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## Article

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# A framework and risk analysis for supply chain emission trading

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**Abstract** Reports show that it is necessary to control greenhouse gas emissions from the supply chain perspective. Numerous authors have already started quantifying the impacts of emission trading on supply chain performance in terms of cost and emissions. However, rare effort is made to conceptualize this implementation. This paper generates firstly one conceptual framework for supply chain emission trading through a review of previous work and then asserts how practically it could work out. In addition, the risks confronted by firms and supply chains under emission trading are identified considering each step involved in the framework. These risks are further classified based on the concept of supply chain risks. Results show that the implementation of emission trading on supply chain would raise additional risks into existing supply chain risk portfolio. At last, this paper provides some risk mitigation measures for those identified risks.

**Keywords** Emission trading · Supply chain greenhouse gas emissions · Risk analysis · Supply chain emission trading

## 1 Introduction

In order to be prepared for future environmental regulations and to improve market competitiveness, companies are realizing that they have to reduce greenhouse gas (GHG) emissions from a supply chain perspective. Supply chain GHG emissions account for around 75 % of the whole GHG emissions from an industry sector, while companies' direct GHG emissions average only 14 % of their supply chain GHG emissions prior to use and disposal across all industries [1]. The United States Environmental Protection Agency (USEPA) [2] released one report certifying that managing supply chain GHG emissions can effectively avoid exposure to lack of preparedness for complying with carbon regulations. In fact, numerous firms from the electronic industry (i.e., HP and DELL) and retail industry (i.e., Walmart) have already devoted themselves to voluntary supply chain GHG emissions reduction programs. Although there is so far no policy targeted on supply chain GHG emissions reduction, researchers have recognized that companies in pursuit of green supply chain strategies could leverage the opportunities offered by market-based instruments such as emission trading. Gupta and Palsule-Desai [3] mention that considering the social cost of carbon emissions in greening supply chain is one of future research opportunities. Long and Young [4] study intervention options to enhance the management of supply chain GHG emissions in the UK. They clarify supply chain tax, emission trading, and credit schemes as economic instruments among others to control supply chain emissions.

The general principle of emission trading is giving a limit, also called 'cap' on the overall amount of GHG emissions [5]. Initial permits under this cap are allocated to firms. One permit gives a right to emit one unit of GHG

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emissions. At the end of a certain period, emission producers have to surrender permits in equivalent to their accurate emissions. Entities subject to emission trading are allowed to exchange permits via carbon markets with a certain price as needed. The price of permits is theoretically decided by the demand and supply in the market but also aligned to government regulation.

Employing emission trading in the context of supply chain limits the overall supply chain GHG emissions and provides flexible compliances for companies to meet their targets. Hence, it is considered as one of the most cost-effective instruments to control supply chain GHG emissions. However, by limiting the GHG emissions from different companies under one common amount, it put supply chain companies in front of new risks emerging from sources that are often related to close cooperation. For example, supply chains intend to reduce GHG emissions from material extraction, transportation, inventory, and production, etc., through optimizing supply chain operations and network. Adopting these measures would, in turn, result in a change in both supply chain GHG emissions and supply chain risks (see Fig. 1). In particular, those measures that need inter-organizational cooperation can create the most emissions saving on one hand, and increase supply chain vulnerability on the other hand. For instance, close cooperation with suppliers and customers can reduce inventory emissions to a great extent while increasing the probability of occurrence of supply and demand disruption [6]. Decreasing these risks needs to build the safety stock and, therefore, would increase emissions from inventory. Emission management and risk management are interacted in the context of the supply chain.

In addition, since emission trading is one market-based policy instrument, subjecting supply chain GHG emissions to the emission trading would also put companies at risk of economic loss/earn, emission market variability, and policy instability. With the increasing trend in the carbon emissions management, risk management has to be extended to

cover issues involved in emissions. To further ensure the implementation of emission trading in the context of supply chain, the following work has to be conducted:

1. To construct a framework for supply chain GHG emissions reduction under emission trading and clarify the practical implementation, and
2. To identify the risks confronted by companies and supply chains subject to this system and to classify them into existing supply chain risk groups.

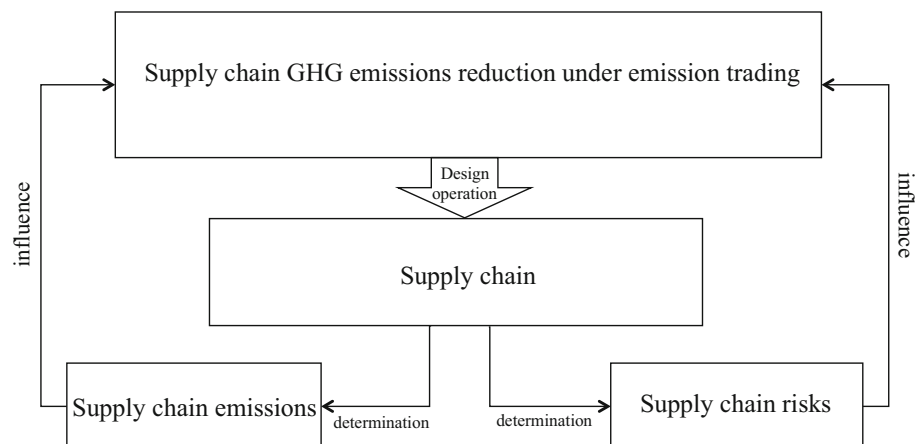
The rest of the paper is structured as follows. In Sect. 2, it proposes one concept and one framework for supply chain emission trading and discusses how such a scheme might be implemented practically. In Sect. 3, it identifies risks confronted by companies and supply chains in this system, classifies risks, and provides mitigation measures. Section 4 gives a conclusion concerning contributions and deficiencies of this work.

## 2 Including supply chain GHG emissions into emission trading

### 2.1 A framework for supply chain emission trading

Literature shows that emission trading might be employed as one cost-effective instrument for supply chain emissions reduction. Benjaafar et al. (2012) employs a lot sizing model to analyze two modes of emission trading coverage on supply chain. They find that imposing supply chain-wide emission caps is more cost-effective than individual cap installation on each firm and it also increases the value of collaboration [7]. Jin et al. [8] propose the mixed-integer linear programming to investigate the impact of three carbon policies on supply chain design. The result shows that it costs the retailer less under cap-and-trade to significantly reduce the emission (e.g., by 50 %) compared to the

**Fig. 1** Relations between supply chain emissions and risk management



other two policies. Fareeduddin et al. (2015) present one optimization model based on carbon regulatory policies for a closed-loop supply chain design. Optimal results show that cap-and-trade is the most cost-effective one among others [9]. Zakeri et al. [10] present an analytical supply chain planning model to examine the supply chain performance under two policy schemes. They find that emissions reduction in a carbon trading scheme follows a relatively linear trend with a nonlinear cost increase [10]. Carbon trading scheme results in better supply chain performance in terms of emissions generation, cost, and service level than carbon pricing. Chaabane et al. [11] provide a multi-objective mixed-integer linear programming model to address supply chain design problems and justifies that emission trading market may be used to reduce the carbon abatement cost.

The literature is common in presenting mathematical models to integrate carbon prices explicitly in green supply chain design and to justify the cost-effectiveness of applying the emission trading policy into the context of supply chain [12–17]. This quantitative analysis allows evaluating impacts of different decision alternatives in terms of logistics cost and carbon footprint. It also allows offsetting the impact of GHG reduction through both supply chain redesign and emission trading. However, none of them proposes any concept or application-oriented framework addressing the implementation of emission trading in the supply chain context. Based on a review of previous literature, this paper generates one concept—supply chain emission trading (Fig. 2).

*Supply chain emission trading*—this concept is extending emission trading to cover firms in the range of supply chains. It means, entities covered by emission trading scheme (ETS) could be not only single firms and installation, but also supply chains. Supply chain emissions as a whole are limited to a certain amount (so-called cap). Permits under this limit are allocated to supply chains for

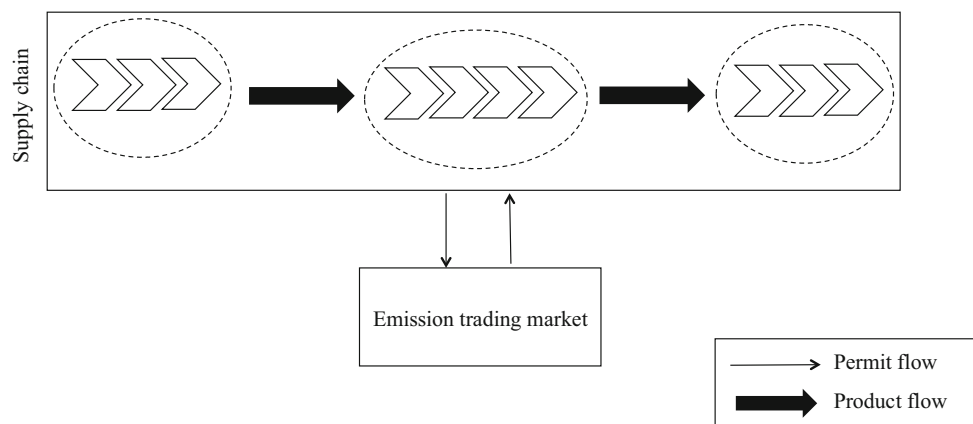
free, or for certain auction cost. Supply chains have to get permits equivalent to their accurate GHGs. At the end of a regulated period, supply chains have to buy emission permits from markets as any other organizations if their accurate emissions exceed the amount of allocated permits. Vice versa, supply chains could bank their extra emission permits for the use of next periods or sell for an earning.

In addition, this paper also conceptualizes one framework for supply chain emission trading (see Fig. 3). This framework enables companies to understand the steps for managing their supply chain emissions and implementing the detailed processes according to given instructions.

Supply chain GHG emissions as a whole are subjected to a cap due to government regulations. Given an emissions reduction target, companies have to firstly understand the carbon footprint of their supply chains. In order to draw the emission heap map, emission sources should be identified and measured from operational processes within and beyond individual companies, facilities, factories and other installations along the supply chain. For supply chains under emission trading, they can adopt three measures to meet the emission reduction targets (see Fig. 4). They are internal measures (i.e., adopting energy-efficient operations to reduce emissions within the board of individual company), inter-organizational measures (i.e., cooperating with suppliers and customers to reduce emissions from inventory, product manufacturing, and transportation), and external measures (i.e., trading permits from the emission market).

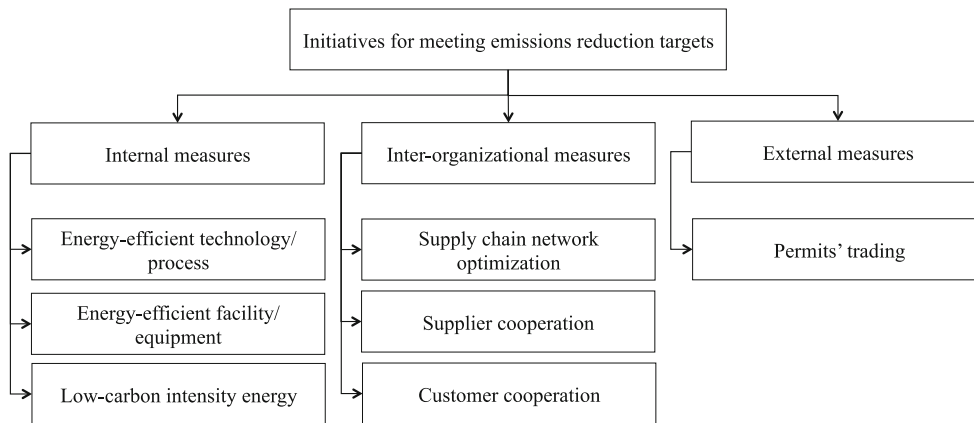
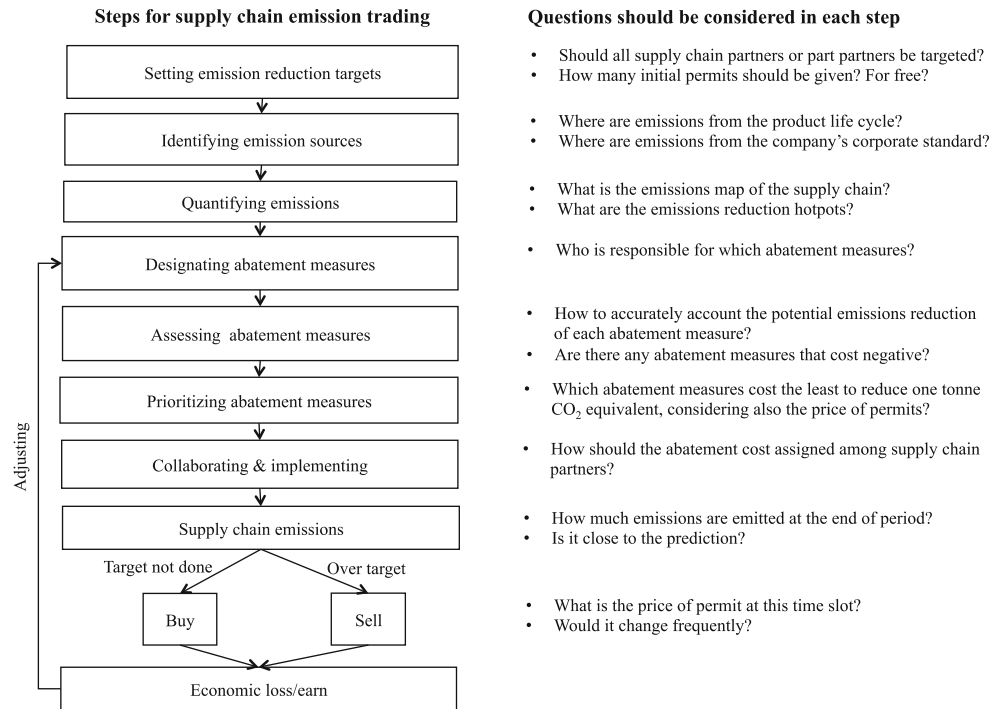
## 2.2 Discussion for the practical application

Literature analyzes this concept only from the quantitative aspect, for example, by justifying the cost-effectiveness of this concept on supply chain performance. However, there is a lack of research in the application of this concept. This paper discusses some practical issues involved and provides some solutions as followed.



**Fig. 2** Illustration for supply chain emission trading

**Fig. 3** Framework for supply chain emission trading



**Fig. 4** Supply chain emission abatement measures under emission trading. *Source:* Chaabane et al. [11]

1. How is responsibility assigned within the supply chain?

This concept appoints that supply chain works as a single company to perform emission abatement measures and to trade emission permits in current trading markets. Hence, one actor is responsible for the supply chain GHG emissions. This actor is so-called the focal organization. A focal company is needed to 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.

2. Who is responsible for the whole supply chain GHG emissions?

If there are companies, which are already subjected to emission trading, these companies could be regarded as the focal organizations responsible for its Scope 3 emissions. Otherwise, a focal company needs to be assigned. To realize the implementation of emission trading policy on supply chain GHG emissions, this paper proposes some practical options 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 in the supply chain would probably pursue green strategies and, therefore, have incentives to manage supply chain GHG emissions. The one with the most power affects the actions of other supply chain partners and the supply chain performance to the most. Hence, they might be targeted mandatorily as focal companies in the emission trading policy to manage their supply chain GHG emissions. Actors downstream in the supply chain are dealing with end products and are facing to customers. They could have an overview of supply chain GHG emissions and guide customers to choose green products. Assigning these actors as focal organizations might benefit in managing GHG emissions 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 might be possible to save a larger amount of emissions by spending less. Since emission trading scheme (ETS) 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 GHG emissions.

### 3. How to set one supply chain emissions reduction target?

Literature assumes that it is either voluntary or mandatory for a supply chain to join emission trading and they analyze mainly the impact of emission trading policy to supply chain GHG emissions and cost through quantitative optimization models. Instead, this paper focuses on the conceptual work and issues involved in the practical application. Emission trading scheme is so far enforced to installations over certain emissions level in some industries in the European Union (EU), and it is getting implemented in more and more countries and sectors all over the world. It is not difficult to imagine that emission trading would be in the future employed as one mandatory regulation for supply chain GHG emissions management. Therefore, this paper hypothesizes an enforcement of emission trading on a supply chain, which means supply chain has a mandatory cap, and it is allowed to trade emission permits in the existing markets as same as other organizations. Besides, this paper proposes a conceptual work by referring to a general supply chain instead of any specific one.

## 3 Risk analysis for supply chains under emission trading

### 3.1 Risk identification

Risk is generally understood as a negative impact on the objectives of a company that is associated with

disadvantages, damages, and losses. Risks within the supply chain are mainly triggered by disruptions of the material, information or capital flow between the partners [18]. Kersten et al. (2006) define supply chain risk as follows. “Supply chain risk is the damage—assessed by its probability of occurrence—that is caused by an event within a company, within its supply chain or its environment affecting the business processes of at least one company in the supply chain negatively” [19]. The task of supply chain risk management is “a collaborative and structured approach to risk management, embedded in the planning and control processes of the supply chain, to handle risks that might adversely affect the achievement of supply chain goals” [20].

Literature addressing supply chain emission trading in operational research points out that supply chain collaboration is one of the biggest risks to realize the implementation [7]. Employing emission trading in the whole supply chain would result in cost-effectiveness as well as cost shift among supply chain partners. How to distribute the spared cost to supply chain partners is the key to get supply chain partners collaborated. Besides, emission trading is a politically established market-based instrument to reduce GHGs. Applying emission trading on the range of supply chain is subject to potential risks not only from market variation, but also from political interventions as well [21].

Considering potential damages, losses, and disadvantages of emission trading’s exploration on supply chain firms, this paper suggests a risk portfolio and expands risks identified already in the literature (see in Fig. 5).

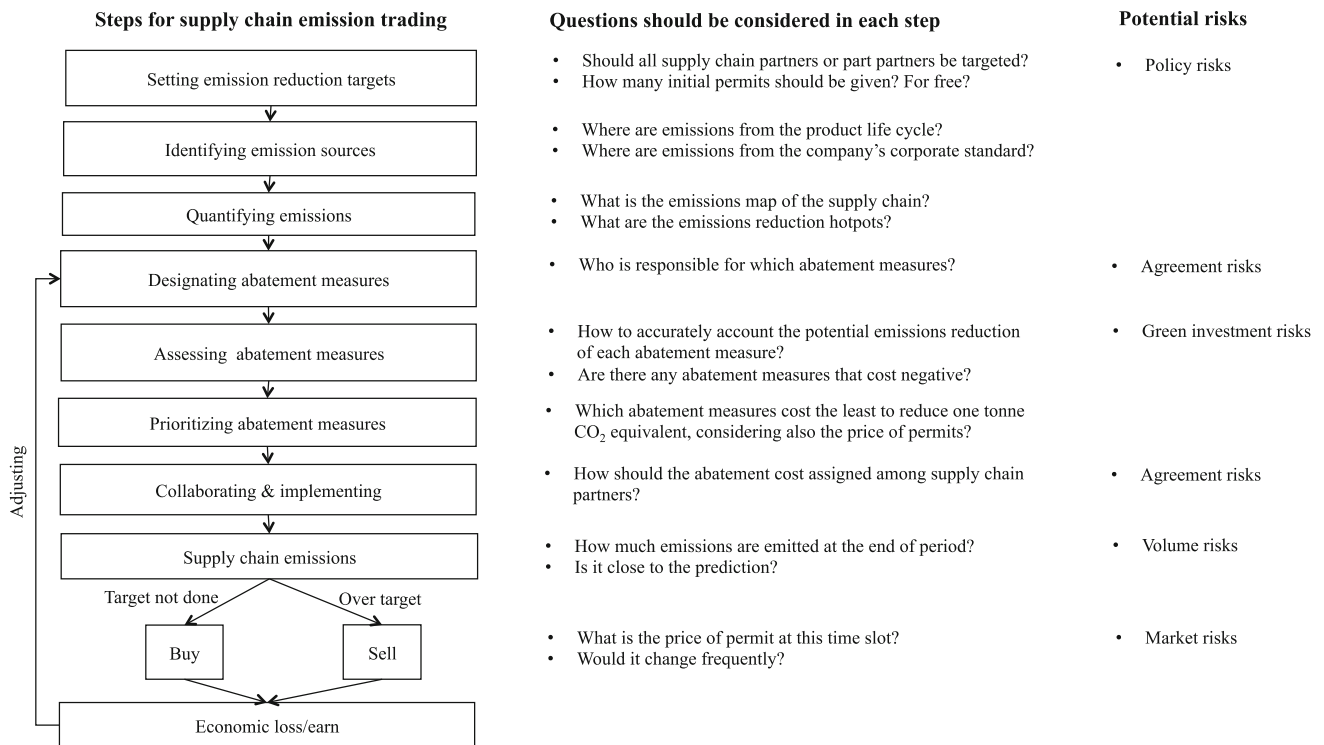
#### 1. Agreement risks (responsibility allocation dispute)

By including supply chains into emission trading, supply chain partners work together as a single firm. Different supply chain partners have different emission abatement marginal costs. Their goal is to reduce supply chain emissions as a whole at the minimal cost. To meet this goal, emission reduction cost might be transferred from one company to another where companies who are more cost-effective in emissions reduction would reduce more. Since there is an extra benefit from supply chain integration, it might be allocated to each supply chain firm as compensation. In this situation, there are risks when compensation methods are unfair or not satisfied for all inclusive supply chain firms [7]. Supply chain partners might terminate contracts with others due to increasing emissions cost or low interest in emissions reduction. Therefore, supply chains under emission trading are more vulnerable to supply chain instability than normal supply chains.

#### 2. Green investment risks (green investment uncertainty)

One of the main alternatives for supply chain firms under the emission trading is to adopt green investment (also





**Fig. 5** Risk sources and identification for supply chains under emission trading

called abatement measures). Green investment refers to adopting actions and resources for saving energy and eco-friendly transportation, which includes technological efficiency improvement and operational efficiency improvement. For example, companies could optimize their supply chains in order to save emissions from inventory, production, and transportation. However, such behavior is going to intensify the supply chain risks brought by supply chain inter-dependence. Furthermore, compared to permits' purchasing, green investment is a proactive measure as it has a long-term and sustainable effect on supply chain firms' performance, moving toward the goal of reducing GHG emissions [22]. Some abatement measures provide extremely high cost, while some provide revenue rather than cost. Firms have to decide which abatement measures should be adopted to reduce internal emissions according to their economic and operational performance, but the long-term cost and benefit of the implementation is unpredictable. In addition to usual risks, companies are also confronted with risks resulted by inappropriate investment in green technologies and other green practices.

### 3. Volume risks (emissions accounting failure)

Supply chain companies need to submit equivalent permits at the end of each year to cover all of their accurate emissions. However, it is not possible to pre-estimate supply chain emissions accurately before going through this year. Companies buy and sell permits from time to

time according to the price change in the market. Inaccurate forecast of supply chain emissions could result in overstock or shortage of permits [21]. Each permit stands for cost and revenue for companies, and overstock or shortage of permits would possibly bring economic losses for companies.

### 4. Market risks (trading market instability)

The price of permits is theoretically decided by demand and supply in the market. Such a market competition system enables the high market volatility on one hand but it results in uncertainty in permits' price on the other hand. The EU ETS, so far the largest ETS around the world, has gone through starting phases from 2005 to 2007 as the first, and from 2008 to 2012 as the second. In the first phase, the price of permits in the EU market is almost zero due to the oversupply of permits allocation to firms [23]. And the low price in the second phase is largely attributed to declining economic activity levels after the big economic crisis in 2007 [24]. As a result, the uncertainty of permits' price brings the risk of an unpredictable cost incurred by emission trading.

### 5. Policy risks (trading policy uncertainty)

Emission trading is a politically established market-based instrument to reduce emissions of GHGs and others. And therefore, it is subjected to any policy change and government decisions, such as the cap-setting and allocation

plan [21]. Although more and more countries are implementing or plan to implement ETS, it is so far still in an infant stage. Policies change from time to time according to the first-hand experiences attained in practice. The EU ETS sets free allocation for all emission permits in the first phase and the proportion of free allocation is getting smaller in the later phases. Different allocation methods and the combination of them are put into practice. For example, only electricity generators can get some proportion of free allocation in the third phase while other industrial manufacturers have to auction for permits that they need [5]. Such policies' change put companies at the risk of the unstable cost burden.

### 3.2 Risk categorization

Supply chain risks can be categorized in many different ways and from different perspectives. One possible way is the classification of supply chain risks into two types: operational risk and disruption risk [25–27]. Operational risk is defined as “the risk of loss resulting from inadequate or failed internal processes, people, and systems or from external events” [25]. Examples of operational risks are quality, delivery or service problems [27]. Disruption risk is referred to natural or manmade disasters such as terrorist attacks, sociopolitical instability, strikes, earthquakes, hurricanes and floods [26, 27].

Another way is to identify sources of risks within the three areas: company, supply chain, and environment (see Fig. 6). Internal risks within a company include process risks (i.e., disruption of the production processes) and control risks (i.e., management failure or inflexible decision rules). Supply and demand risks are disruptions of the material, information or capital flow between suppliers and customers [6]. All potential damage caused by sociopolitical, macroeconomic or technical changes are represented by environmental risks [18].

Based on the concept of supply chain risks, this paper classified these risks into each group of supply chain risks according to the distribution of risk sources (see Fig. 7).

Supply chains under emission trading are exposed to additional risks. Being subject to the cap-and-trade, supply chains are confronted with risks from both policy and

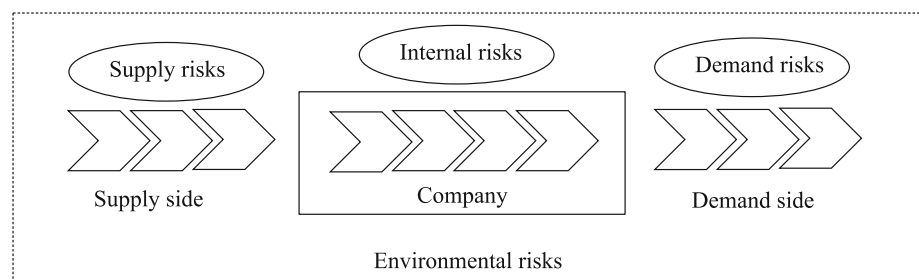
market perspective. By committing to reduce emissions under the cap, supply chain firms encounter new risks of green investment uncertainty and emissions accounting failure. Accounting failure would result also in surrendering not enough permits at the end of a certain period. In addition, supply chain firms must be exposed to the risk of responsibility allocation dispute when assigning the emissions reduction responsibility among supply chain partners. This risk is also raised by distributing the spared cost or extra benefit to supply chain partners.

### 3.3 Strategies for risk mitigation

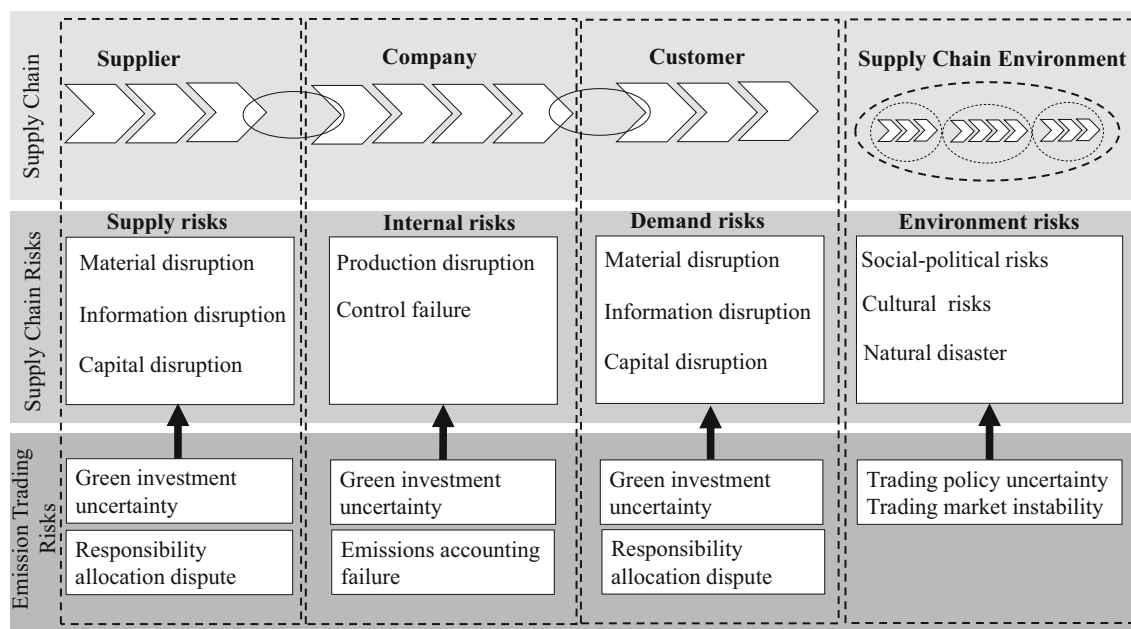
The implementation of emission trading on supply chain would not only intensify some risks for supply chain companies but also increase some additionally. All these risks could be regarded as disadvantages in including supply chains into emission trading from business and political point of view. They take essential roles in promoting supply chain firms reducing emissions and collaborating with each other. These risks are also what government should focus on when they are considering employing emission trading on supply chains. Although this paper is limited in conducting the risk assessment, authors contribute still in providing some risk mitigation measures for both policy-makers and business companies.

- (a) To engage supply chain into emission trading based on leading firms in each supply chain. Leading firms are powerful to encourage supply chain partners to collaborate in reducing emissions together. And leading firms could also set emission reduction targets for other partners due to its large power and business attractiveness. Therefore, leading firms could be targeted as main subjects in the first step of including supply chains.
- (b) To learn experiences from existing ETS to set the supply chain emission limit so called cap. The cap could either be drafted by firms and permitted by governments or directly issued by governments. Permits could be allocated to supply chain partners according to the method ‘benchmark’ which benefits green firms and punishes others.

**Fig. 6** Sources of risk within a supply chain. *Source:* Kersten et al. [19]







**Fig. 7** Risk categorization for supply chains under emission trading

- (c) To jointly regulate permits price by market system and governmental intervention at the beginning. Too high or too low price would prohibit the goal of supply chain emission reduction. Proper intervention from the government is necessary to keep the price fluctuate in a reasonable range.
- (d) To clarify benefits and costs of green technologies through official third parties. Professional parties have experiences and experts to verify emission savings and costs of main green technologies, and these parties could be connected to the department of permits verification in existing ETS.
- (e) To import offset/credit concepts within the range of supply chain. It means, the leading company in the supply chain could get credits by investing into emissions reduction projects within the board of other supply chain firms. These credits could be used as additional permits in the existing emission trading market. Credit projects could also be invested by other supply chain firms and sold to the leading companies at a certain price.
- (f) To add agreements in business contracts among supply chain partners concerning cost/benefits allocation. There are many kinds of contracts that could compensate the loss of firms induced by emission trading, such as product price discount, operational contract extension, and so on. It would also offer mind share to refer to some quantitative models in operational research.

#### 4 Conclusion

It is well recognized that in order to combat climate change, GHG emissions need to be managed from the supply chain perspective. This paper moves one more step forward on the base of literature by introducing one concept—supply chain emission trading and one framework in addressing emission trading in the context of supply chains. To implement the supply chain emission trading, this paper proposed to assign the responsibility of supply chain GHG emissions to the focal company in the supply chain by including the scope 3 emissions of the focal company into ETS. Moreover, this paper discerns itself from others by identifying risks for supply chains under emission trading program. From a corporate perspective, these risks are from policy instability, market variation, supply chain agreement dispute, green investment uncertainty, and supply chain GHG emission accounting failure. Moreover, based on the concept of supply chain risks, this paper attributes green investment risks to internal and external risks, policy and market risks to supply chain environmental risks, accounting risks to internal risks, and agreement risks to external risks.

The concept proposed in this paper lays the foundation for future research to address further qualitative issues involved in employing emission trading in the context of supply chain, such as analyzing the challenges and opportunities within the implementation processes. Besides, supply chain companies could follow the detailed

steps and instructions provided in the framework when they are considering leveraging the opportunities offered by emission trading to manage their supply chain GHG emissions. Furthermore, having an overview of companies' risks provides mind share for policy-makers before they start implementing emission trading in the context of supply chain. For example, they could make efforts to decrease the accounting failure risk by importing one unified supply chain GHG emission measurement tool or standard. Last but not least, this paper contributes in connecting supply chain risk management and supply chain emissions management through classifying identified risks into each group of supply chain risks. By doing so, it makes the resources and experiences in the area of supply chain risk management accessible to facilitate the implementation of supply chain emission trading, and paves the way for future research in risks assessment and evaluation.

However, this paper is just a first step towards realizing the employment of emission trading in the context of supply chain and it has limitations. The supply chain emission trading proposed in this paper works on the base that there exists a focal company in the supply chain. Nevertheless, it doesn't apply to supply chains that are composed by many small and equally powerful companies.

Future research might consider conducting an analysis of challenges and opportunities involved in the implementation processes. For instance, the Monitor, Review, and Verify (MRV) system of ETS has to be extended to adapt for the supply chain scale in supply chain emission trading. In addition, it is worthy to explore other mechanisms to realize supply chain emission trading concerning different supply chain organizational structures. As suggested in this paper, supply chain credit scheme that incorporates the concept of credit/offset into the supply chain emission trading would provide flexibility. Furthermore, it is interesting to assess and evaluate those identified risks and investigate how they interact with the existing supply chain risk portfolio.

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