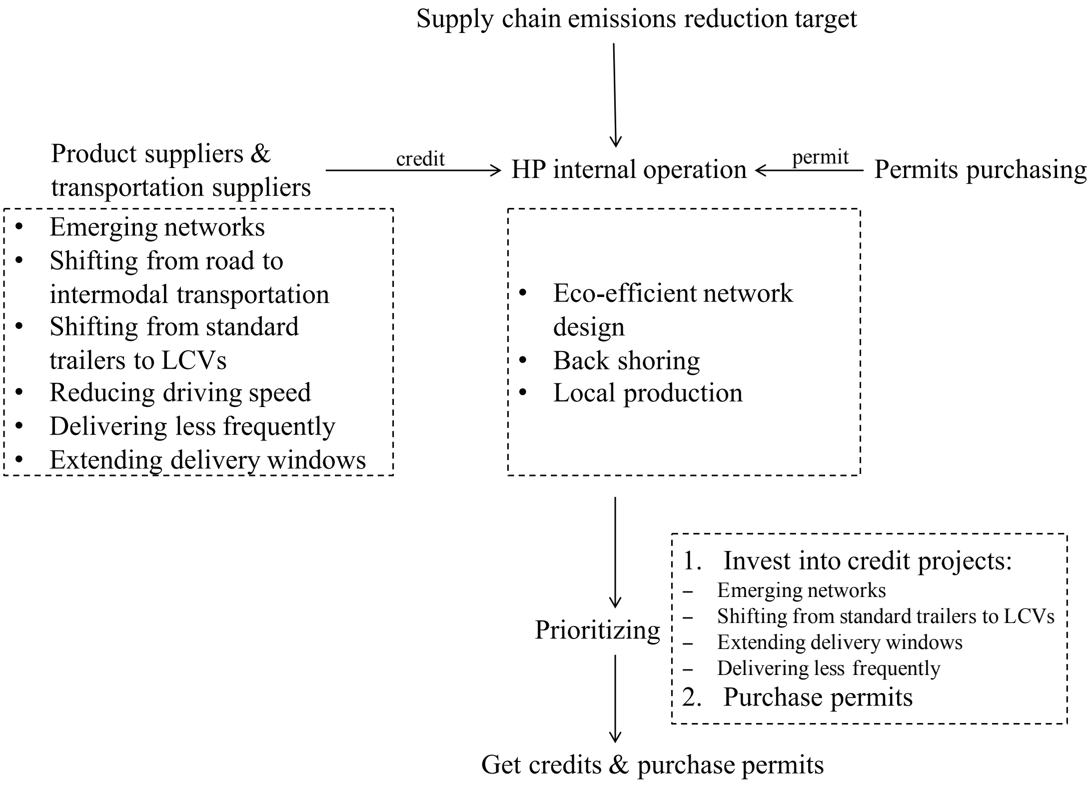


Figure 4-14 Decision processes of supply chain credit trading program

HP is assumed to be subject to emission trading, and it is allowed to invest into credit projects in the range of its supply chain. It means that, HP could invest into emission abatement measures in product suppliers and transportation suppliers. The cost of emissions reduction is fully taken by HP under the credit program. The calculation processes of the basic scenario program (b1) are presented in Tab 4-9.

Tab 4-9 Supply chain credit trading – cap and trade (b1)

| | | Average cost (€/t $CO_2e$) | Emissions reduction (t $CO_2e$) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for HP only** | | | -726,043.5 | |
| **Emission abatement measures** | Merging networks | -245 | -3,700 | -906,000 |
| | Shifting from standard trailers to LCV | -2,054 | -450 | -924,000 |
| | Delivering less frequently | -4,496 | -2,250 | -10,000,000 |
| | Extending delivery windows | -3,245 | -1,400 | -4,543,000 |
| | Permit purchase | 30 | -718,243.5 | 21,547,305 |
| **Administration fee for credit projects** | | | | 1,000*4=4,000 |
| **The final emissions change (sum)** | | | -726,043.5 | |
| **The final cost change (sum)** | | | | 5,178,305 |
| **Average cost change** | | 7.132 | | |

Source: Own calculations

The cost of investing into credit program should be taken into account. In this paper the cost for each credit project concerning registration, monitor, and verification is assumed as 1,000 euro. Due to the additional cost incurred by credit projects' administration, the final result differs little from supply chain permit trading program. The difference will get bigger when the credit administration cost is assumed higher.

However, this program makes it clear that how the increased cost is allocated to supply chain partners. HP, subject to emission trading, is taking full responsibility of the increased cost. Why HP would accept it? In order to answer the question, this paper would like to quantify the cost-effectiveness of two other scenarios. Scenario (b2): HP is subject to emission trading which doesn't allow the use of credits. Scenario (b3): HP is subject to cap and penalty. The cost and benefit of both scenarios are separately calculated in Tab 4-10 and Tab 4-11.

Tab 4-10 HP without credit trading – cap and trade (b2)

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|---|
| **Emissions reduction target for HP only** | | | -726,043.5 | |
| **Emission abatement measures** | Permit purchase | 30 | -726,043.5 | 21,781,305 |
| **The final emissions change (sum)** | | | -726,043.5 | |
| **The final cost change (sum)** | | | | 21,781,305 |
| **Average cost change** | | 30 | | |

Source: Own calculations

The average cost of reducing one unit of emissions remains as same as the situation where HP is subject separately to emission trading because in this example HP internal abatement measures cost more than purchasing permits for reducing each unit of emissions. To be cost-effective, HP chooses to purchase permits to meet their emission reduction targets in both cases. The difference is that HP in this case has a larger emissions reduction target and it takes the full responsibility of reducing GHGs in its supply chain. The total cost increases when the emissions reduction target increases (i.e., the cap becomes smaller).

Tab 4-11 HP without credit trading – cap and penalty (b3)

| | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€) |
|---|---|---|---|
| **Emissions reduction target for HP only** | | -726,043.5 | |
| **Penalty** | 100 | -726,043.5 | 72,604,350 |
| **The final emissions change (sum)** | | -726,043.5 | |
| **The final cost change (sum)** | | | 72,604,350 |
| **Average cost change** | 100 | | |

Source: Own calculations

The company who has an extreme tight emissions reduction target would pay a lot for the penalty if no compliance is taken. In this case, it would either seek for supply chain collaboration (supply chain permit trading program) or join emission trading to release the cost pressure.

c) Supply chain offset trading program

In this program, the emissions reduction target is allocated only to HP internal operation. The targeted companies might follow the decision processes shown in Figure 4-15.

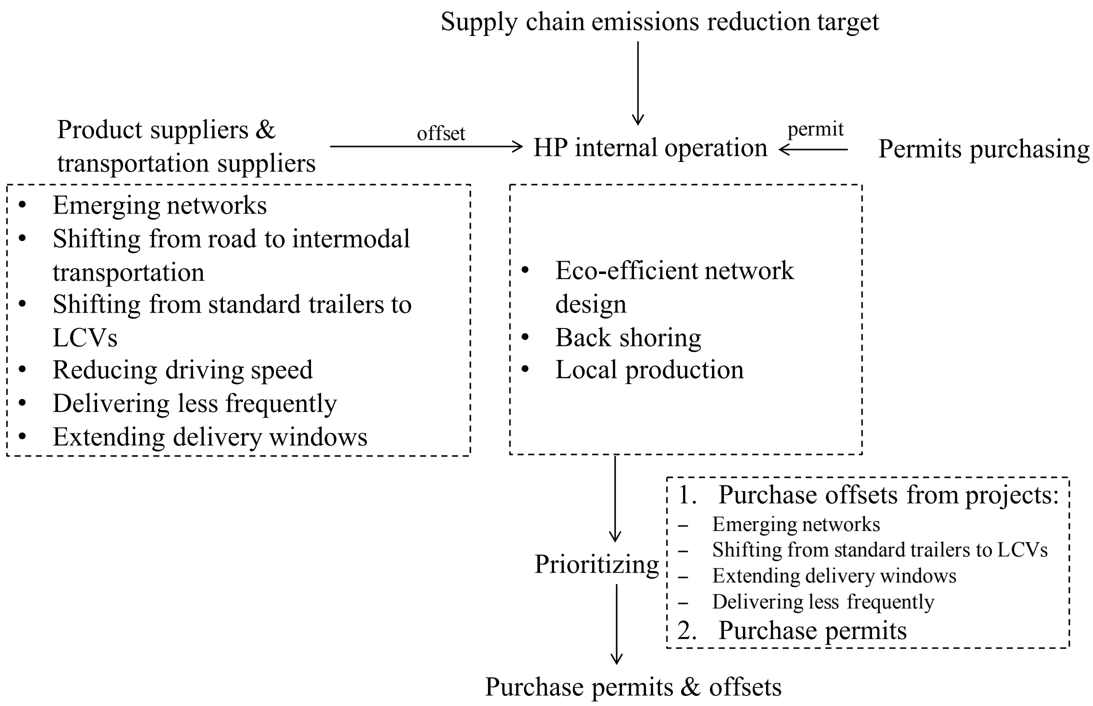


Figure 4-15 Decision processes of supply chain offset trading

The calculation processes are presented in Tab 4-12. Decision processes in this program are elaborated after the table in the next page.

Tab 4-12 Supply chain offset trading – cap and trade

| | | Average cost (€/t $CO_2$e) | Emissions reduction (t $CO_2$e) | Cost change (€ ) |
|---|---|---|---|---|
| **Emissions reduction target for HP only** | | | -726,043.5 | |
| **Emission abatement measures** | Merging networks | -245 | -3,700 | -906,000+1,000= -905,000 |
| | Shifting from standard trailers to LCV | -2,054 | -450 | -924,000+1,000= -923,000 |
| | Delivering less frequently | -4,496 | -2,250 | -10,000,000+1,000= -9,999,000 |
| | Extending delivery windows | -3,245 | -1,400 | -4,543,000+1,000= -4,542,000 |
| | Permit purchase | 30 | -718,243.5 | 21,547,305 |
| **The final emissions change (sum)** | | | -726,043.5 | |
| **The final cost change (sum)** | | | | 5,178,305 |
| **Average cost change** | | 7.132 | | |

Source: Own calculations

HP is assumed to be subject to emission trading, and it is allowed to use offsets as additional permits in existing markets. It means that, suppliers invest into emissions abatement measures and sell offsets to HP at a certain price for each unit of emissions. HP and its suppliers collaborate and share the cost in the offset trading program depending on the price of offsets. Suppliers will embrace the cost of investing into offset projects and the revenue by selling offsets. HP will cover the cost for purchasing offsets and permits.

The cost-effectiveness of the supply chain offset program equals to the supply chain credit program. The only difference is that suppliers pay for the credit project administration cost in offset program. Note that in the supply chain offset program, suppliers (offset sellers) are able to influence the price of offsets. The price of offsets could be lower than the cost when suppliers are collaborating with HP (offset buyers) in reducing supply chain GHGs. It could also be higher than the cost when sellers want to make a profit from the offset trading. But the price of offset should not exceed the price of permits in the market, or else HP would choose to purchase permits.

In this special example, the costs of adopted abatement measures are all negative. It means that suppliers could not reduce GHGs but also save cost by investing into these ideal measures. When suppliers would like to collaborate with HP in emissions reduction, they can pass through a certain proportion of the benefit to HP.

Given the four ideal emission abatement projects, corresponding project developers have large margin to decide the price of offsets in the OTC mode. Let $p_i$ denote the price of offsets created from project $i, i = 1,2,3,4$ and project $i$ denote the four ideal emission abatement measures in above figures. For example, for the project emerging networks, the price margin for benefiting both parties is $-245 < p_i < 30$. The offset seller can decide either to share the cost saving with buyers $(-245 < p_i < 0)$ or charge buyers a price lower than the permit $(0 < p_i < 30)$. For both cases, both the buyer and the seller of offsets achieve a win-win situation.

In addition, the special example in this paper assumes that there're only two offset providers (i.e., HP product supplier and HP transportation supplier) and they have limited credit projects which create limited amount of offsets. Supposing there're many offset providers in the market and the company can choose the seller according to the price of offset, setting the price of offset would be also influenced by other offset providers in the same market.

### 4.3.3 Results and sensitive analysis

1) Results of each scenario

The last section has quantified the cost and benefit of each scenario in each supply chain emission trading program. The results of each scenario are shown in Figures in below.

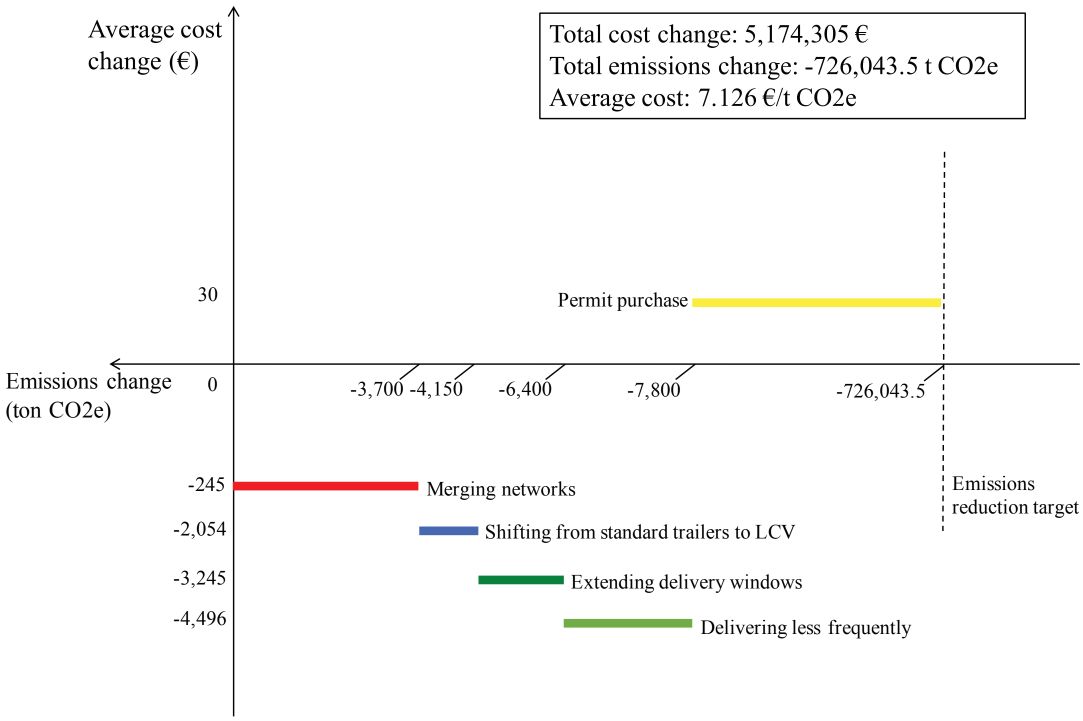


Figure 4-16 Results of scenario (a1)

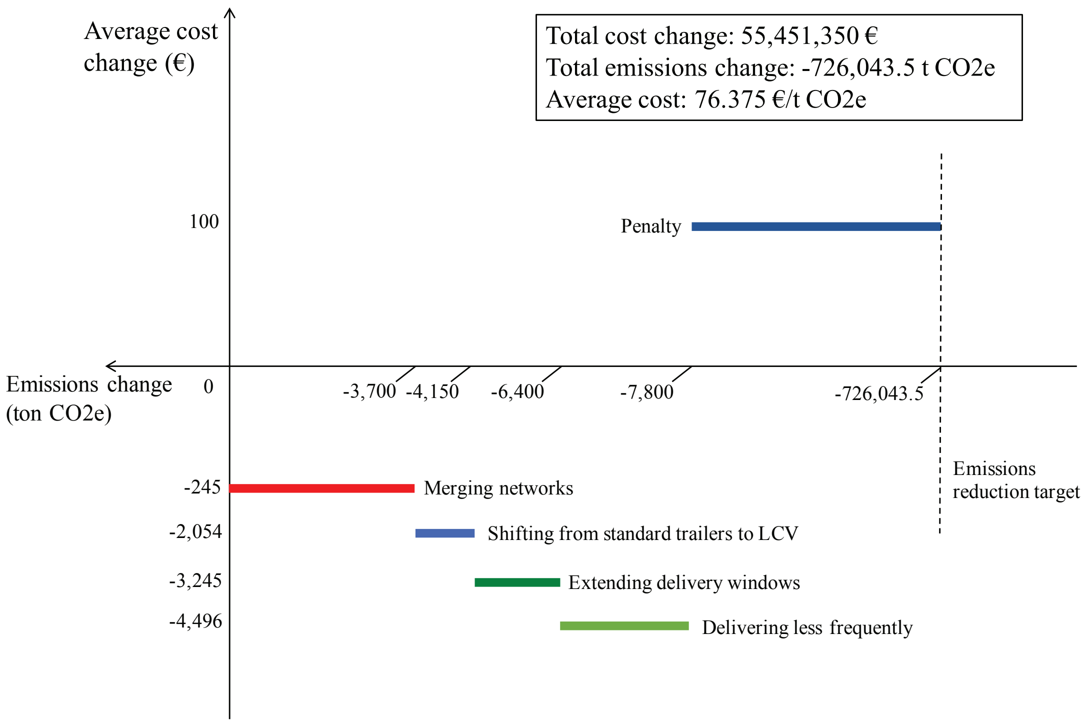


Figure 4-17 Results of scenario (a2)

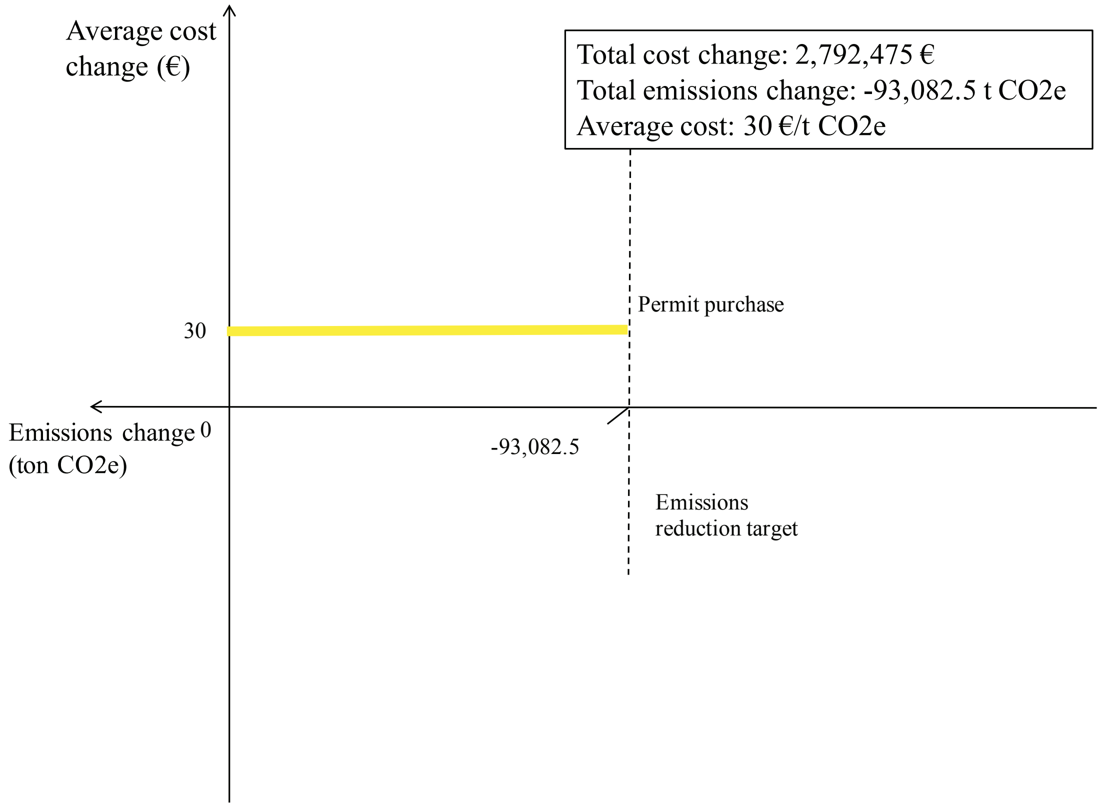


Figure 4-18 Results of scenario (a3)

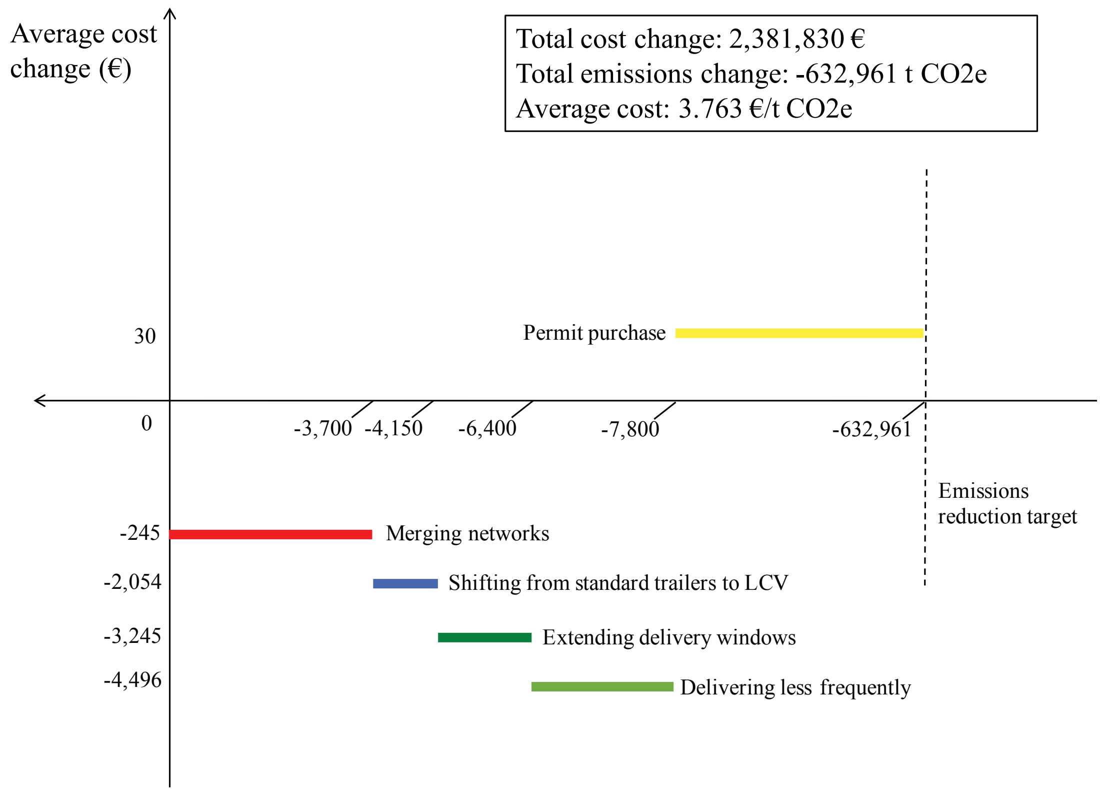


Figure 4-19 Results of scenario (a4)

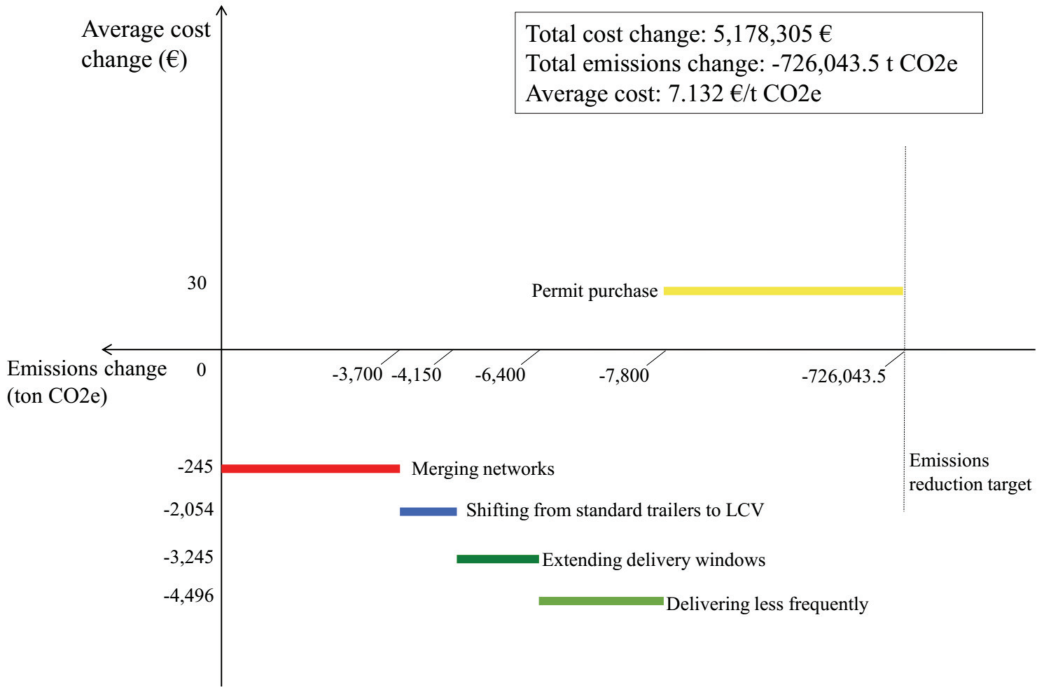


Figure 4-20 Results of scenario (b1)

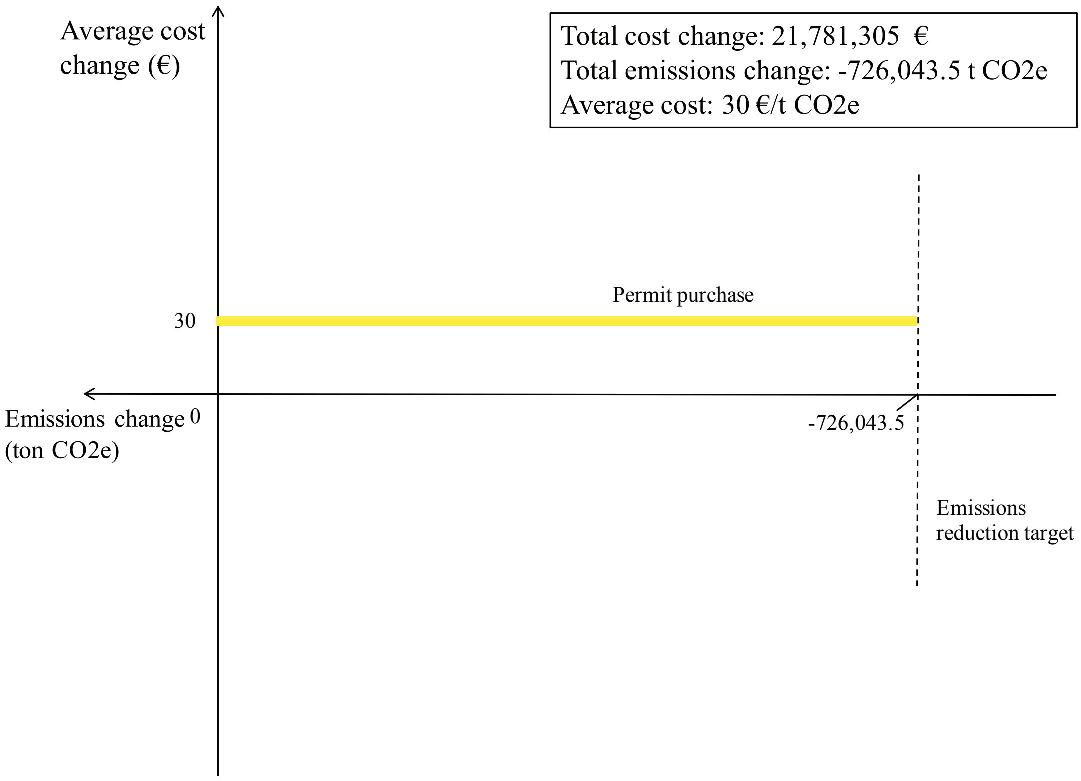


Figure 4-21 Results of scenario (b2)

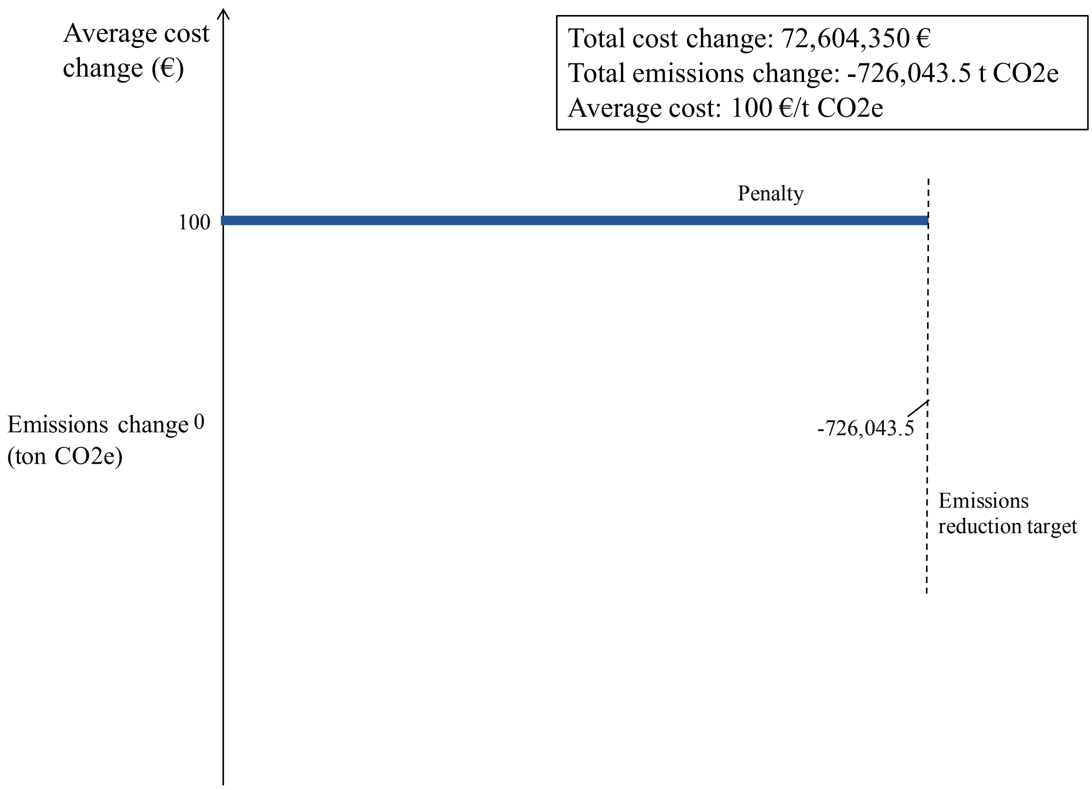


Figure 4-22 Results of scenario (b3)

Considering the particularity and individuality of the case study, the absolute numerical results cannot provide any meaningful and adaptable value for any other cases. Only the comparative results and the results from a sensitive analysis can be used. Therefore, this paper is going to give a comparative analysis as well as a sensitive analysis based on the results.

2) Comparative analysis

a) Comparing programs according to the average abatement cost change (Figure 4-23)

Comparing the scenarios within model A: The supply chain permit trading program (a1) is the most cost-effective program among all scenarios and it is followed by the supply chain credit trading program (b1). In addition, the supply chain offset trading program is as same cost-effective as the supply chain credit trading program from the supply chain perspective. Scenario (a2) has a higher average abatement cost change than scenario (a1) because the penalty of one unit of emissions is set higher than the price of one unit of permit. Comparing scenario (a1) to scenario (a3) and (a4), including supply chain partners jointly into ETS would decrease the cost for some while increase for others. It averages the cost saving and emission reduction generated from emission reduction projects among the level of supply chain.

Comparing the scenarios within model B: The supply chain credit trading program (b1) is also more cost-effective than scenario (b2) and (b3) where HP is not accessible to credit trading and ETS. By assigning the total supply chain GHGs reduction target to the focal company in the supply chain, the focal company is confronted with increased cost incurred by investment into internal GHGs reduction measures. Allowing the focal company to join ETS and use supply chain credits in ETS would reduce the total cost to the largest extent. Compared to scenario (b2), scenario (b1) minimizes the GHGs reduction cost from the range of supply chain. Compared to scenario (b3), it minimizes the GHGs reduction cost from the whole society.

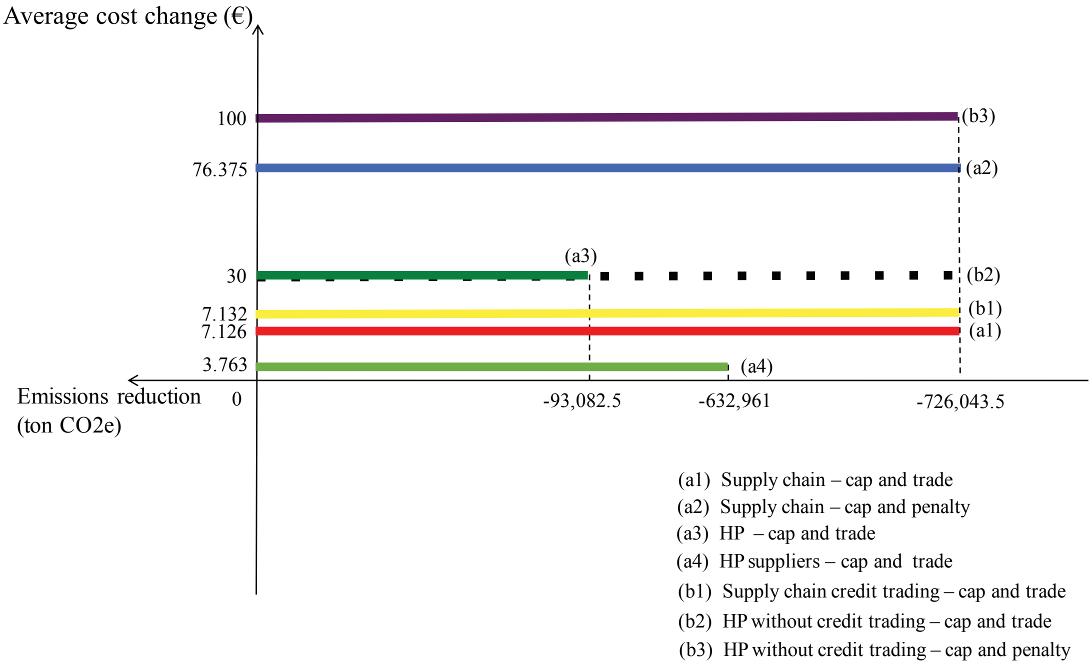


Figure 4-23 Average abatement cost change of different scenarios

Comparing the scenarios of model A to the scenarios of model B: The average cost change of scenario (b1) is relatively larger than that of scenario (a1) because in scenario (b1) the administrative cost of developing credit projects are taken into account. Comparing scenario (a3) and (b2), the average cost change for these two scenarios are same but scenario (b2) has a larger emission reduction. This is because in both scenarios the emission reduction target is given to the focal company (i.e., HP) but scenario (a3) has a smaller emission reduction target than scenario (b2). Since HP has no cost-effective emission abatement measures other than purchasing permits, it chooses to purchase permits to achieve the entire emission reduction target. Therefore, the average cost change is same for both scenarios and it equals to the price of permits. Comparing scenario (a2) and (b3), the average cost change of scenario (a2) is smaller than scenario (b3). Both scenarios are confronted with the same emission reduction target. Given no access to ETS, companies have to pay for the penalty when their emission reduction targets are not achieved. Scenario (a2) has a smaller average cost change because it allows the transferring of reduced emission units within the supply chain while the scenario (b3) doesn't allow the focal company to invest into credit projects in other supply chain partners.

b) Comparing programs according to the total supply chain GHGs and cost change (Figure 4-24)

Comparing the total cost and GHGs change of each scenario in each program shows that scenario (a3) brings the smallest cost change among others. This is because in scenario (a3) a separate cap (i.e., sub-supply chain GHGs reduction target) is given to HP. This target is smaller than the targets in other scenarios. Therefore, scenario (a3) results in the smallest cost change as well as the smallest GHGs reduction. Comparatively, scenario (a4) has a larger cost and GHGs change than scenario (a3).

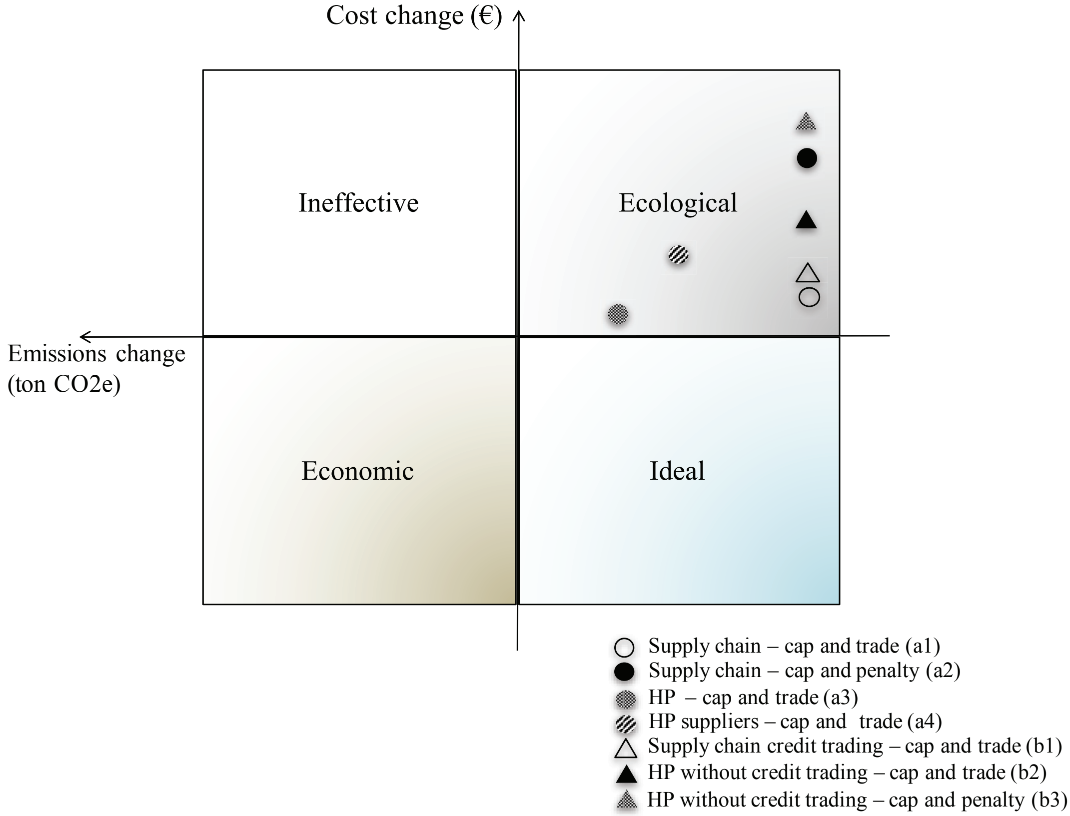


Figure 4-24 Total supply chain cost and emission change

Except scenario (a3) and scenario (a4), all other scenarios have the same GHGs reduction. For these scenarios, a same total supply chain GHGs reduction target is applied. The target is given to the whole supply chain in scenario (a1) and scenario (a2) while the target is issued to only the focal company (i.e., HP in the case study) in scenario (b1), (b2), and (b3). In scenario (a1) and (b1), it allows the supply chain GHGs target to be achieved by collaborative efforts from the whole supply chain. Therefore, these two scenarios have relatively lower cost change than others. In scenario (a2) and (b3), the cost change is largely influenced by the penalty level for each unit of GHGs. The result would change depending on the different settings of penalty.

3) Sensitive analysis

a) Changing the price of permit

This section does a sensitive analysis and aims to analyze the impacts of changing permits' price (€) on the average cost change (€) for achieving the emission reduction target in each scenario (see Tab 4-13). Due to the specialty of the example in the case study (i.e., the costs of emission abatement measures chosen in the case study are largely varied), the price of permit ranges from 30 to 6000 euro in the sensitive analysis. Although the data adopted in the case study is from specific cases, it is feasible to find out some common trends from the sensitive analysis. Since scenario (a2) and (b3) are considering the penalty with a fixed price, these two scenarios are removed from the sensitive analysis.

Tab 4-13 Average cost change to the change of permits' price

| | 30 (€) | 100 (€) | 1000 (€) | 2000 (€) | 3000 (€) | 4000 (€) | 5000 (€) | 6000 (€) |
|---|---|---|---|---|---|---|---|---|
| **a1 (€/t $CO_2$e)** | 7.126 | 76.375 | 966.7 | 1942.19 | 2937.27 | 3911.9 | 4886.56 | 5859.35 |
| **a2 (€/t $CO_2$e)** | / | 76.375 | / | / | / | / | / | / |
| **a3 (€/t $CO_2$e)** | 30 | 100 | 1000 | 2000 | 2941.5 | 3839.45 | 4737.39 | 5620.87 |
| **a4 (€/t $CO_2$e)** | 3.763 | 72.9 | 961.8 | 1949.49 | 2936.65 | 3922.57 | 4829.5 | 5894.42 |
| **b1 (€/t $CO_2$e)** | 7.132 | 76.38 | 966.71 | 1942.19 | 2937.28 | 3911.92 | 4886.57 | 5859.35 |
| **b2 (€/t $CO_2$e)** | 30 | 100 | 1000 | 2000 | 2992.5 | 3979.42 | 4966.35 | 5951.39 |
| **b3 (€/t $CO_2$e)** | / | 100 | / | / | / | / | / | / |

Source: Own calculations

It is clear to see from the above table that the average cost change for all scenarios increases as the price of permit increases. Scenario (b1) has a relatively higher average cost change than scenario (a1) for all price settings of permits. This is because scenario (b1) takes the administrative cost of developing credit projects additionally into account. The cost difference between these two scenarios depends on the administrative cost of credit projects.

Among them, the scenario (b2) has always the largest average cost change among others in all price settings of permits. This is because this scenario has the largest emission reduction target and is not allowed to invest into credit projects in the supply chain. Furthermore, companies can get a lower average cost change when they have more options for proper emission abatement measures.

Comparing to scenario (a1), the difference of average cost change between scenario (a1) and (a3) is varying according to the change of permits' price. Assuming companies always choose the most cost-effective way to achieve emission reduction targets, when the price of permits is increasing, companies are confronted with a larger range of options for emission reduction. Let $p$ denote the price of permits. When $p$ is increased, companies could invest more into emissions reduction projects to meet their targets. Due to the increased price of $p$, companies are also motivated to proactively reduce emissions from projects and sell extra emissions to permit trading markets with a higher price. Hence, a higher price of $p$ would promote investment into emissions reduction projects. When the price falls, companies are inclined to buy permits as the compliance to reach their targets. However, because the price of permit is influenced by supply and demand of market, the price will increase in turn due to the large demand and decrease due to the small demand.

b) Changing the emission reduction target

This section does a sensitive analysis and aims to analyze the impacts of changing emission reduction targets (t $CO_2$e) on the average cost change (€) in each scenario (see Tab 4-14).

As the emission reduction target increases (i.e., cap decreases), the average cost change of most scenarios increase, from negative to positive, from small to large. This makes sense because reducing larger amount of emissions requires larger investment into emission abatement measures including internal, external, and market measures. When the emission reduction target is zero (i.e., no emission reduction target is applied), corresponding average cost change is zero. This is the basic situation to which other scenarios are compared.

Note that scenario (a1), (a2), (a4), and (b1) have negative average cost change before the emission reduction target comes to a certain point. This is because these scenarios are optional to adopt a range of ideal measures. The average cost change of both scenario (a3), (b2), and (b3) is not varied as the emission reduction target increases. In scenario (a3) and (b2), the focal company to which the emission reduction target is given chooses to purchase permits to achieve the entire emission reduction target. In scenario (b3), the company would pay for the penalty instead of investing into emission reduction measures cause the penalty is even lower than emission abatement costs. Therefore, the average cost change keeps still as the price of permits or the amount of penalty.

Tab 4-14 Average cost change to the change of emission reduction target

| | **5,000 (t $CO_2$e)** | **50,000 (t $CO_2$e)** | **100,000 (t $CO_2$e)** | **500,000 (t $CO_2$e)** | **600,000 (t $CO_2$e)** | **726,043.5 (t $CO_2$e)** |
|---|---|---|---|---|---|---|
| **a1/a4 (€/t $CO_2$e)** | -2109.87 | -302.14 | -136.07 | -3.214 | 2.322 | 7.127 |
| **a2 (€/t $CO_2$e)** | -2109.87 | -243.06 | -71.53 | 65.69 | 71.41 | 76.375 |
| **a3/b2 (€/t $CO_2$e)** | 30 | 30 | 30 | 30 | 30 | 30 |
| **b1 (€/t $CO_2$e)** | -2109.36 | -302.06 | -136.03 | -3.206 | 2.328 | 7.132 |
| **b3 (€/t $CO_2$e)** | 100 | 100 | 100 | 100 | 100 | 100 |

Source: Own calculations

The impact of changing the emission reduction target on the average cost change for scenario (a1) and (a4) is the same because these two scenarios have same range of emission abatement measures. Companies in the two scenarios would make same decisions to achieve the emission reduction target. The same principle also applies to scenario (a3) and (b2).

It is worthy to note that when the emission reduction target is 5000 t $CO_2$e, scenario (a1), (a2), (a4) and (b1) can adopt ideal emission abatement measures to reduce 7800 t $CO_2$e. 5000 t $CO_2$e will be used and retired in ETS and the other 2800 t $CO_2$e are sold to emission market at the price of 30 € per t $CO_2$e. Therefore, in this case, companies cannot only save cost by investing into ideal emission abatement measures, but also make earnings from selling extra permits to emission markets.

Given other parameters, the change of $cap$ could result in the change of total emissions reduction and cost. When $cap$ increases, it will decrease the cost for companies because the required emissions reduction becomes smaller for companies. When $cap$ decreases, it would increase the cost for companies by investing into emissions reduction projects or purchasing permits. As a result, setting proper values of $cap$ and $p$ are directly affecting the market volatility of permit trading and the initiatives in emission reduction projects.

## 4.4 Summary

This chapter proposed three programs as optional policy interventions to manage supply chain GHGs: supply chain permit trading program, supply chain credit trading program, and supply chain offset trading program.

Among them, the supply chain permit trading program, taking the supply chain as a single unit, is the most cost-effective program in reducing supply chain GHGs. The supply chain credit trading program and the supply chain offset trading program apply to the supply chain that is composed of multiple supply chain partners with different interests. In these two programs, the total supply chain GHGs reduction target is assigned to the focal company in the supply chain only. In the supply chain credit program, the focal company of the supply chain develops and invests into emission reduction projects, and gets credits in turn. Whilst in the supply chain offset trading program the focal company buys offsets from supply chain partners that develop and invest into emission reduction projects. From the supply chain perspective, the supply chain credit trading program is as cost-effective as the supply chain offset trading program. The total cost of these two programs includes in addition the administrative cost incurred by registering and monitoring emission reduction projects. Furthermore, the offset program introduces many options for the supply chain collaboration in reducing supply chain GHGs through the provision of price setting of offsets.

In addition, multiple scenarios are proposed in each program. Though using data from specific conditions, the case study shows still reliable results through the comparative and sensitive analysis. The supply chain permit trading program is the most cost-effective program among others and it is followed by the supply chain credit trading program. These two programs reduce the total cost by allowing the reduced GHGs units transferred within the supply chain. Besides, setting a common GHGs reduction target on the whole supply chain is more cost-effective than setting separate targets on individual supply chain partner. All supply chain partners have to pay more to reach the corresponding GHGs reduction target than under a common target. Last but not least, as verified by most literature, this paper also finds that the average cost change of each scenario in each program has positive relation to the price of permits and the emission reduction target.

# 5. Implementation of emission trading in the context of supply chain

The aforementioned case study has verified the cost-effectiveness of supply chain emission trading programs from the theoretical (mathematical) perspective. Implementing emission trading in supply chain involves the participation of various parties such as government policy-maker, supply chain manager or coordinator, MRV system for supply chain, supply chain GHGs accounting, and so on. An appropriate collaboration and transfer of knowledge among these parties is the prerequisite of effective supply chain GHGs reduction. This chapter discusses the possible mechanisms to implement each program and analyzes challenges as well as opportunities involved in the processes of designing and implementing each program. At last, it employs knowledge management (KM) processes in the area of supply chain GHGs management and provides implications of KM for managing supply chain GHGs at strategic, tactical, and operational levels.

## 5.1 Supply chain permit trading program

### 5.1.1 Discussion about the implementation

Based on the concept of supply chain permit trading program, the supply chain should be owned by one big single company or different organizations closely collaborate and operate this supply chain.

- In the first case, the supply chain GHGs are in fact included into the Scope 1 and 2 emissions of the company, since the company owns all the facilities and vehicles. By targeting this company directly into ETS, it is able to limit the supply chain GHGs of this company.
- In the second case where the supply chain is composed by multiple organizations with different interests, it is possible to include the focal company of the supply chain into ETS and require the focal company to be responsible for its scope 3 emissions. If the focal company is already included into existing ETS, it could be possible to extend the coverage of ETS to target the Scope 3 emissions.
- Before the supply chain GHGs are included into mandatory ETS, the assigned focal company of the supply chain can also participate into the voluntary emission trading markets to offset its supply chain GHGs.

The company in the first case could be managed with existing experiences of ETS as including any other companies, and it is not going to be addressed in this paper. The section is going to focus on the second case, which denotes one focal company in the supply chain and assigns the supply chain GHGs to this focal company. The supply chain GHGs are the Scope 3 emissions of the focal company. The organizational structure of this program is seen in Figure 5-1.

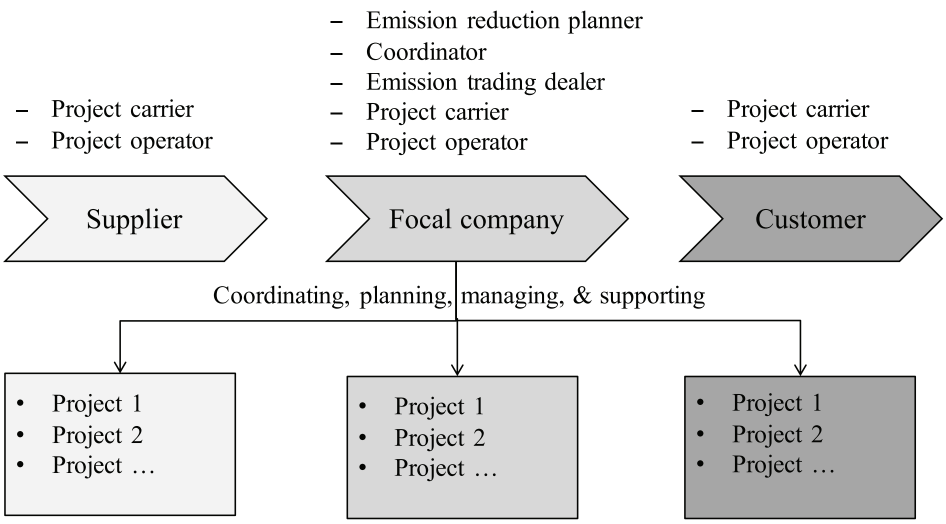


Figure 5-1 Organizational structure in the supply chain permit trading program

Focal companies are those companies that usually 1) rule or govern the supply chain, 2) provide the direct contact to the customer, and 3) design the product or service offered (Seuring & Müller, 2008). Focal companies of supply chains might be held responsible for the environmental and social performance of their supply chains to improve the value of products when it is impaired by the environmental and social burden incurred during different stages of supply chain (Seuring & Müller, 2008). This is especially the case for brand-owning companies, as they are likely to come under pressure from stakeholders, e.g., NGOs. These companies are asked to consider the environmental and social problems present in their entire supply chain. For example, apparel distributors such as Nike, Benetton, Adidas or C&A have been blamed in recent years for problems occurring during the production of their clothing (Seuring & Müller, 2008).

The environmental crisis is less a technological problem than it is a social and behavior one (Wackernagel & Rees, 1998). The management of supply chain GHGs, through and by supply chain leading organizations aligns more closely GHGs with consumption (Munksgaard & Pedersen, 2001). Since the focal organization has power to affect the activities and processes of supply chain to the most extent through product choice editing and marketing campaigns, it might play a central role in reducing the GHGs associated with products and services (Bocken and Allwood, 2012). Distributing supply chain GHGs to the focal organization in the supply chain allows responsibility to be assigned for their management (Bastianoni et al., 2004). By attributing GHGs to organizations that lead and control supply chains, policy and regulation can target these organizations to affect a larger proportion of GHGs (Mózner, 2013).

### 5.1.2 Challenges of the implementation

Since so far supply chain GHGs are yet subject to emission trading, there exist challenges in developing and realizing the supply chain permit trading scheme. For example, it is difficult to determine emissions reduction quota to target a supply chain into emission trading; even if determined, there are still problems such as how emissions quota will be allocated in the supply chain? Whether it should be for free? Who should do the distribution? What criteria should be taken? This section discusses some challenges among them in detail as followed.

1) Measurement of supply chain GHGs

Due to the complexity of measuring and accounting Scope 3 emissions, mandatory ETS is targeting so far only Scope 1 and 2 emissions. To include Scope 3 emissions of companies into ETS requires accurate measurement of GHGs in the supply chain.

In retrospect to the beginning phase of the EU ETS, the system didn't function well during the first and second phase due to the lack of accurate market information. Accurate emissions data from inclusive installations are not available before permits are free allocated to them. As a result, overloaded permits posed the price of permit to the ground. In the third phase, through the emissions record from the last phases, the demand and supply of permits are becoming more balanced in the market. The price of permit indicates the level of stability of emission trading market, and the accurate measurement of emissions is essential to realize the demand-supply balance as early as possible.

The accurate emissions measurement also guarantees setting a more effective baseline for inclusive supply chain GHGs. It would be advisable to have the historic data of supply chain GHGs in the last several years (grandfathering). The annually sustainable report of some supply chain companies would provide the information. Otherwise, it could also refer to the available information from other supply chain competitors, or supply chain companies in the same sector (benchmark). Since the management of supply chain GHGs is in the infancy stage and it is noted in relation to voluntary corporate action on climate change, companies might take different accounting standards to calculate their supply chain GHGs. Setting the baseline according to the same principle would be unfair for companies that use different measuring tools. In addition, as accounting technics are improving, the data of reported emissions is little reliable for setting an effective baseline.

2) Global agreement

The scale and scope of specific interventions could prove troublesome if imposed nationally, in the absence of a global agreement (Long & Young, 2016). In the case of the global supply chain where supply chain processes spread overbroad, targeting supply chain GHGs into ETS should be attained after reaching the global agreement. When GHGs are addressed from the perspective of supply chain, it exceeds the national limit.

Even when the supply chain GHGs are attributed to the focal company in the supply chain and are managed according to the characteristics of the focal company, without a global agreement, it is difficult to get accurate emissions data from supply chain partners in other countries. Different nations are managing their GHGs in different rules and for example rules for emission accounting could be contradictory between supply chain partners in different nations. The report data from the supplier's survey might not comply with the methods of the focal company. A global standardized rule for GHGs accounting should be in place before supply chain GHGs are included into ETS.

In addition, the agreement would avoid double counting of supply chain GHGs in different nations. When the supply chain GHGs are included into the ETS where the focal company belongs to, emissions from its supply chain partners should not be ruled again in local nations. Without a global agreement on a unified registry and administration platform, national environmental government might not be informed about the GHGs condition that are already managed in other nations. A double counting of supply chain GHGs would raise the opposition of targeted companies and therefore make trouble to reach the initiative goal.

3) MRV

In existing ETS, the registry and administration institutions and technics are available to monitor, review and verify GHGs reduction from individual installations. Including supply chain GHGs into ETS requires these institutions and technics to be extended and improved for the level of supply chains.

The management of such an enlarged system would likely be a substantial administrative undertaking, with especial implication for the verification of GHGs (Long & Young, 2016).

Besides, it is also difficult to monitor the completion of emissions reduction. If supply chains and companies cannot meet the target, whether to give a fiscal penalty is also a problem. For the supply chain owned by a single company, the design of existing ETS is effective. The company is going to be punished as same as other individual companies covered in the scheme. For the supply chain composing different companies, whether the penalty should be higher than the normal level and who is going to get this penalty is controversial. A higher level of penalty would promote the incentive of supply chain GHGs reduction, since supply chain companies are sharing the burden. In addition, who is supposed to allocate the punishment among the supply chain? Should the penalty go only to the focal company in the supply chain and the focal company allocates the punishment to its supply chain partners by itself? Or should the MRV in existing ETS directly punish all supply chain partners? Before including supply chain GHGs into ETS, issues around the MRV are essential to be discussed and decided.

4) Cost/benefit distribution in supply chain

In the supply chain permit trading program, supply chain partners are collaborating under a same goal while they keep different interests. To meet the GHGs reduction goal in a cost-effective way, supply chain partners have to agree on the GHGs reduction plan as well as the benefit/cost distribution plan.

The core company makes an ambitious low carbon strategy (e.g., supply chain GHGs reduction plan) based on the overview of supply chain GHGs reduction potentials. Meanwhile its business partners should also accept the notion of low carbon and cooperate with the core company. Otherwise, those short-sighted business partners who reject low carbon idea will leave the supply chain. In order to implement the low carbon strategy, a shared vision is the premise for members of a supply chain to reach a commonsense (Zhong & Zhong, 2013).

Besides, according to the mathematical calculation in Chapter 4, it shows that companies in the supply chain might undertake different cost/benefit share resulted by the emission trading due to their different MACs. Supply chain GHGs reduction goes under the principle that companies that are more cost-efficient in GHGs reduction would reduce more and vive verse. Those cost-efficient companies in GHGs reduction are suffering a larger cost compared to the situation without supply chain collaboration. If it is not voluntary behavior, these companies usually would ask for a certain kind of compensation in terms of cost/benefit distribution. Furthermore, there might be extra benefit from reducing more GHGs than the target or penalty for not reaching the target. If a proper distribution method is not satisfied, it is difficult to let those companies join. And accurately it is the participation of those cost-efficient companies that reduce the overall cost for supply chain GHGs reduction.

5) Supply chain data sharing system

The supply chain works as a single unit in the supply chain permit trading program. An environmental management system (EMS) should be constructed and accessed for the whole supply chain partners in order to improve the efficiency of environmental management. GHGs reduction should be explicitly established as one column. This system allows supply chain partners to input their actual emission data and share this data with each other. Since each unit of emissions stands for certain economic meaning, sharing and updating emission data from time to time would facilitate supply chain partners to always make the best decisions in their separate operation. EMS is necessary to realize the cost-effectiveness of the supply chain permit trading scheme.

In practice, EMS is established only in some big companies. There’s no supply chain standard for EMS.

It remains a challenge to extend EMS of the focal company to the supply chain level. Supposing each supply chain partner has build individual EMS already, there might exist challenges to connect those EMS from the technical perspective.

6) Voluntary market for offsetting supply chain GHGs – certificate standard, quality, and price variation

In contrast to climate protection projects under the Kyoto Protocol, in particular in the usage of the CDM, no common procedures and no common binding standards for voluntary offsets exist. For instance, different standards are adopted in the Germany voluntary emission trading market (see Figure 5-2).

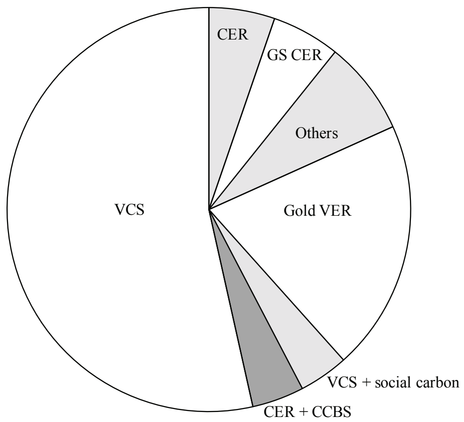


Figure 5-2 Volume of retired certificates and quality standard
Source: Wolters et al. (2015)

The standard VCS accounts for the largest market share of voluntary certificates in year 2013 and it is followed by Gold standard (Wolters, et al., 2015). These standard are different at origin, quality and price. The voluntary market is growing rapidly and diversely. However, too many types of standards can lead to fluctuating quality levels within a market and this is increasingly confusing consumers. According to the report (Wolters, et al., 2015), it shows that the complexity of market composes one of the main barriers for companies to participate into voluntary market and offset their emissions (Figure 5-3).

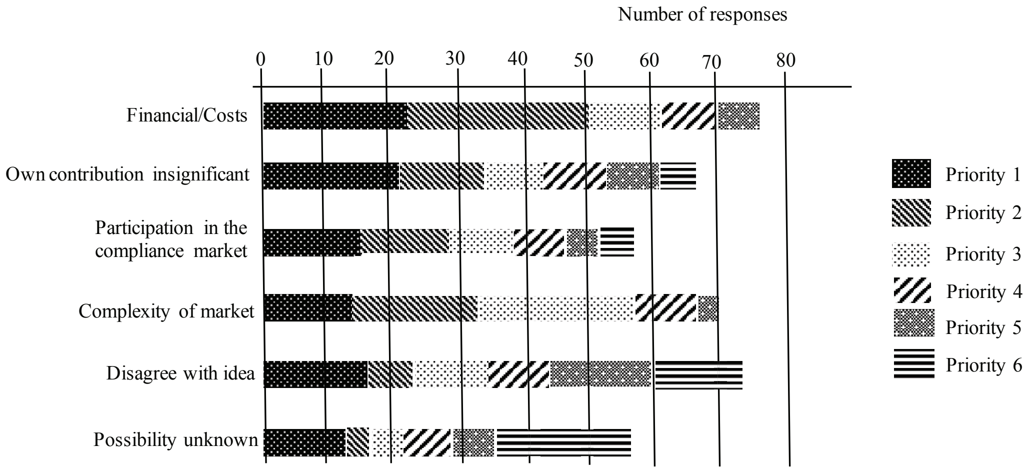


Figure 5-3 Reasons for not offsetting GHGs
Source: Wolters et al. (2015)

On average, consumers assess the quality of CERs at present slightly higher than of other standards, partly because they are better known. Providing more information on voluntary carbon standards is an important prerequisite to improve their popularity.

### 5.1.3 Opportunities for the implementation

Though confronted with lots of challenges, establishing the supply chain permit trading scheme sees also some opportunities since the management of supply chain GHGs are getting increasing attention from both theoretical and practical aspects. In this emerging space of supply chain GHGs measurement, the GHG Protocol Scope 3 Accounting Standard and the CDP supply chain program represent the current state of the art. Besides, the active participation of companies in the voluntary emission trading market to offset their supply chain GHGs provides the prerequisite for establishing the mandatory supply chain permit trading scheme.

1) Measuring supply chain GHGs – GHG protocol

During the last years, supply chain sustainability and climate change concerns have become a high priority in the corporate community. Private and public institutions are developing standards and tools for supply chain corporate and product GHGs management, including Wal-Mart's supply chain initiative, the CDP Supply Chain Leadership Collaboration, various product-labeling initiatives, and emerging guidelines on product GHG measurement, such as by the Carbon Trust, British Standards Institute, and UK Defra.

The GHG Protocol includes calculation tools and other guidance to support standard users. Standards are available globally at no charge to users. The GHG Protocol serves as the de facto standard for GHGs accounting at the corporate and project levels and is recommended as part of several measurement and reporting schemes (though it does not provide any data collection or reporting capabilities of its own). The corporate standard and product life cycle standard developed by the GHG protocol are the most widely used tools for companies to account their supply chain GHGs. Tab 5-1 shows the users of GHG protocol in detail.

Tab 5-1 Corporates using GHG protocol in managing supply chain GHGs

| Sector (number of corporates) | Name of corporate | | |
|---|---|---|---|
| Automobile Manufacturers (4) | General Motors, USA<br>Volkswagen, Germany | Daimler Chrysler, Germany<br>Ford Motor Company, USA | |
| Cement companies (12) | Lafarge, France and North America<br>RMC, UK<br>St. Lawrence Cement Inc., Canada<br>Siam Cement, Thailand | Holcim, USA (and worldwide Holcim facilities)<br>Italcementi, Italy<br>Votorantim, Brazil<br>Cimpor, Brazil | Cemex, Mexico<br>Cia. de Cimento Itambé, Brazil<br>Heidelberger Cement, Germany<br>Taiheiyo, Japan |
| Consumer Goods Manufacturers (23) | Norm Thompson Outfitters, USA<br>Pfizer Inc., USA<br>Raytheon, USA<br>SC Johnson, USA<br>Sony Electronics, Japan<br>Starbucks Coffee, USA<br>Staples Inc., USA | Sun Microsystems<br>Target Corporation, USA<br>Timberland Company, USA<br>Unilever HPC, USA<br>United Technologies Corporation, USA<br>Johnson & Johnson, USA<br>Miller Brewing Company, USA | Bank of America<br>Body Shop, UK<br>Cargill, USA<br>Dell Corporation, USA<br>Eastman Kodak, USA<br>Fetzer Vineyards, USA<br>IBM, USA |

| | | | |
|---|---|---|---|
| | Nike, USA | IKEA International, Sweden | |
| Energy Services (22) | Exelon Corporation, USA<br>First Energy, USA<br>FPL Group, Inc., USA<br>General Electric, USA<br>Green Mountain Energy, USA<br>Kansai Electric Power, Japan<br>We Energies, USA<br>Wisconsin Electric, USA | Mirant, USA<br>N.V. Nuon Renewable Energy, Netherlands<br>PSEG, USA<br>Seattle City Light, USA<br>Tokyo Gas, Japan<br>ENDESA, Spain<br>Entergy, USA | American Electric Group, USA<br>Birka Energi, Sweden<br>Calpine, USA<br>Cinergy, USA<br>Constellation Energy Group, USA<br>Duke Energy, USA<br>Edison Mission Energy, USA |
| Oil and Gas (4) | Shell Canada, Canada<br>Suncor, USA | Norsk Hydro, Norway<br>BP, USA | |
| Industrial Manufacturers/ Mining (35) | Alcoa, USA<br>Anglo American, UK<br>Arch Coal, USA<br>Ball Corporation, USA<br>BASF, Germany<br>Baxter International, USA<br>Bayer, Germany<br>Javierre, S.L., Spain<br>United States Steel Corporation<br>Weyerhaeuser, USA<br>DuPont, Inc.<br>ITC Inc., India | Lockheed Martin Corporation, USA<br>Philips & Yaming, China<br>Praxair, US<br>Rio Tinto, UK<br>Simplex Paper & Pulp, India<br>STMicroelectronics, Switzerland<br>StoraEnso, Finland<br>Tata Steel, India<br>Georgia-Pacific, USA<br>Imperial Chemical Industries, UK<br>Interface, Inc., USA<br>International Paper, USA | ABB Group, Switzerland<br>Abitibi-Consolidated, Canada<br>Air Products and Chemicals, Inc.<br>Alcan Aluminum Corporation Inc., USA<br>Baltimore Aircoil, USA<br>Bethlehem Steel Corporation, USA<br>BHP Billiton, Australia<br>Caterpillar, USA<br>CODELCO, Chile<br>Cia. de Cimento Itambé, Brazil<br>Deere & Co., USA |
| Services (15) | ifPeople, USA<br>PE Europe, Germany<br>PowerComm, Canada<br>Price Waterhouse Coopers, New Zealand<br>European Bank for Reconstruction & Development | Royal Bank of Canada: Finanacial Group, Canada<br>Think Creative Studios, Australia<br>United Parcel Service, USA<br>Verizon Communications, USA<br>FedEx, USA | 500 PPM GmbH, Germany<br>AstraZeneca, UK<br>Carbon Credit Capital LLC, USA<br>Casella Waste Systems, Inc., USA<br>DHL, USA |
| … | … | … | … |
| Trading Schemes | Chicago Climate Exchange, USA | EU Emissions Trading Scheme, EU | UK Emissions Trading Scheme, UK |

Source: GHG protocol (2012)

The framework is widely used by GHG standards and programs as well as individual companies and has become the basis for virtually all other accounting and reporting schemes. For example, the Environmental Protection Agency (EPA) Climate Leaders program, the Climate Registry (CR), and International Organization for Standardization (ISO) all refer the GHG Protocol as the source for their accounting guidance, or as an accepted practice to meet their own reporting objectives (Zhong & Zhong, 2013). The CDP and global reporting initiative (GRI) use the GHG protocols and allow organizations to report their GHGs, including those embodied within their supply chains (Zhong & Zhong, 2013). The EU ETS accept and adopt the GHG protocol standards as well (GHG protocol, 2012). It sends one important signal that the EU ETS is probably going to include supply chain GHGs by asking companies to be responsible for their Scope 3 emissions or product emissions.

2) Reporting supply chain GHGs – CDP supply chain program

Reporting represents a commitment to emissions measurement by disclosing data to the public or a requesting entity (Bosch, 2011). Numerous initiatives have been developed to allow and encourage GHGs data and management strategy reporting. Among them, CDP provides a robust, consistent, and publicly recognized method for reporting Scope 1, 2, and 3 GHGs. Because companies can choose their own calculation methods, reporting to CDP is compatible with other measurement and reporting activities in which companies engage. For example, while the method for calculating GHGs is not specified, CDP does recommend that companies use the GHG Protocol accounting standards.

The CDP Supply Chain program requests data from suppliers on behalf of member companies. The Supply Chain program includes a Supplier Module through which responding companies allocate their emissions to the requesting company (CDP, 2011). In 2009, 44 member companies reached out to 1,402 of their suppliers (CDP, 2011). In 2015 the following 75 organizations engaged their suppliers through CDP (see Tab 5-2). As CDP supply chain members they leveraged their US$2 trillion of procurement spend to request information from over 7,800 suppliers (CDP, 2015).

Tab 5-2 Organizations engaged in CDP supply chain program in 2015

| | | |
|---|---|---|
| Bank of America | Bridgestone Corporation | Sky plc |
| Dell Inc. | Bristol-Myers Squibb | Sopra Steria Group |
| Goldman Sachs Group | British American Tobacco | Starwood Hotels & Resorts |
| Imperial Tobacco Group | BT Group | Worldwide, Inc. |
| Juniper Networks, Inc. | Caesars Entertainment | Swisscom |
| JT International S/A | Caixa Geral de Depósitos | Taisei Corporation |
| L'Oréal | CIA Ultragaz | Toyota Motor Corporation |
| Microsoft Corporation | Cisco Systems, Inc. | Unilever plc |
| PepsiCo, Inc. | CNH Industrial NV | U.S. General Services |
| Philip Morris International | Colgate Palmolive Company | Administration |
| PricewaterhouseCoopers LLP | CSX Corporation | Vodafone Group |
| Royal Philips | Deutsche Telekom AG | Volkswagen Group |
| The Coca-Cola Company | Diageo plc | Wal Mart de Mexico |
| The Lego Group | Eaton Corporation | World Resources Institute (WRI) |
| Wal-Mart Stores, Inc. | Electronic Industry | Ford Motor Company |
| Abbott Laboratories | Citizenship Coalition | Gas Natural Fenosa |
| Accenture | Elopak | climate change |
| Acer Inc. | Enagás | water |
| Amdocs Ltd. | Endesa | action exchange |
| Arcos Dourados | Fiat Chrysler Automobiles NV | Nokia Group |
| AT&T Inc. | General Motors Company | Northrop Grumman Corporation |
| Banco Bradesco S/A | IMI plc | Pirelli |
| BMW Group | Jaguar Land Rover | Rexam |
| Braskem S/A | Johnson & Johnson | SABMiller |
| KPMG LLP | Johnson Controls | S.C. Johnson & Son, Inc. |
| MetLife, Inc. | KAO Corporation | Nissan Motor Company |
| National Grid | Kellogg Company | Nestlé |

Source: CDP (2015)

In practice, a growing number of leading companies are engaging their suppliers into managing GHGs beyond their own operations. In 2008, 34 multinational corporations asked suppliers to report their

GHGs inventories through the CDP Supply Chain Program. The following year, 56 participation companies asked their suppliers to report their carbon footprint to the CDP. EPA's climate leader team interviewed partners that are active in managing supply chain GHGs: Alcatel-Lucent, American Electric Power, Applied Materials, Dell, IBM, Intel, Johnson & Johnson, Kimberly-Clark, PepsiCo and Steelcase. Most of the companies interviewed are, at this stage, only asking suppliers to measure and report their GHGs. Some have asked their suppliers to publicly report their GHGs and state their reduction goals. Some companies have corporate GHG goals that explicitly include supply chain reductions. All are moving toward asking suppliers to publicly disclose GHGs reduction. In addition, companies are providing support for their partners in emissions reduction, either in terms of knowledge, technology, or finance.

The CDP questionnaire collects quantitative information about company greenhouse gas emissions (Scopes 1, 2, and 3) as well as qualitative responses about physical, regulatory, and financial risks and opportunities associated with climate change; organizational governance and business strategy related to climate change, including reduction targets and activities; and climate change communications (CDP, 2009). The CDP then discloses these results on their website. The results are disclosed fully for companies that choose to make their reports public and in aggregate for those that do not. The CDP also compiles, synthesizes, and reports results for interested stakeholders. Through this publicly available data, the data summary and reporting that CDP conducts, and the diversity of industries involved, CDP makes climate change information available to a wide audience (CDP, 2009).

3) Voluntary market for offsetting supply chain GHGs

There's increasing trend that product emissions and corporate emissions are included into the voluntary emission trading markets. The Germany voluntary carbon offset market has seen a growing volume of offset transaction over the last numbered years (Wolters, et al., 2015). Standing from climate and environmental protection as well as corporate social responsibility, an increasing number of people and organizations (as the demand side) want to offset the climate damaging GHGs they emit. One example is offsetting of flight emissions, which travel agencies and airlines offer their customers directly during the booking process. And more and more companies are interested in offering certain products or their entire business activities in a "climate neutral" way (see Figure 5-4).

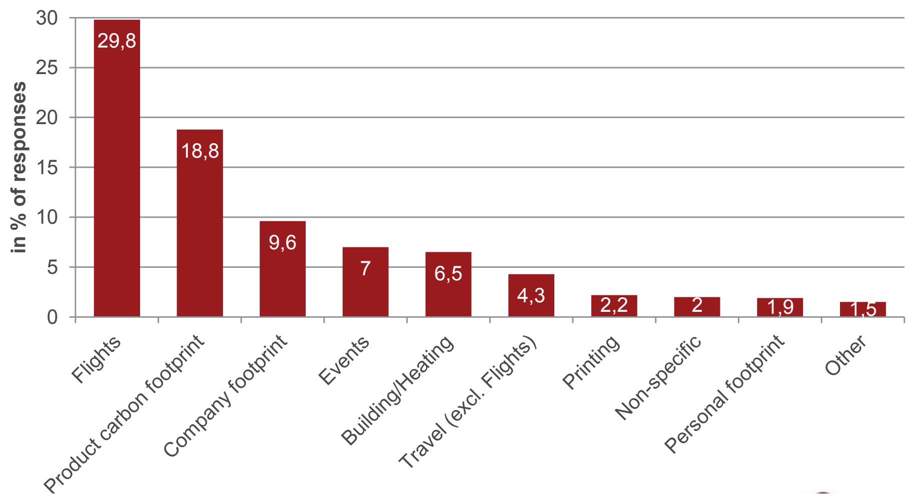


Figure 5-4 Usage of certificates for carbon offsetting

Source: Wolters et al. (2015)

From the report of Wolters et al. (2015), it shows that among all kinds of certificates transacted from the year 2012 to 2013, the certificates used to offset product carbon footprint account for 18.8% of the total amount. The certificates used for company footprint offsetting follow with a 9.6%. They two accumulatively cover certificates up to a quarter of total certificates in the Germany voluntary offset market.

This report also shows the composition of certification users in the voluntary market (see Figure 5-5). Companies are responsible for approx. 80% of the demand for certificates and constitute therefore by far the most important group. Small and medium-sized as well as big companies are relevant to the same extent. Companies from the energy sector contribute the biggest share.

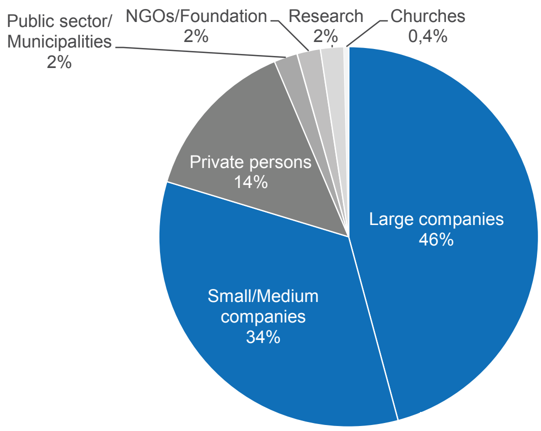


Figure 5-5 Market share of consumer groups

Source: Wolters et al. (2015)

This result further verifies the fact that large companies are the main group moving proactively towards GHGs reduction. The large companies act usually as the leading companies in their supply chains. Embodied GHGs, or the sum of all emissions involved in the production of a good or service, pose the leading supply chain companies exposed to corporate responsibility and future regulatory risks (Long & Young, 2016). Since more and more big corporates are recognizing the fact, it lays the feasibility to cover the supply chain GHGs of the focal companies into existing ETS.

The market for voluntary compensation has developed dynamically and has diversified over the last number of years, though the compliance market partly faces difficult conditions such as the overload of permits in the EU ETS. Before Scope 3 emissions of companies are compulsively included in ETS, companies might use the voluntary market to offset their supply chain GHGs and meet their reduction targets on supply chain GHGs. The voluntary carbon market should be a further instrument to reach the two degrees' temperature control by neutralizing supply chain GHGs in a cost-effective way.

### 5.1.4 Suggestion

The two key steps of implementing supply chain permit trading scheme is to assign the supply chain GHGs to the focal company in the supply chain, and include the focal company into the compulsive/voluntary emission trading markets. The processes of implementation are confronted with challenges as well as opportunities, according to which this section proposes some suggestion and insights for related policy-makers to implement the supply chain permit trading scheme.

- Mandatory measuring and reporting of supply chain GHGs is the first step before they are included into ETS. A common emission measuring standard such as GHG protocol corporate standard that provides mature technics for an accurate calculation of supply chain GHGs should be employed by ETS for all inclusive supply chains. Besides, companies have to report their supply chain GHGs to a third party such as CDP supply chain program to construct an emission database.

- A nationally unified registry and administration platform should be brought into practice. A mature MRV system is the guarantee for a successful ETS. To put the supply chain permit trading scheme into place, a corresponding registry and administration platform is required. And this platform should be accessed to all national business units which are willing to manage their supply chain GHGs through emission trading.
- A defined method for benefit/cost distribution in supply chain is the prerequisite of this program to be effective. A benefit/cost sharing plan should be designed on the principle that cost-efficient companies in GHGs reduction are motivated to reduce more. This plan could be agreed in the form of financial share, contract change (e.g., extending contract length or enlarging contract volume), and technic or knowledge support (e.g., training, workshop, group meeting, etc.).
- The availability of a supply chain data sharing system could improve the efficiency and effectiveness of supply chain collaboration in GHGs reduction. Technical support and managerial implication are needed to connect individual EMS of supply chain companies or extend the EMS of the focal company to the supply chain level.
- Voluntary emission trading markets could be used as experiments for companies to offset their supply chain GHGs before a mandatory supply chain permit trading scheme is implemented. Meanwhile, in order to transfer gradually into or be prepared to link to mandatory emission trading markets, it is necessary to enhance the effectiveness of voluntary emission trading markets by managing certificates' standard, quality, and price.

## 5.2 Supply chain credit/offset trading program

### 5.2.1 Discussion about the implementation

In the supply chain credit trading program, one company in the supply chain (often the focal company) is subjective to ETS and it is allowed to develop credit projects and use credits to offset emissions in the existing emission trading markets. It means that the company is the credit project developer and the user as well. The trade is often completed in a regulated exchange center. The focal company as the emission reduction project developer is most often just responsible for covering the cost for developing, registering, and operating the project. But the actual work is done by the supply chain partners where the emission reduction project locates. Especially when the supply chain is global spread, it is not practical for the focal company to bring groups of resources (i.e., labor, facility, equipment, vehicle, etc.) to the destination. It requires participation and collaboration of supply chain partners and the focal company covers all the cost of their participation in the project. To ensure the effectiveness and efficiency of emission reduction projects' operation, the focal company might bring one supervision team to supply chain partner companies. The organizational structure is shown in Figure 5-6.

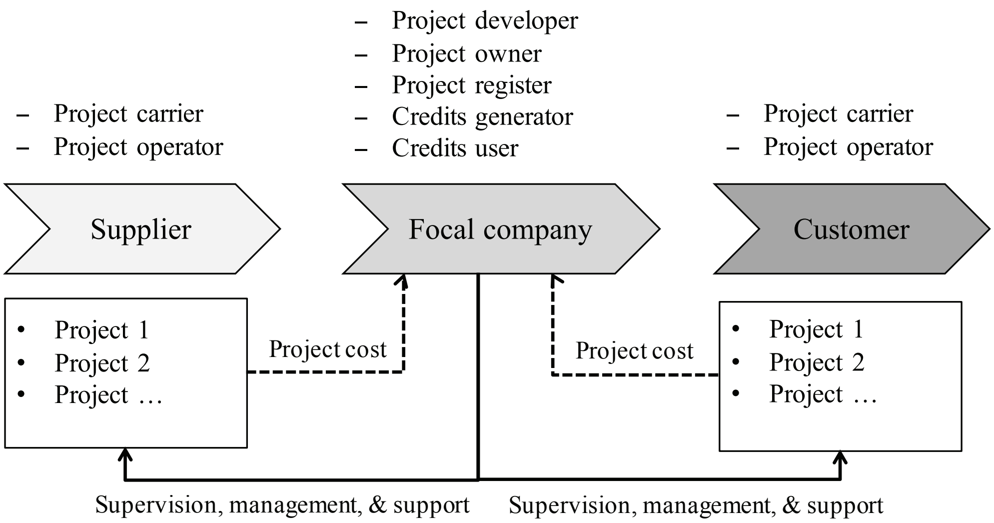


Figure 5-6 Organizational structure in the supply chain credit trading program

In the supply chain offset program, supply chain partners implement emission reduction projects by themselves and take responsibility of the project cost. The organizational structure in the supply chain offset trading program is given in Figure 5-7. The company (often the focal company) in the supply chain offset trading program is the credit buyer and other supply chain partners are credit project developers and credit sellers. The trade in this case is often through Over the Counter (OTC) completed. OTC means that credits buyers and sellers identify each other in the market and they two do the trade apart from the open market (Talberg & Swoboda, 2013). Considering only the primary trading market for a simplified case, the credit buyer is also the credit user.

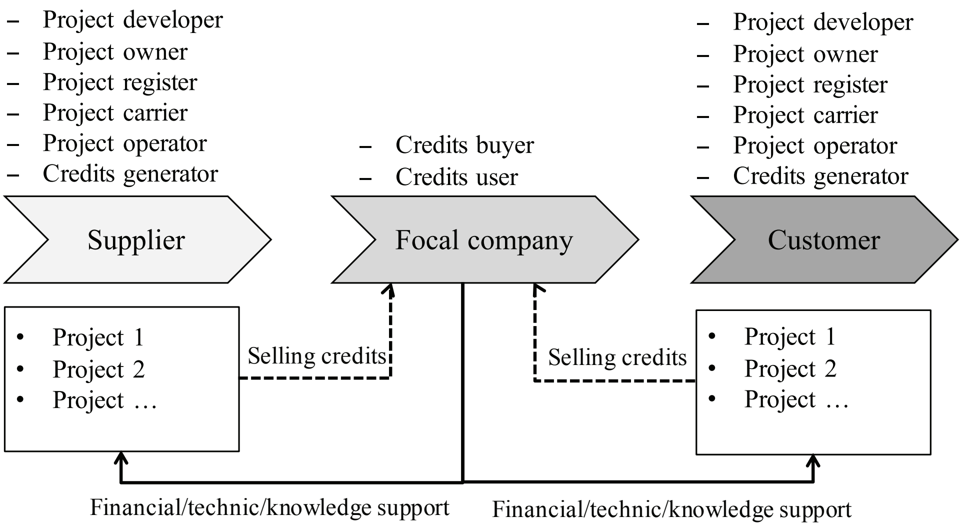


Figure 5-7 Organizational structure in the supply chain offset trading program

The incentives for them to develop emission reduction projects might be the earnings by selling credits at a higher price than the cost, or other benefits getting from the focal company such as contract extension and contract volume enlargement.

According to the geographical locations of supply chain companies, the credit project could either be CDM project, JI project, or any other voluntary emission reduction projects. Used credits should be retired by the ETS registry.

- Considering the focal company is located in any Annex I country under Kyoto Protocol, when the host (supply chain partner) of the credit project is located also in an Annex I country, the project could be registered as a JI project. The credit produced by the project is ERU.
- When the host is located in Annex II countries, the project could be registered as a CDM project. The credit created by the project is CER.
- In other cases, the project can be registered as a voluntary emission reduction project, and the produced credit is VER.

OTC or off-exchange trading is a method of trading that does not take place on an organized venue such as a regulated market. Contrasted with exchange trading, it is done directly between two parties without any supervision of an exchange. In an OTC trade, trading parties may agree on an unusual quantity and price of credits, and the price is not necessarily published for the public (Talberg & Swoboda, 2013). An exchange trading has the benefit of facilitating liquidity, mitigating all credit risk concerning the default of one party in the transaction, providing transparency, and maintaining the current market price (Wikipedia, 2016).

### 5.2.2 Challenges of the implementation

Constructing the supply chain credit/offset program is different from the supply chain permit trading program. Supply chain permit trading is taking supply chain GHGs as a whole based on an integrated supply chain, and emission exchange takes place between the supply chain representative and other entities in existing ETS. Supply chain credit/offset program takes individual supply chain partners separately and emission trading is taking place between supply chain partners. Therefore, establishing the supply chain credit/offset program has to fix questions faced in registering, operating, verifying, and retiring CER/ERU/VER projects. The challenges confronted by implementing the supply chain credit/offset program are introduced as followed.

1) VER is yet acceptable in ETS

In either supply chain credit program or supply chain offset program, credits created by emission reduction projects aim to be used in existing ETS. However, existing ETSs accept only CER and ERU credits from CDM and JI projects while voluntary credits VER are yet acceptable in ETS (ICAP, 2016). Voluntary emission trading markets are so far apart from mandatory emission trading markets. Due to diverse standards used in the voluntary emission trading market, the quality of certificates differs upon different types of standard. As a result, the import of voluntary offsets into ETS is confronted with challenges, such as unifying the standard of voluntary offsets, connecting voluntary offsets with ETS permits in terms of quality, ensuring the influence of imported voluntary offsets on the price of ETS permits, etc.

2) Limited use of CER and ERU in ETS

The creation of CDM and JI projects relieved the burden of countries under the target of Kyoto Protocol, but unlimited use of CDM and JI credits in ETS would impair the local emission reduction and sustainable development which could only ensured by national investment into green technologies and energy-efficient initiatives. Therefore, most ETSs around the world including existing ETS (e.g., the EU ETS) and ETS under implementation (e.g., China national ETS) allow a limited use of CDM and JI credits. The limitation is in term of both quantitative and qualitative perspective. Quantitative limitation indicates a certain up level for the import of CER and ERU while qualitative limitation means that only the CER and ERU generated from certain predefined projects could be used in ETS. For example, most categories of CDM and JI credits are allowed in the EU ETS except projects from industrial gas credits (projects involving the destruction of HFC-23 and N2O) (ICAP, 2016). Since the start of phase three (1 January 2013), newly generated (post-2012) international credits may only come from projects in Least Developed Countries (ICAP, 2016). The limitation of international credits in ETS would restrict the development of supply chain emission reduction projects to some extent.

3) Supply chain trust and reliability

In the supply chain credit program, all GHGs reduction pressure is given to the focal company only. Other supply chain partners get no incentives to reduce GHGs except the leverage from the focal company. When the focal company doesn't require any participation from them and the focal company decides to reduce emissions independently within supply chain partners (e.g., in the supply chain credit scheme), it is possible that supply chain partners would break their contracts and jump out of this initiative. In this case, the focal company will lose all investment it has taken and gets no credits in return. It is also the case in the supply chain offset trading program. The focal company is challenged of mutual trust and reliability problems with supply chain partners.

Supply chain partners might have no interest at all to collaborate with the focal company by operating the emission reduction projects. Although they do not have to pay for the cost, they need organize labor sources for the emission reduction projects. Without a proper incentive, supply chain companies might not join at all.

In addition, supply chain partners might join this program at the beginning but fall out in the middle due to some other corporate problems. For example, in both supply chain credit and offset program, credits' production relies on the operation of supply chain partners because emission reduction projects locate within the boundary of supply chain partners. Developing emission reduction projects and creating credits face to challenges such as fiscal bankruptcy of supply chain partners, operation malfunction caused by manual interruption or nature disaster, employee strike, and so on.

4) Uncertain participation in emission reduction from supply chain partners

In the supply chain offset program, supply chain partners beside the leading company are GHGs reduction projects developers. They have to identify emission reduction potentials within their own organizations, assess emission abatement measures, register for emission reduction projects, and perform these projects. It consumes time, labor, and knowledge for the whole development and operation of emission reduction projects. If the project proves to be ideal which brings directly some economic benefit, they might be interested in it. When the project is not cost-effective, they might hesitate of participating. The report from Wolters et al. (2015) shows that cost is one of main reasons for companies choosing not to participate in voluntary offset market. As a result, to realize the supply chain credit/offset program might be challenged by the uncertain motives for supply chain partners to join emission reduction projects.

5) Price volatility of credits

In the supply chain offset trading program, the credits are developed by supply chain partners and traded to the focal company and other offset buyers in emission trading markets. The credit is here a market-based product which has ups and downs in price according to the market change. Theoretically the price of credits is decided by the demand and supply in the markets. Therefore, it introduces instability into the cost structure of the focal company.

### 5.2.3 Opportunities for the implementation

Compared to the supply chain permit trading scheme, it is more feasible and practical to establish the supply chain credit/offset program since existing resources and experiences of emission trading could be directly employed and the responsibility of supply chain GHGs is clear for supply chain partners. In addition, it also defines the benefit/cost allocation method for supply chain partners.

1) Existing resources and experiences of ETS could be used

Unlike the supply chain permit trading which have to extend the cover of ETS to the supply chain scope, the credit/offset program can work on the base of existing emission trading scheme, by simply allowing companies subject to emission trading to use credits gained from their supply chain emissions reduction projects as additional permits in the market. As most ETSs allow importing CDM and JI credits, supply chain credit/offset program follows the same principle and practice.

2) Existing resources and experiences of credit projects could be used

Either supply chain partners (in offset program) and the leading company (in credit program) are developers for emission reduction projects. Existing resources and experiences of CDM/JI/voluntary offset markets could be directly used. For instance, there exist authorities appointed by the CDM/JI administrator for the MRV of GHGs reduction. It doesn't need to build new capacity to realize the supply chain credit/offset program.

A concern might be that the leading company is also allowed to buy permits from the emission trading market when the price of permit is even lower than the price of credits/offsets got from its supply chain partners. Setting an appropriate floor for the amount of credits/offsets got from supply chain emission reduction projects could mitigate this problem. This could also make effect in the supply chain permit trading program.

3) CDM and JI credits could be directly used in ETS

If supply chain emission reduction projects create CER and ERU, they could be directly used in existing ETS. According to the rules of different ETS, some of them are closed to ETS, but most ETS accept the credits from CDM and JI projects. For example, EU ETS allows a regulated operator to use carbon credits in the form of ERU, certified by the JI project's host country or by the JI Supervisory Committee, and CER, produced by a carbon project that has been certified by the UNFCCC's CDM Executive Board to comply with its obligations (ICAP, 2016). Therefore, it is feasible to perform supply chain credit/offset programs.

4) Cost allocation method is defined

In the supply chain credit program, all the cost is taken by the focal company while in the supply chain offset program, the cost/benefit allocation is adjusted by the price of credits. When the cost of emission reduction project is negative (i.e., ideal initiatives), supply chain partners can pass partial benefits to the focal company by setting a negative price for credits (i.e., benefit sharing). When the cost of emission reduction project is positive (i.e., ecological initiatives), supply chain partner can pass partial cost to the focal company by limiting the price of credits to a certain level under the cost of credits per unit (i.e., cost sharing). Both of two cases reflect the collaboration between the focal company and supply chain partners in emission reduction. It is also possible to let the focal company be fully responsible for the cost of GHGs reduction by passing the full or even higher cost from supply chain partners. In addition, when the price is set as zero, it means all the cost/benefit would be taken by supply chain partners. These cases show that there's low collaboration between the focal company and supply chain partners in GHGs reduction.

### 5.2.4 Suggestion

- Unifying and improving voluntary emission standards is necessarily the first step to connect voluntary and mandatory emission trading markets and therefore facilitate the implementation of the supply chain credit and offset program.
- In order to enhance the supply chain trust and reliability, collaboration issues are better written down as definite terms in the contract before the emission reduction project is implemented. For example, how to perform the collaboration and what tasks and responsibilities of each party should perform in the contract period. In addition, compensation measures should be considered and explicated when any interruption happens during the operation period of emission reduction projects.
- The focal company should leverage its power over other supply chain partners to give them incentives for active GHGs reduction. The supply chain credit scheme may increase supply chain partner engagement efforts, stimulate the measurement of supply chain GHGs performance, and identify cost effective abatement options. GHGs performance standards could be introduced into supplier contracts and supply chain leading organizations may attempt to motivate suppliers to reduce GHGs independently, minimizing their own involvement (Long & Young, 2016).
- Trading credits through OTC transaction mode might put the price of credits into control. In the supply chain offset trading program, price of credits could be levered to comply with the requirement of supply chain collaboration. The transaction mode OTC would facilitate the price control of credits.

## 5.3 Knowledge management for supply chain GHGs reduction

### 5.3.1 Knowledge management and a low-carbon supply chain

1) Knowledge and knowledge management

"Knowledge is regarded as a fluid mix of framed experiences, values, contextual information, and expert insight that drives the strategic realization of an organization" (Davenport, 1998). It is not only recorded in documents but also reflected in organizational routines, processes, practices, and norms. The knowledge of an organization employees gives implications on how the organization work. "The knowledge is worthy of attention because it tells firms how to do things and how they might do them better" (Davenport, 1998).

Knowledge could be categorized through different methods. Most often it is divided into two types: tacit and explicit knowledge. Explicit knowledge represents content that has been captured in words, audio recording, or images while it is difficult to articulate tacit knowledge into some tangible forms (Dalkir, 2013). Sometimes defined between tacit and explicit knowledge, there's another group of knowledge: implicit knowledge. "Implicit knowledge is that an individual is aware of but which they may not have yet articulated in a form accessible to others (orally or in written form)" (Fazey et al., 2006). Implicit knowledge is distinct from tacit because it can be articulated. Explicit knowledge is being better recognized in both academic and practical fields than tacit and implicit knowledge because explicit knowledge is easier to be controlled, codified, planed, and stored (Boiral, 2002).

In addition, knowledge is also categorized with three broad headings: local knowledge, scientific knowledge, and hybrid knowledge (Raymond et al., 2010). Local knowledge usually refers to the personal but possibly expert understanding which might be either implicit or tacit. Scientific knowledge often refers to explicitly reliable information such as scientific research results which are derived from applying formal methods. Hybrid knowledge is created by understanding and integrating different types of knowledge, i.e., through multi-, inter-, or trans-disciplinary research. There're different dimensions of knowledge according to different categorization. "The method of classifying knowledge might involve ensuring that experts engaging in the process have sufficient depth of experience directly relevant to the problem to be addressed" (Fazey et al., 2006).

To manage knowledge often means to create or locate knowledge, to transfer and apply knowledge in an effective and efficient way for the long-term benefit of an organization (Darroch & McNaughton, 2002). "Knowledge management (KM) is a method of systematically and actively managing insights, ideas, information, and practical know-how for creating value from an organization's intangible assets" (Wu & Haasis, 2011). KM is developed on the basis of information technology (IT) which assists capturing and transferring knowledge from one project to another (Carrillo et al., 2000). There's a common confusion and misuse between KM and Information Management (IM). To differentiate them, it can be said that "KM starts where IM stops and it is the inability of IM to handle knowledge that has created interest in KM" (Stenmark, 2000). Without the assistance of a IM system, it might not be able to realize the KM concern associated with formalizing context, validating information, and connecting the personal know-how (Terra & Angeloni, 2003).

The strategy of KM is designed to shrink the gap between a company's accurate know-how and what a company needs to know by providing approaches to align knowledge resources and capabilities of a company to the intellectual requirements of the corporate strategy (Zanjani et al., 2008). KM has generally three processes: knowledge capture/creation, knowledge dissemination/share, and knowledge utilization/application. Knowledge feedback is the complementarity for the KM cycle (see Figure 5-8).

- Knowledge acquisition: identifying and creating knowledge from both internal know-how within the board of an organization as well as environmental aspects (Dalkir, 2013).
- Knowledge share: processes transferring, disseminating, and distributing knowledge in order to make it available to those who need it (Massa & Testa, 2009).
- Knowledge application: incorporating knowledge into an organization's products, services and practices to derive value from it (Huber, 1991).

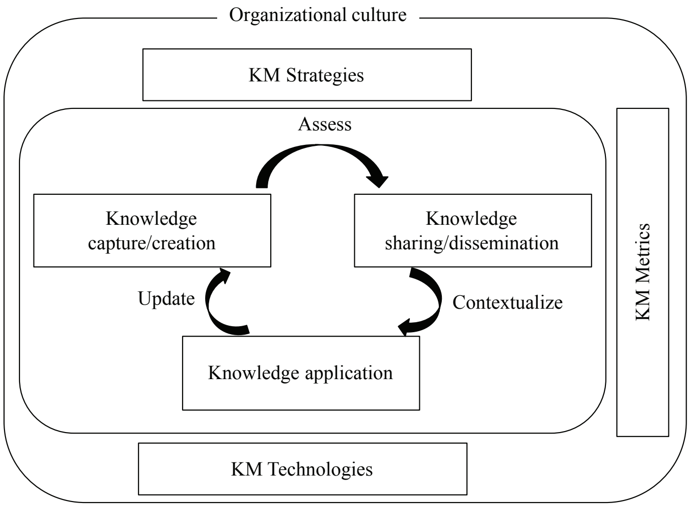


Figure 5-8 KM strategy and KM metrics in an integrated KM cycle
Source: Dalkir (2013)

In this cycle, the interactive functions are described as assess, contextualize and update among these three stages (Dalkir, 2013). A good metrics framework is to monitor progress toward those organizational goals (Wu & Haasis, 2011). KM strategy, supported by KM technologies and organizational culture, focuses on two dimensions: 1) exploration, transition, and application of an organization's explicitly documented knowledge and 2) knowledge sharing via interpersonal interaction (Choi & Lee, 2002). A sound KM strategy is linked to and support the overall business objectives of the organization.

2) KM, sustainability, and environmental management

KM has become an important strategy for an organization to improve the organizational competitiveness and performance. Through using technologies, techniques and procedures in a collaborative environment, KM is able to improve the organizational performance, enhance customer value, and induce innovation (Beckman, 1999). At the age of knowledge economy and scientific management, it is the knowledge rather than physical capital that produce long-term sustainable competitive advantages for organizations (Prusak, 2001). "Due to the growing importance of intangible assets and knowledge, KM can be considered as an important component for accelerating an organization proceeding towards sustainability" (Schaefer & Harvey, 2000). "The proper management and leveraging of knowledge can propel an organization to become more adaptive, innovative, intelligent and sustainable" (Yew Wong & Aspinwall, 2004).

KM would seem to be quite appropriate for assisting the environmental management of organizations (Boiral, 2002). On one hand, companies' environmental initiatives usually require learning new practices and knowledge such as introducing clean technologies (Shrivastava, 1995). On the other hand, it is required to involve all employees, harness the existing know-how, and generate new work methods in the process of developing preventive approaches to reduce pollution at the source (Hart, 1995). In addition, through rigorous documentation and highly codification, the environmental management systems (EMS) such as ISO 14001 is increasingly contributing to the dissemination and retention of environmental knowledge within companies (Boiral, 2002).

The main functions of the environmental management are based above all on the management of explicit knowledge in technical, administrative, and social aspect (Boiral, 2002). The technical aspect is associated with collecting formal environmental information (impact studies and measurement of contaminant discharge, etc.) and green solutions (clean technologies and environmental programs, etc.). The administrative aspect is primarily concerned with perceiving environmental regulations (conformity with current standards and exchanges of information with governments, etc.) and managing documentation (implementation of an environmental management system and declarations of accidental spills, etc.). The social aspect focuses on training, communicating and coordinating with employees and public.

The main activities of KM are improving the sustainability level of an organization on different layers (see Figure 5-9). At the base layer, KM infrastructures provide the tools (e.g. Intranet, Internet, groupware, etc.) to identify, obtain, classify, communicate and share knowledge. KM functions in the middle layer form creative processes towards achieving the sustainability goal and help solving problems in the process of sustainable development. By means of KM implementation in the upper layer, companies are able to realize their expected sustainability and efficiency level.

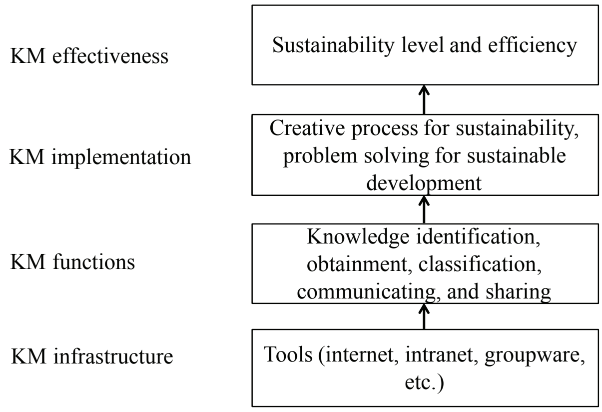


Figure 5-9 KM in relation to sustainability and environmental management
Source: Wu & Haasis (2011)

3) KM and supply chain GHGs management

Green supply chain management or low carbon supply chain management can be understood as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing process, delivery of the final product to the consumers, as well as end-of-life management of the product after its useful life" (Srivastava, 2007). Managing supply chain GHGs is one essential branch of sustainability development of big organizations besides economic and social aspects. Low carbon supply chains, which have the least consumption of resources and do little harm to environment, can be achieved by means of the increase of efficiency and the application of green technologies. Thus, environmental friendly supply chains and sustainable development are hopefully obtained.

Low carbon supply chain requires low carbon ideas to apply to the whole processes of plan, design, purchase, manufacturing, delivery and recycling (Zhong & Zhong, 2013). The knowledge about the distribution of carbon emissions is very helpful for designing a low carbon supply chain (Zhong & Zhong, 2013). Considering the carbon emissions created across multiple supply chain stages, it deserves attention since at the designing phase to green supply chains (Sundarakani et al., 2010). "While supply chains products and services are complex, decision makers must be clearly informed with technology-related information and knowledge" (Pedroso & Nakano, 2009). It is a complex process to build a low carbon supply chain, which requires the knowledge and the application of systems engineering, parallel engineering, marketing, and so on. Knowledge is seen as one of the most important resources for innovation. If we consider the whole supply chain as a system, it's very important to implement collaborative knowledge management to reach the goal of low carbon supply chain (Zhong & Zhong, 2013).

Due to the requirement of two degrees' temperature control, it will become more and more important for big organizations to manage their supply chain GHGs, as soon as possible. As aforementioned, managing supply chain GHGs would decrease the risk exposure of big organizations to stakeholder demand, market shift, competitive pressure, environmental regulation, and fuel price volatility, etc. However, theoretical and practical experiences show that it is still in an early stage of supply chain GHGs management. To achieve the most outcome of supply chain GHGs management, companies need to identify and integrate the sustainability-oriented knowledge (especially in the direction of GHGs) into their corporate strategic, tactical, and operational levels through out the supply chain. KM is adopted in this paper to give implication for supply chain GHGs management according to three KM processes: knowledge capture, knowledge share, and knowledge application (see Figure 5-10). The KM processes enable the leading organization in the supply chain to identify and locate GHGs reduction-related knowledge, disseminate, and apply the knowledge to instruct supply chain GHGs management practices.

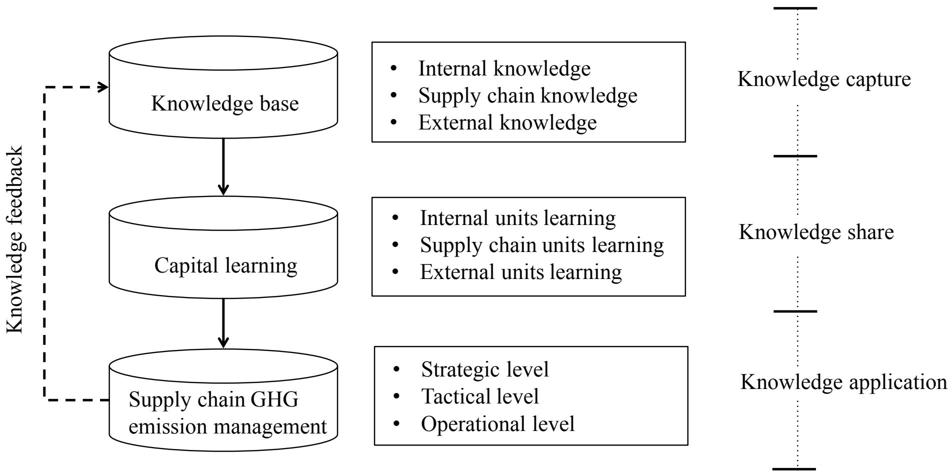


Figure 5-10 KM processes for managing supply chain GHGs

The process begins with capturing knowledge and constructing the knowledge base according to three groups of knowledge sources: internal, supply chain, and external knowledge. After the knowledge base is established, knowledge is shared and disseminated in three levels of scope: within the organization, within the supply chain, and beyond the supply chain. The share and dissemination of knowledge is completed in the form of units learning. At last, knowledge is applied into routine practices of the leading organization at three levels: strategic, tactical, and operational level. The employment of KM processes aims to improve the supply chain GHGs performance through affecting the decision making at all three levels.

### 5.3.2 Knowledge capture

Large organizations manage their GHGs produced within the boundary of their own operation as well as beyond, including GHGs created from up- and downstream activities and processes of their supply chain. The focal organization might take the leadership in managing supply chain GHGs (Plambeck, 2012). First of all, the knowledge exists internally with regard to each business activity and operation in the leading organization. In addition, managing supply chain GHGs refers to the participation of multiple firms along the supply chain. Acquiring the right knowledge for supply chain GHGs management has to consider the possible contribution of all activities and processes existing in the supply chain. Furthermore, the overall environment surrounding the supply chain could provide knowledge and insights for establishing a low-emission supply chain.

According to the source of knowledge in supply chain with regard to GHGs, this work classifies the knowledge into three groups: internal knowledge, supply chain knowledge, external knowledge or environmental knowledge (see Figure 5-11). Internal knowledge is the knowledge located within the boundary of the leading organization in supply chain and it emerges from the routine activities of the organization. Supply chain knowledge is the knowledge located in the interaction between the leading organization and its supply chain partners. External knowledge is created from external environment including regulation, standards, formal norms, third party expert, etc. All knowledge is consisted in both an explicit (i.e., standard files, training materials, etc.) and a tacit (i.e., awareness, idea, inspiration, etc.) level. All three kinds of knowledge together comprise the knowledge base of the leading organization with regard to managing supply chain GHGs. The knowledge base could be updated, improved, and revised. This knowledge base provides a source for the enhancement of operational capabilities, and it is the basis for the next KM processes.

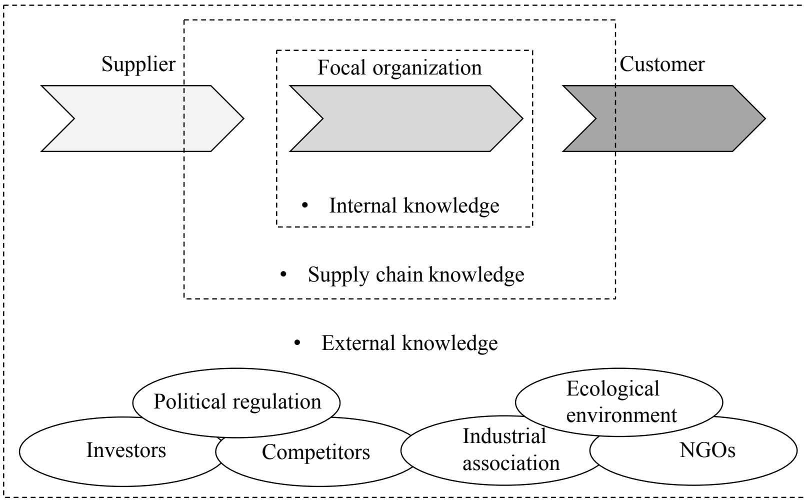


Figure 5-11 Knowledge base in organizations regarding to supply chain GHGs management

A variety of information acquisition strategies exists for companies to use, and it mainly includes experiences' learning, bench-marking, importing environmental knowledge through outside experts and management systems, and building up an information searching and collecting system (Schaefer & Harvey, 2000).

1) Internal knowledge

Internal knowledge within the leading organization is accompanied by business processes with regard to technologies, people, and technique (Bhatt, 2001). Due to the organization's unique history and culture, it cannot be easily imitated by other organizations. Accordingly, the internal knowledge within the leading organization is aligned to the business objective of organization in reducing cost and GHGs, etc.

Process-oriented knowledge is the knowledge embedded in business processes of an organization (Woitsch & Karagiannis, 2005). For an original equipment manufacturer (OEM) organization, process-oriented knowledge is the knowledge created by procuring materials, storing materials, manufacturing middle and final products, storing middle and final products, delivering final products to customers, etc. For a retailer, process-oriented knowledge is mainly related to making orders, receiving orders, storing orders, selling and recycling products. For a LSP, process-oriented knowledge is mainly regarding to receiving goods, storing goods, handling goods, and delivering goods. For any of them, the major processes could be generated into: receiving, storing, producing, and delivering. Here the producing process stands for the main business activity of each organization. For example, the producing process of an OEM is manufacturing; the producing process of a LSP is transporting; the producing process of a retailer is selling.

Knowledge of technologies and techniques concerning GHGs within the leading organization applies to the areas including low-emission material procurement, energy efficient equipment and facilities, energy efficient transportation, green packaging, and reverse logistics. For example, knowledge related to warehousing should concern with facilitating efficient material handling, utilizing high space, scheduling of loading and unloading activities, and order picking (Wu & Haasis, 2011).

Knowledge of people is the knowledge existed in the mind of managers, leaders, and employee. Some of the knowledge is explicit (e.g., executive files and documents composed by leaders) but most of them are implicit or even tacit. For example, implicit knowledge is developed through contacting directly with the equipment at the source of contaminant discharge and this knowledge can significantly assist industrial organizations in their attempts to prevent pollution (Boiral, 2002). Organizations are enabled to sustain its competitive advantages by creating a nurturing and "learning - by - doing" kind of environment (Bhatt, 2001).

2) Supply chain knowledge

Supply chain knowledge is the knowledge learned from up- and downstream supply chain partners. Standing from the particular role that an organization takes in the supply chain, the economic performance of the organization would be affected by its suppliers and customers directly. Environmental performance concerning GHGs would be influenced as well.

On one hand, most of emission sources are included in the upstream supply chain – raw material extraction and manufacturing. The manufacturing process is where the largest amount of pollution is generated and where the largest amount of resources is consumed (Simpson & Power, 2005). Therefore, it is key for the leading organization to choose suppliers according to the greening level of products and services that they provide. This is exactly the case for large organizations that located in the downstream of supply chain such as retailer. Suppliers have to pass certain types of evaluation before they receive the purchasing contracts. Conducting such evaluation focusing on the greening level of provided product and services forms the knowledge transfer between the leading organization and suppliers. Acquiring knowledge from suppliers is to understand the emission embedded in products and services that they provide, to negotiate possible cooperation patterns, to establish trust and relationship with suppliers.

On the other hand, customers are increasingly demanding for low-emission products and services. The green demand of customers plays an essential role in affecting the operation of the leading organization. For example, when an OEM outsources the delivery business to a third LSP and it requires low emission transportation and logistics services. LSPs, as suppliers of this service might shift its focus from cost to emission regarding to the whole transportation and logistics, including employing low-emission transportation mode, multi-mode transportation, low emission warehousing, and energy efficient fuel consumption, etc. Knowledge acquisition from customers means understanding the demand of customers, building relationship with customers, and getting know-how to satisfy customers' demand.

3) External knowledge

External knowledge is the knowledge existing outside of the supply chain and can be learned from environmental regulation, ecological regulation and NGOs, third party experts and industrial association, corporate investors, and market competitors, etc. Although GHGs are produced from activities in the supply chain, external players can also exert their influences in reducing supply chain GHGs. They have responsibilities to indirectly affect the supply chain performance level in terms of GHGs.

Political environment mainly consists of international, national, state/provincial, and local municipality. Political regulation concerning GHGs control provides the motive for targeted organizations to behave in a green manner. For example, an organization must comply with the compulsive standards and requirements to provide commercial and sustainable development solutions. An organization might have the incentive to reduce its GHGs when the action is going to be rewarded under certain regulation. ETS as one policy instrument punishes heavy emitters and rewards green companies. Identifying this knowledge (explicit) provides motives for companies to engage in GHGs reduction measures. Compared to companies that neglect or doesn't get this knowledge, the companies participating into ETS gain opportunities to improve their competitive advantages. Furthermore, knowledge (technologies, skills and experiences) existing in political environment is vital to ensure a sustainable development of the organization (Wu & Haasis, 2011).

Public relations of organizations with ecological environment and NGOs have significant contributions to strengthen the concept of GHGs management. Various international NGOs require freight villages to establish measurable targets (i.e., reducing their carbon footprint) so as to manage and improve their future environmental performance(Wu & Haasis, 2011). Knowledge acquisition in this field means knowing the requirement, complains, and suggestions from the ecological environment, and responding actively to the ecological environment. The knowledge is in the form of document, discussion, and negotiation, etc.

Third parties such as CDP and GHG protocol provide organizations directly with deep knowledge and broad know-how on the trends in managing supply chain GHGs. Without access with these providers, it would consume organizations time and money to explore the necessary knowledge (i.e., supply chain GHGs quantification methods) by themselves. The knowledge is in the form of new methods for measuring and accounting supply chain GHGs, new platforms for organizations to know their emissions reduction hotspot, new perspectives for organizations to tackle with their supply chain GHGs, etc. By collaborating with industrial associations, an organization can acquire innovation-based approaches and execute benchmarking to determine how well it is performing compared with other organizations elsewhere.

External knowledge also exists in the interaction between organizations, investors and their market competitors. Understanding the demand from investors might influence both the strategic and operational decisions of organizations surrounding GHGs. The knowledge exists also in knowing the interests and behaviors of competitors in managing their respective supply chain GHGs. Getting this knowledge would create opportunities for a competitive advantage.

### 5.3.3 Knowledge share

Knowledge sharing aims at identifying and locating knowledge and knowledge sources based on the knowledge base. It is the preparation for the knowledge utilization. Due to the ambiguity and uniqueness to firms, knowledge dissemination and responsiveness to knowledge are considered to exert the most impact on the creation of a sustainable competitive advantage (Day, 1994). The distribution of acquired and created knowledge across the enterprise is the force to translate valuable knowledge, and it is often referred as codification of tacit and explicit knowledge so as to facilitate more widespread dissemination (Wu & Haasis, 2011). Tacit distribution includes the sharing of experiences, stories, demonstrations. Explicit knowledge is distributed by mathematical, graphical, and textual presentations, from magazines and textbooks to electronic media. According to the knowledge base categorization, this work considers mainly the distribution and dissemination of knowledge between these groups. Knowledge sharing processes are in the form of internal units learning, supply chain units learning, and external units learning.

1) Internal units learning

The leading organization is composed of different units which are responsible for different activities and tasks. One internal unit could be a discussion group, a project team, a department, a production line, etc. Each unit could be the source of knowledge for GHGs control. For example, the idea of green packaging design created by the product group could be shared with other working groups such as packaging office documents in a green way. Even the green packaging itself can be shared and distributed to the logistics department. The knowledge might either be tacit such as one inspiration and one graph idea, or explicit such as standardized document, processes, and corporate policies. The sharing and dissemination of knowledge within the scope of organization would maximize the benefit of such knowledge by spreading it over all internal units, which would not likely occur without the dissemination process. "KM focuses on the relationship between knowledge and learning within a company" (Baets, 2006). Learning inside the internal units and cross-functional units lays the foundation for updating sources.

2) Supply chain units learning

Supply chain associates with a range of business units working together to provide customers with appropriate products or services. To maintain sustainable competitive advantages, companies have to learn not only from their own (past) experiences, but also benchmark from other companies. In these companies, KM focuses on the interaction between knowledge and learning within a supply chain. For example, the leading organization might transfer their advanced experiences in reducing GHGs to its suppliers through cite-training or workshop. Knowledge learning within supply chain units could improve the competitiveness and integration level of the whole supply chain by sharing common knowledge.

3) External units learning

"Stakeholder alliance among the business units within a freight village has the ability to ensure effective and sustainable cooperation and participation of stakeholders in the planning, implementation, monitoring and review of policy and management" (Wu & Haasis, 2011). The establishment of stakeholder alliance is enabled by knowledge sharing and dissemination. Stakeholder alliance in sense of a supply chain includes the participation of multiple external parties, such as industrial association, government environmental department, ecological association, and technology/knowledge-oriented third parties, etc. KM focuses in this process on the relationship between the leading organization and external parties. For example, close relationship between the leading organization and third parties (i.e., GHG protocol, CDP) can increase the awareness and know-how of the leading organization about cutting-edge technologies and tools in supply chain GHGs management.

Basically, the supply chain management department receives knowledge from external environment and delivers knowledge to internal units and supply chain units. Supply chain emission trading is one of examples. The idea and approach of emission trading learned from governmental regulation would be transferred and shared with supply chain partners so as to improve supply chain GHGs performance, through applying the principle of ETS in the supply chain and extending ETS to cover supply chain GHGs.

### 5.3.4 Knowledge application

Only knowledge application can ensure that the organization knowledge represents a viable source of competitive advantage. Knowledge application is the integration process by which an organization introduces current knowledge claiming to its operating environment (Tab 5-3).

Tab 5-3 KM implications for managing supply chain GHGs

| | Tasks of knowledge application | Characteristics of knowledge |
|---|---|---|
| Strategic level | • Setting supply chain GHGs reduction target<br>• Making strategies for reaching the target (e.g., ETS)<br>• Committing agreement with supply chain partners<br>• Establishing information systems for measuring GHGs and data sharing of the supply chain | Awareness, vision, mission, ethics, uncertain information |
| Tactical level | • Designing green supply chain network<br>• Constructing infrastructure, area, buildings and transport routes<br>• Scheduling delivery and transport<br>• Engaging third parties<br>• Engaging supply chain partners | Relatively definite information |
| Operational level | • Procuring<br>• Receiving<br>• Storing<br>• Producing<br>• Internal transporting<br>• Selling<br>• Delivering | Well defined data, orders, precise information |

1) Strategic level

The aim of knowledge application at the strategic level is to ensure the capability of the leading organization in fulfilling supply chain GHGs management. In this aspect, the most knowledge applied is in the form of awareness, ideas, missions, corporate strategies, and other uncertain information.

The first step is committing to reduce supply chain GHGs to a certain extent. This commitment might be public announced or just communicated within the organization. Applying knowledge in this process means giving the commitment to launch supply chain GHGs management. Making strategies to realize this commitment becomes the duty of the top management. This strategy is one form of knowledge in this step. The questions that should be considered in proposing strategies are: What technologies do exist to reduce GHGs? What are the effects of applying green technologies? What policies are related to GHGs management? What sources could be used? All these questions should be reconsidered both within and beyond the internal scope of the organization. This strategy provides instructions for knowledge application at the tactical level.

In addition, knowledge application also refers to seeking for an agreement between the leading organization and its supply chain partners in reducing supply chain GHGs. A common sense of emissions issue is the perquisite for a strategic collaboration between supply chain partners. All members should have the common consensus of low carbon and their interests should be coordinated (Zhong & Zhong, 2013). They know that low carbon design is the key component to build core competence for the future. For example, the designers of new products must have the sense of low carbon and take low carbon idea into their consideration. They should balance the aspect of low carbon design against cost, profit, interest of other business partners, etc.

Furthermore, constructing systems that is used to share GHGs data and operational decision is another aspect of knowledge application. A shared information and knowledge platform is of great importance to reach a collaborative design and reduce R&D cost (Zhong & Zhong, 2013). This system is the platform for supply chain collaboration in reducing GHGs. Isolated island of information will bring more risks for core firms in a supply chain.

2) Tactical level

The tactical level is a link between strategic level and operational level. It follows the instructions and rules of the strategic level and offers the relatively definite guidelines for next operational levels (Wu & Haasis, 2011). Regarding the goal of supply chain GHGs reduction, it follows the rules of strategies and provides the practical solutions for the operational tasks, such as designing green supply chain network, constructing infrastructure, area, buildings and transport routes, scheduling delivery and transport, and engaging third parties and supply chain partners, etc.

Supply chain network design decides the green efficiency and green effectiveness of the supply chain structure. Designers from the height of the whole supply chain, integrate the knowledge, functions, capabilities and resources of all members in the supply chain to reduce carbon emission and optimize the use of resources (Zhong & Zhong, 2013). Constructing facilities according to the green supply chain network also contributes in reducing GHGs. For example, building an energy-efficient warehouse can directly reduce GHGs from storing and handling in the warehouse. Scheduling delivery to meet customers' demand could also reduce GHGs. A less-frequent and larger-size delivery might save GHGs from external transportation. GHGs reduction related knowledge needs to be taken into account and integrated into the planning level of those activities.

In addition, engaging supply chain partners and third parties involve the process of knowledge application as well. Knowledge in this step could be discussion and negotiation with suppliers, an explicit contract, training, building membership for certain techniques, etc. Questions in the step should be considered are: What suppliers should be engaged? How to effectively engage those suppliers? How to track the progress of those suppliers in GHGs reduction? Academic and practical experiences tell that emission-intensive suppliers or core suppliers that provide competitive products or services should be considered. Tracking the progress of suppliers could be realized through constructing membership with third parties that provide accounting and verification services. Therefore, engaging the knowledge of third parties might improve the efficacy of managing supply chain GHGs.

3) Operational level

Knowledge application at the operational level focuses on the specific business units within the organization, including receiving, storing, producing, integral transporting, and delivering, etc. These precise tasks are normally conducted on the basis of well-defined data, orders, and precise information. Application of adaptive knowledge in operational activities will bring direct effects for the strategic realization, by procuring low-emission products or services, importing energy-efficient production line or equipment, transferring freight to greener transport modes, reducing the environmental impact of warehousing, as well as increasing fuel efficiency and switching to alternative fuels.

Green procurement means to purchase environmentally friendly products and services, to select contractors and to set environmental requirements in the purchasing contract. To ensure the on-going success of a green procurement program, it is essential to involve the engagement of purchasing staff and senior management as well. Applying appropriate knowledge in internal and outbound logistics activities could reduce GHGs as well. The knowledge could be in the form of new method, energy-efficient technologies, experiences-resulted guidelines, and so on. In addition, knowledge could be applied in the product marketing process by giving a carbon label that shows customers the embedded GHGs of this product.

## 5.4 Summary

This chapter analyzed how each supply chain emission trading could be implemented and what challenges and opportunities are confronted within the implementation. It also proposed some suggestion for the preparation of implementation. The supply chain permit trading program could be realized by extending the coverage of ETS to the Scope 3 emissions or allowing companies to use voluntary certificates to offset their supply chain GHGs. Including Scope 3 emissions into ETS needs build corresponding capacity of MRV for supply chain GHGs. Voluntary emission trading markets are growing rapidly in the last years, and there exist diversified certificate standards which differentiate from each other in terms of quality and price. Voluntary markets could be used as experiments before supply chain GHGs are finally included into ETS but it is necessary to unify the certificate standards and improve the market stability. The supply chain credit and offset program, compared to the supply chain permit trading program, is more practical and feasible to be implemented since it is based on the principle of credit trading. Existing resources and experiences obtained from ETS, CDM, JI, and voluntary emission reduction markets could be directly applied to these programs. All programs require an accurate accounting and reporting of supply chain GHGs as the base of future management. As a result, for government policy-makers, it is notable that mandatory measuring and reporting of supply chain GHGs might be the first step for managing supply chain GHGs.

KM is recognized as one essential method to improve the corporate sustainability due to the increasing importance of invisible assets and knowledge. This section discussed how KM processes could be employed to manage supply chain GHGs. It separated knowledge into three groups: internal, supply chain, and external knowledge. The learning between these groups forms the knowledge sharing. Finally, knowledge could be applied at three levels for the supply chain GHG management: strategic, tactical, and operational levels. By employing KM in the supply chain GHGs management, this section emphasized the concept of emission trading as one kind of external knowledge which could be identified and shared within the supply chain. Supply chain emission trading programs are the results of applying the knowledge of emission trading on the scope of supply chain.

# 6. Conclusion

## 6.1 Contribution

Corporate communities play an essential role in combating climate change by reducing and mitigating their GHGs. Since more and more companies are getting transparency of their GHGs, they find that their supply chain GHGs account for almost three fourth of the total GHGs in one industry. Therefore, it is necessary to manage GHGs from the supply chain perspective. In addition, as some forward-thinking companies have started managing their supply chain GHGs, their surprising experiences indicate that GHGs could be possibly reduced without increasing the cost. Managing supply chain GHGs could enhance the competitive advantages, reduce the risk of exposure to environmental regulations, and attract emerging customers that prefer to green products. Hence, more and more companies are starting managing their supply chain GHGs, especially the large brand companies. Supply chain GHGs management is key to achieve retaining the temperature increase of the earth under two degrees. However, it is still in an infancy stage and confronted with lots of barriers. The biggest barrier so far is lack of proper policy and regulation on supply chain GHGs. The potential for companies to profitably reduce their supply chain GHGs is substantial, but without effective climate policy it is likely insufficient to avert dangerous climate change.

Emission trading, also called cap and trade, is increasingly being employed around the world as one cost-effective instrument in reducing GHGs. The Paris agreement has announced that emission trading will form part of the national climate policy of many countries. It highlighted also the transfers of emission reduction units and linkage of international climate policies need to be part of the future international climate framework to achieve the greatest mitigation outcome at the lowest possible cost. Besides, the agreement encouraged voluntary efforts of all parties to address and respond to climate change. The supply chain GHGs could be best managed through goal-oriented and market-based mechanisms like cap and trade that provide flexibility in choosing compliance levers to the targeted companies or industries. Considering the cost-effectiveness of emission trading and the necessity of managing supply chain GHGs, this paper proposes employing emission trading in the context of supply chain to manager supply chain GHGs. The main contributions and conclusions of this paper are summarized in following.

1) Proposing three programs/mechanisms to apply emission trading in the context of supply chain

This paper proposes the concept “supply chain emission trading” to describe the application of emission trading in the context of supply chain and then suggests three programs/mechanism to realize the supply chain emission trading: supply chain permit trading program, supply chain credit trading program, supply chain offset trading programs. Basically, all three programs are characteristic of allowing the transfers of emission reduction units within the range of supply chain while providing different flexibility and options for supply chain companies to achieve the supply chain GHGs reduction target. They apply to different supply chains.

- Supply chain permit trading program

Supply chain permit trading program takes the supply chain as same as a single unit. A limit is given to the overall supply chain GHGs and supply chain partners need to work closely to achieve this target. If possible, GHGs need to be reduced from anywhere in the supply chain as one of the collaborative efforts. When actual supply chain GHGs are reduced under the limit, supply chain partners benefit from selling the extra reduction units to emission markets as permits. When not, they are allowed to purchase permits from existing emission markets to cover the exceeding emission units. Either the profit from selling permits or the cost incurred by purchasing permits has to be shared among supply chain partners. This program applies to the supply chain owned and operated by one big company or the supply chain having a high level of collaboration among multiple supply chain partners.

- Supply chain credit trading program

Supply chain credit trading program assigns the supply chain GHGs to the focal company in the supply chain. The focal company is usually the leading company in either the up- or downstream supply chain. The focal company is subject to ETS and it is allowed to invest into emission reduction projects within the supply chain and get credits which could be used in existing ETS as additional permits in turn. The focal company is responsible for both the management and cost of developing and operating emission reduction projects including registration, monitor, and verification, etc. This program makes use of the leverage and knowledge of the focal company to regulate the supply chain GHGs, and it applies to the supply chain which is leaded by a focal company.

- Supply chain offset trading program

Supply chain offset trading program still assigns the supply chain GHGs to the focal companies in the supply chain. The focal company is subject to ETS and it can purchase offsets from emission reduction projects in the supply chain to offset its GHGs target under ETS. The emission reduction projects are developed and operated by other supply chain partners. In this program, the focal company is the buyer of offsets while other supply chain partners are the sellers of offsets. By giving a trading mechanism within the supply chain, this program allows the transfers of emission reduction units in the supply chain and provides various options for the supply chain collaboration based on the price setting of offsets. Given ideal emission reduction projects, both the focal company and its supply chain partners are possible to get benefits from this program with an explicit benefit allocation method. This program applies to the supply chain in which supply chain partners have the right knowledge and are interested in reducing their supply chain GHGs.

2) Comparing the cost-effectiveness of three programs

After proposing three programs to realize supply chain emission trading, this paper performed one case study in addition to quantify the cost and benefit of each program, and therefore to compare the cost-effectiveness of all three programs. The results of the comparative analysis might provide insights for some forward-thinking supply chain companies and related policy-makers to improve their management practices and decision-making processes.

- To reduce the same amount of supply chain GHGs, supply chain permit trading program is the most cost-effective one among others. The cost increment in supply chain credit program and supply chain offset program includes additionally the administration fee for emission reduction projects (i.e., registration and verification, etc.)
- Targeting supply chain jointly into ETS is as same cost-effective as targeting supply chain partners separately from the level of supply chain. The average cost change in the mode of joint inclusion is between that of two separate modes. It means, jointly employment will decrease cost for some supply chain partners while increase for others.
- From the supply chain prospective, supply chain credit trading program results in the same total cost as supply chain offset program to reduce the same amount of supply chain GHGs. In supply

chain credit program, the focal company takes responsibility for the total cost while in supply chain offset program, the cost/benefit is allocated between the focal company and other supply chain partners according to the price setting of offsets.

- Allowing transfers of emission reduction units in the supply chain in supply chain credit program decreases the cost of the focal company to reduce a given level of GHGs. The access to other supply chain emission reduction projects relieves the cost burden of the focal company under ETS.
- The total cost of each program increases as the supply chain emission reduction target increases (i.e., the cap decreases). Given ideal emission abatement projects and a low emission reduction target, supply chain companies might get profits from selling permits.
- The total cost of each program increases as the price of permits in ETS increases. Increasing the price of permit or penalty would facilitate supply chain companies to turn to emission abatement projects.

3) Discussing issues related to the implementation of the three programs

Last but not least, this paper discussed the issues related to the implementation processes of each program. Each program is confronted with individual challenges as well as opportunities.

- One method for implementing supply chain permit trading program is to assign the focal company in the supply chain to be responsible for its scope 3 emissions by including its scope 3 emissions mandatorily into ETS.

  By doing so, one unified method is needed to measure the supply chain GHGs exactly and the MRV system of existing ETS has to be improved and extended to cover supply chain GHGs. In addition, the mechanism for cost/benefit allocation among supply chain partners has to be defined which is the prerequisite for the supply chain collaboration in GHGs reduction. Furthermore, an integrated supply chain information system regarding to GHGs and emission reduction initiatives has to be accessed and shared by all supply chain partners in order to improve the efficacy of supply chain GHGs management.

  Despite the challenges, supply chain permit trading program also embraces some opportunities. There're increasing methods and tools available for quantifying the supply chain GHGs, for example, the corporate standard and product standard designed by the GHG protocol are becoming the mainstream of supply chain GHGs accounting. Besides, according to the reports of CDP supply chain program, more and more companies are reporting their supply chain GHGs, which indicates that there's a growing trend of managing supply chain GHGs. Furthermore, before the supply chain GHGs are mandatorily included into ETS, it is feasible for the focal company to participate into the voluntary market to offset its supply chain GHGs.
- Supply chain credit program and supply chain offset program are applying the concept of emission reduction projects and transfers of emission reduction units within the range of supply chain where the focal company is subject to ETS. They are connected with CDM, JI, and voluntary emission trading markets.

  However, it is so far not allowed to use the certificates (as same as credits and offsets) from voluntary emission trading markets in the mandatory ETS. In voluntary markets, the quality, price, and supply of certificates vary a lot. Due to the complexity of voluntary certificates, it is difficult to link them to permits in mandatory markets. In addition, in most ETS around the world there's a limit for the use of CDM and JI credits in ETS. The limit is either quantitatively or qualitatively or both. Furthermore, supply chain credit trading programs is challenged also by the supply chain trust and reliability problems. Because in this program the focal company is taking care of all processes related to GHGs reduction within the boundary of supply chain partners, it could lose all the investment when supply chain partners withdraw their participation. Supply chain offset program is also confronted with challenges when supply chain partners have no interest in participating emission reduction projects.

It is comparatively easier to put supply chain credit program and supply chain offset program into implementation since existing experiences in ETS and credit projects could be directly applied. It is not necessary to extend the MRV system of ETS in this program. When the supply chain complies with the requirement of CDM and JI projects, this program could easily be realized.

Considering the challenges and opportunities of each program, this paper provided some suggestions to implement supply chain emission trading from both business and political perspectives.

For business:

- Exerting the leverage of the focal company to encourage the participation of supply chain partners into GHGs reduction and mitigation
- Contracting the mechanisms of supply chain collaboration in GHGs reduction
- Getting first hand experiences from participating into voluntary markets to offset their supply chain GHGs

For policy-makers:

- Improving and standardizing the measurement for supply chain GHGs
- Enhancing the management of voluntary emission trading markets and unifying the voluntary certificates
- Including supply chain GHGs into ETS could start with mandatorily asking leading companies to measure and report their supply chain GHGs.

## 6.2 Limitation and outlook

This paper is one of the minor literatures in addressing the political intervention options in supply chain GHGs management. It performs a conceptual study as well as a case study and provides meaningful insights for the management practices in both business and political fields. However, there exist some limitations in this work which deserves further research.

- In the conceptual study, this paper assumes an extremely simple supply chain structure to simplify the process of elaborating these concepts. How to extend these concepts to a more complex supply chain structure before applying these programs to practical world remains to be done.
- In the case study, the emission reduction measures as well as the cost-benefit data of each measure adopted in the case study is quite specific. With the availability of data, a more standardized case with comprehensive real data should be addressed.

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# Acknowledgement

Firstly, I would like to give thanks to my doctor father Prof. Dr. Hans-Dietrich Haasis for his guidance, patience, and support during my whole Ph.D. study. Without his supervision and trust, I cannot finish my dissertation so efficiently. Besides, it is the positive feedback from him that always provides me with inspiration and gives me confidence to keep my own idea. I have learned how to be an independent researcher from the Ph.D. work, which would likely not occur if I didn’t meet my supervisor.

Secondly, my thanks are given to Prof. Dr. Irina Dovbischuk for offering me the student job. We talked a lot about the culture differences between Eastern and Western countries. It was relaxed and joyful to work with her.

In addition, I appreciate the organization of International Graduate School (IGS) and those friends I have meet there. Prof. Dr. Ingrid, the leader of IGS, kindly arranged everything and was willing to provide every opportunity to the IGS members. It was nice being one member of the big IGS family.

Furthermore, the Ph.D. study brightened my life because I was accompanied by the group of lovely colleagues: Arshia, Lydia, Sami, and Sylvia. I desired your smile whenever I came to meet you. Without you, my Ph.D. life would be just dark and exhausted. Thank you for listening to me no matter how boring and confusing my topic is. Thank you for being always ready to give me help. I am so happy that I have you as partner in my Ph.D. study.

Furthermore, thank my dear friends Yalei, Bingbin, and Jingjing who have provided support and assistance in printing and assembling my dissertation. You make me feel Bremen is always home.

Last but not least, I am deeply grateful for having the full support from my husband Meng for all long. You were so considerate and took good care of everything in our common life, which allows me to work on my dissertation with hundred percent concentration. You had such a strong and positive mind that always pulled me out and kept me away from my darkness and sadness. Thank you for understanding me and helping me more than the best. I would also thank my sweetie daughter Tongyu who is just two years old. Your coming was the best surprise for my life. Watching your smile was the happiest time for me. At last, I would like to express appreciation to my parents. Without your support, I would not have met my beautiful life in Germany.