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Supply Chain Carbon Management

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ABSTRACT: Sustainable supply chain and carbon management have seen a growing interest in the last decade due to the increasing concerns about global warming and climate change. Policymakers, researchers, and executives have taken various roles in efforts to better measure and control greenhouse gas emissions. This book chapter aims to discuss the current state of the art, and key motivations for businesses to decrease emissions, and different policies and regulations that have been designed to incentivize carbon reduction and enhance the environmental awareness of all stakeholders. The chapter also examines the methodologies for measuring and managing carbon emissions of an organization and its supply chain. Further, it discusses carbon management issues related to reverse logistics, life cycle assessment and double counting of emissions.

KEY WORDS: ***Supply chain; Sustainable; Carbon emissions; Environmental regulations***

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1. Introduction

Climate change is arguably an integral part of all levels and types of decision making; whether strategic, tactical or operational decisions, made by individuals, corporations or governments. According to the United Nations Framework Convention on Climate Change (UNFCCC), 'climate change' is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (Protocol, 1997). Sea level rising, increase in global temperature, warming oceans, shrinking ice sheet declining arctic sea ice, and extreme events are the more obvious evidences of global warming.

Figure 1 shows the global annual changes in land and ocean surface temperature (Figure 1a), sea level changes (Figure 1b), greenhouse gas (GHG) concentrations (Figure 1c), and anthropogenic carbon emissions (Figure 1d). Different datasets are represented in different colors, and shadows show the variations in data. In particular, Figure 1c shows the concentration of average GHGs (CO2, CH4 and N2O) determined from ice core data (in dots) and direct atmospheric measurements (in lines). Figure 1d plots carbon dioxide (CO_2) emissions generated through forestry and other land use, burning of fossil fuel, and cement production and flaring.

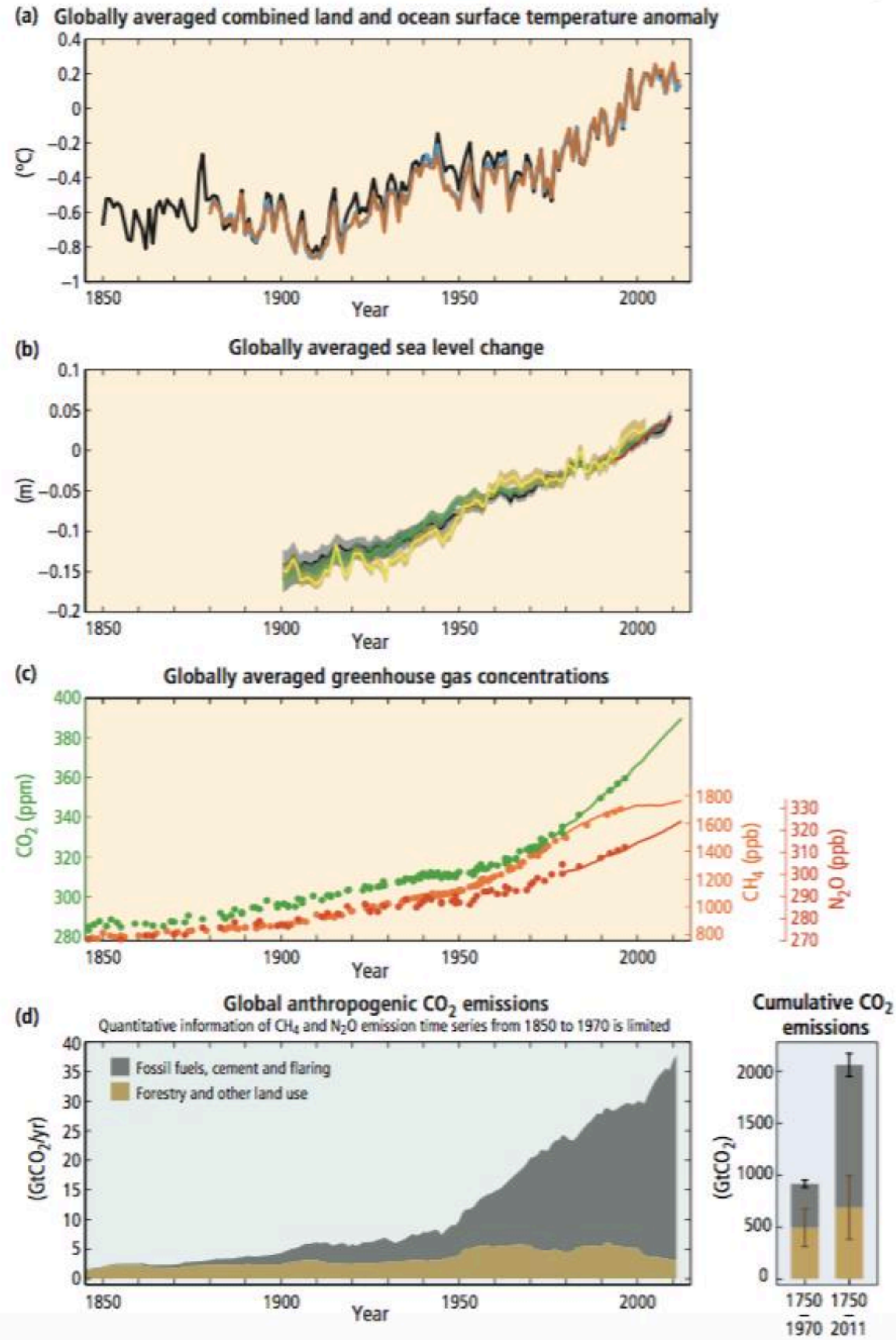
(a) Globally averaged combined land and ocean surface temperature anomaly
(°C)
Year
(b) Globally averaged sea level change
(m)
Year
(c) Globally averaged greenhouse gas concentrations
CO_2 (ppm)
CH_4 (ppb)
N_2O (ppb)
Year
(d) Global anthropogenic CO_2 emissions
Quantitative information of CH_4 and N_2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
($GtCO_2$/yr)
Year
Cumulative CO_2 emissions
($GtCO_2$)
1750–1970
1750–2011

Figure 1 Global annual changes in land and ocean surface temperature (1a), sea level (1b), GHG concentration (1c), and CO2 emissions (1d) –(Pachauri et al., 2014)

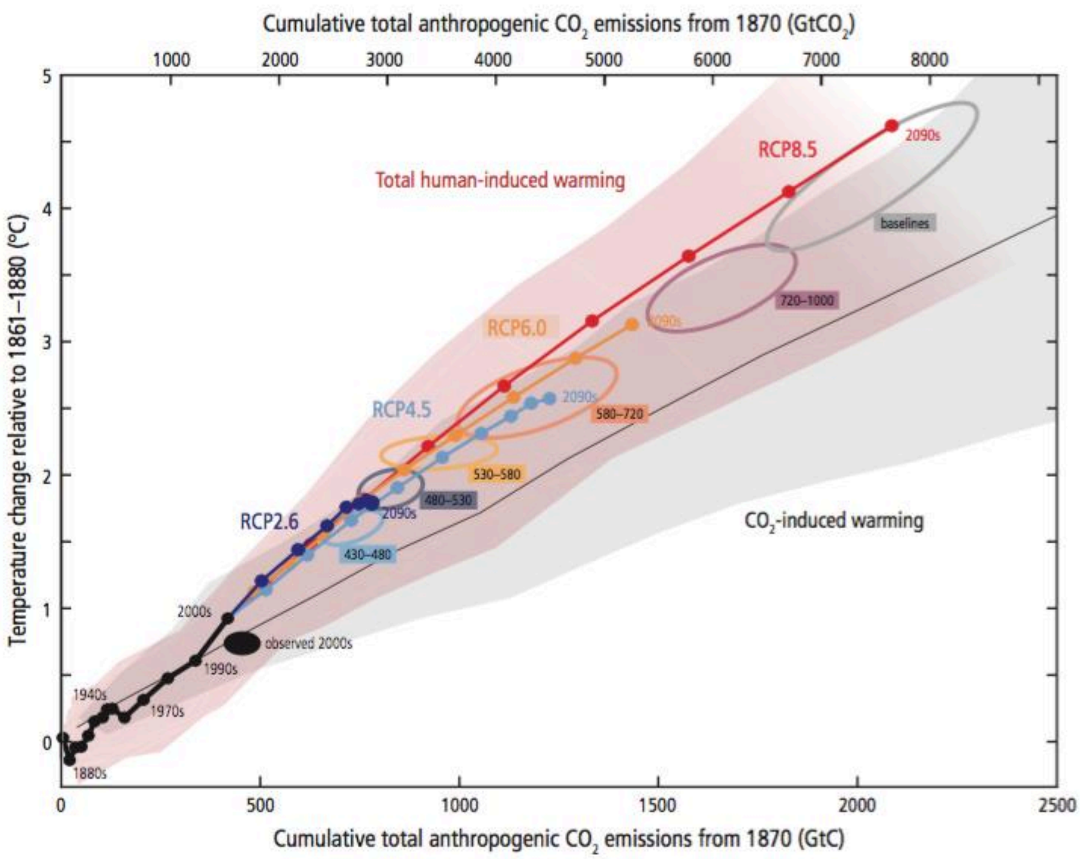

Figure 2 The total anthropogenic warming versus cumulative CO2 emissions (Pachauri et al., 2014)

There is a consensus by most climate scientists that global warming is primarily caused and intensified by the increasing level of CO2 in the atmosphere which is mainly due to human activities (Karl, 2009; Oreskes, 2004). As shown in Figure 2, global mean surface temperature increases with the cumulative total global CO_2 emissions. Colored lines in this figure represent results from a hierarchy of climate carbon-cycle models for each Representative Concentration Pathway (RCP) until 2100. The plume regions show the multi-model spread over four RCP situations, and the average values over decades are shown by dots. The total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 (obtained from the median climate response) under the scenario categories used in WGIII is shown in ellipses. The black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties (Pachauri et al., 2014).

Considering these facts and observations, CO2 emissions reduction has been considered a major step towards climate change mitigation (Tseng & Hung, 2014). General public, policymakers, media and businesses have been extensively using carbon footprint in different concepts, regulations and debates on environmental responsibilities and global warming. This chapter aims to discuss the key motivations for businesses and governments to cut their carbon emissions (section 2), the methodologies for measuring and managing carbon emissions (section 3), and carbon management issues at a supply chain level where multiple player are involved (section 4).

2. Emissions Reduction Drivers

Firms may be motivated to take on carbon reduction initiatives for a variety of reasons. Among these we can name the existing policies and regulations that have been designed to incentivize carbon reduction and enhance the environmental awareness of all stakeholders. Most initiatives come with some economic benefits either in the short term through win-win opportunities and picking the lower hanging fruits or in long-term through tradeoff opportunities and reputational benefits.

Governmental pressures imposed through regulatory mandates have been shown to be one of the most effective ways to change consumption rates and emissions generation behavior (Zakeri, Dehghanian, Fahimnia, & Sarkis, 2015). There are those who think that environmental regulations may cause some economic harm and negatively influence the competitiveness of industries. However, research on the topic is not in agreement with this and finds no strong connection between environmental regulations and job destruction or economic decline (Coglianese & Carrigan, 2014).

Increased consumer awareness is another motivation for companies to measure and manage carbon emissions due to its direct relationship with their sales and marketing.

Consumers are now more than ever aware and concerned about the environmental sustainability of the products and services they acquire. Environmentally conscious individuals most likely prefer to deal with companies with greater environmental credential; that is, cost and quality aspects of a product or service are no longer the only factors incorporated into buyers' purchase decision (Boyd, Spekman, Kamauff, & Werhane, 2007; Neto, Bloemhof-Ruwaard, van Nunen, & van Heck, 2008). In general, the externalities imposed by customers and other interest groups can impact the stakeholder decisions (also supported by the stakeholder theory). There is strong evidence that the more sustainable businesses are more appealing to investors when profitability of a business is not a strategic concern (Lash & Wellington, 2007).

Arguably, most excessive and yet avoidable CO2 emissions across the supply chain is generated through excess transportation, supplier management inefficiencies, or energy overuse in the production facilities. These are typically referred to as win-win opportunities in which considering the environmental performance of the operations can both reduce the carbon emissions and bring about some immediate financial gains. Consider this case for example. Natural gas emits between 0.6 and 2 pounds of CO2 equivalent per kilowatt-hour (CO2E/kWh) and coal emits between 1.4 and 3.6 pounds of CO2E/kWh. Compare this with wind emitting only 0.02 to 0.04 pounds of CO2E/kWh and solar emitting 0.07 to 0.2 pounds of CO2E/kWh. Apart from the associated carbon saving and public health benefits that are gained through the use of cleaner energy sources, the acquisition costs have declined dramatically over the past few years making a move toward the use of cleaner energies a wise decision as the strategic financial gains easily outweigh the initial investments.

Practically, firms are required not only to focus on reducing emissions generated through their internal operations, but also to monitor those of their suppliers. Business customers and end-users tend to be more concerned about the ways through which suppliers are selected (Banaeian, Mobli, Fahimnia, Nielsen, & Omid, 2017; C, B, & J, 2017). The choice of suppliers can change the total environmental impact of the supply chain as a whole, and thereby influence the organization's overall positioning and reputation. The carbon performance of the supply chain is reflected in its sustainability reports and this includes both direct and indirect emissions. This will be discussed further in this chapter under 'carbon scoping'.

As an example, DHL realizes that 98 percent of its emissions in Sweden come from the outsourced partner transportation firms. DHL accordingly requests all of its carriers to provide information regarding the type of vehicles used, their fuel efficiency and distance traveled (WBCSD, 2004). Similarly, the world's major retailers are setting the bars higher when it comes to the emission assessment of their suppliers. Wal-Mart, for example, pushes suppliers to rely less and less on carbon-based energy sources (Walmart, 2016). In automotive industry, as another example, Lee (2011) introduced a methodology to measure carbon footprint of automobile parts suppliers so that car manufacturers can better measure and improve the overall supply chain emissions.

3. Measuring and Regulating Emissions

Realizing the significance of emissions reduction for businesses, the question to ask next is how to measure carbon emissions of an organization and its supply chain. There are different opinions and debates on carbon measurement and reporting. Among these discussions is whether carbon footprint involves only CO2 emissions or whether the six GHGs in Kyoto Protocol should be considered. Other discussions are around the emissions that an organization should account for and report. Some consider direct CO2 emissions as a carbon footprint, whereas others may consider the full life-cycle emission. Wiedmann and Minx (2008) review the related literature and define carbon footprint as "a measure of the exclusive total amount of CO2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product".

Introduced in 2005, European Union Emissions Trading System (EU ETS) is the largest CO_2 trading market in the world, aiming to balance the supply and demand of CO_2

emission allowance. The primary goal of EU ETS is to reduce greenhouse gas emission cost effectively (Gopal, 2017). In a carbon trading environment, companies can buy carbon credits/allowances from other registered companies operating in sustainable energy markets. This is commonly referred to as 'carbon offsetting'. Using carbon offsetting, companies are allowed to offset their CO2 emissions against projects that have positive influence on the GHG emissions. There has also been debate on the ways carbon offsetting and the use of renewable energy sources can be considered in the carbon footprint calculation (Finkbeiner, 2009).

3.1 Regulatory Mandates and Incentives

Governments are under increasing pressure to design and implement environmental regulatory mechanisms to confront the anthropogenic global warming. The regulations are expected to provide both pressures and incentives that can change consumption behaviors and encourage more sustainable operations. Many governments have signed the Kyoto protocol and more recently the Paris agreement. The main objectives of the latter agreement are to set emission caps for nations, forcing governments and organizations to redesign their productive systems and introduce new environmental policy instruments.

A number of international standards and protocols have been introduced to date. For example, ISO developed an international environmental standard ISO 14067 on carbon footprint of products. Organizations & The World Business Council for Sustainable Development (WBCSD) has a proposal on carbon footprint. The World Resources Institute (WRI) introduced two standards under their GHG Protocol Product – Supply Chain Initiative: A Product Life Cycle Accounting and Reporting Standard and a Corporate Accounting and Reporting Standard: Guidelines for Value Chain Accounting and Reporting (Finkbeiner, 2009).

The *carbon trading mechanism* (also known as cap-and-trade) and *carbon tax scheme* (also known as carbon pricing) are the most broadly adopted environmental regulatory mandates around the globe (S. Benjaafar, Li, & Daskin, 2013; Zakeri et al., 2015). In a carbon trading scheme (also known as a cap-and-trade mechanism), a limited number of tradable emissions allowances (the cap) is issued for distribution among the players in an economy. Companies generating more emissions than the allocated allowances receive significant fines or purchase emissions allowances off the market from those generating fewer than the allowed emissions. There is an open market where companies who produce less than their permits amounts can sell the excess emissions allowances to those producing more than the limit.

The carbon trading scheme creates both pressures (significant fines for over-polluting) and incentives (financial reward for selling surplus allowances) to encourage emission reduction initiatives. The objective is to either have companies purchase market-priced credits/allowances or to invest in practices and technologies that reduce GHG emissions. There are however challenges with a carbon trading mechanism that has made the scheme not as successful in application as initially expected. Some of the common challenges include (1) on what bases should the initial allowances be allocated to each company? and (2) how should the fine be evaluated for over polluting companies going over the allocated allowances, if they do not wish to purchase allowances?

Some emissions allocation methods have been proposed and investigated in the past (Böhringer & Lange, 2005; Burtraw, Palmer, Bharvirkar, & Paul, 2001; Cramton & Kerr, 2002). Grandfathering is the most widely used allocation method in which emissions allowances are allocated according to the available historical emission data (Böhringer & Lange, 2005). In other words, the allowances are allocated to the players in a way to achieve the agreed upon goals.

Carbon pricing aims to control emissions by taxing the generated carbon. Each carbon emitter is simply charged a tax proportional to the size of the emissions generated. A carbon charge is expected to encourage companies to reduce their emissions using various practices and technologies whose managerial and implementation cost is less than the charge. The primary challenge with this mechanism are (1) how to set a price on carbon so that maximum emissions reduction can be achieved without significant impact on the corporate and national economy? (Fahimnia, Sarkis, Choudhary, & Eshragh, 2014; Fahimnia, Sarkis, & Eshragh, 2014), and (2) how to set the carbon price to cater for possible variations in fuel and energy prices? (Fahimnia, Sarkis, Boland, Reisi, & M, 2014). The impact of introducing a carbon tax on emissions reduction (Fahimnia, Reisi, Paksoy, & Özceylan, 2013; Behnam Fahimnia et al., 2014; Rezaee, Dehghanian, Fahimnia, & Beamon, 2015), energy prices (Bassi, Yudken, & Ruth, 2009; B Fahimnia, J Sarkis, J Boland, et al., 2014), and reverse supply chain operations and the associated carbon reporting challenges (Fahimnia, Sarkis, Dehghanian, Banihashemi, & Rahman, 2013) have been investigated at the strategic and tactical planning levels.

Studies have shown that emissions trading can be theoretically more effective in terms of carbon reduction gals compared to a carbon tax scheme (Zakeri et al., 2015). However, due to the market inefficiency and unequal information access, emission trading implementation has been rather unsuccessful in European Union. Compared to Emission trading, taxing emission is more straightforward in implementation with less uncertainties and clear expected outcomes (Andrew, 2008).

Apart from the regulatory mandates, there are also a number of voluntary programs such as clean development mechanisms that enables countries to fund emission reduction projects in some of the developing countries. There are also joint implementation mechanisms through which companies gain emission credits by carrying out emission reduction projects in other countries.

One of the difficult measurement considerations is where to draw the boundary of an organization's emissions responsibilities. Thus, there has been an effort by the Carbon Disclosure Project (CDP) and the Greenhouse Gas (GHG) Protocol to focus on '*scopes*' of evaluation. There are Scope 1, Scope 2, and Scope 3 emissions considerations (Plambeck, 2012). The purpose of these scope definitions is to avoid double-counting GHG emissions.

The classification and valuations are intended to help organizations determine which GHG they can control (Scope 1) versus and those which they can indirectly influence (Scope 3).

Scope 1 are the most direct GHG emissions. These are defined as emissions from sources that are owned or controlled by the organization.

Scope 1 examples include:

(1) stationary combustion from the combustion of fossil fuels for heating and industrial applications that are not necessarily product process manufacturing related;

(2) mobile combustion from fossil fuels (e.g. gasoline, diesel) used in transportation such as the operation of vehicles;

(3) process emissions released during the manufacturing process in various industrial sectors such as concrete, steel, iron manufacturing); and

(4) fugitive missions that include unintentional GHG releases from such sources as refrigerant systems and natural gas distribution.

Scope 2 emissions are primarily indirect GHG emissions which occur from consumption of purchased electricity, steam, or other energy sources. These sources are typically generated in the upstream supply chain of the organization. The least controlled GHG emission occur with the Scope 3 emissions. These emissions have been called other indirect GHG emissions. Scope 3 emissions result from the operations of an organization, but are not directly owned or controlled by the organization. Many of these emissions come from a variety of sources including employee commuting, business travel, third-party distribution and logistics, production of purchased goods, emissions from the use of sold products, and several more. These emissions are most closely aligned with broader supply chain operations emissions. Typically, Scope 3 GHG emissions are the largest component of organizational carbon footprint evaluations.

4. Carbon Management in the Supply Chain

In responding to carbon reduction mandates and incentives, a range of initiatives have been undertaken by businesses to reduce supply chain emissions. This could be through the use of clean technologies or renewable power sources. Changes in product design and process design (e.g., managing reverse logistic) could be another alternative for emission reduction at the supply chain level.

Reverse Logistics is related to the recycling of the materials or products, and is becoming more of a concern in the last decade since waste reduction is more critical for the supply chains. Fleischmann et al. (1997) defined Reverse Logistics as "the process of planning, implementing, and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain direction for the purpose of recovering value or proper disposal". Reverse logistic is the final stage that closes the supply chain (closed-loop supply chains) and that is mostly driven by economic and regulatory legislation (Atasu, Toktay, & Van Wassenhove, 2009). Savaskan, Bhattacharya, and Van Wassenhove (2004) show that in a closed-loop supply chain the profit of a centrally coordinated system can be achieved through coordination mechanisms.

At the supply chain level, many of the decisions for production, procurement, and inventory management involve tasks, such as transportation, inventory handling, and storage, that are carbon-intensive. By integrating carbon consideration into these decisions, firms can reduce their emission levels. S. Benjaafar, Yanzhi Li, and Mark Daskin (2013) introduced a model that associates operational decision variables with the carbon emission parameters. They show how traditional models can be upgraded by incorporating both carbon and cost concerns.

The organizational implications of government regulatory policies have been studied from a number of perspectives including the development of carbon accounting within organizations (Stechemesser & Guenther, 2012), determining when to invest in technology (Sarkis & Tamarkin, 2005) and the types of products and processes to integrate (Schaltegger & Csutora, 2012). In addition, a range of optimization models and decision support tools have been developed and implemented to balance the economic and emissions performance of the supply chains (see for example (Chaabane, Ramudhin, & Paquet, 2012; Elhedhli & Merrick, 2012; Fahimnia, Reisi, et al., 2013; Behnam Fahimnia et al., 2014; Pishvaee, Torabi, & Razmi, 2012; Rezaee et al., 2015).

Reducing transport emissions through the use of more efficient vehicles/trucks and optimizing distribution networks to minimize the travelling distances can also help improve supply chain the efficiency depending on the type of business and the proportion of transport emissions. Rizet, Browne, Cornelis, and Leonardi (2012) review the available methods of quantifying and managing GHG emissions produced by manufacturers, retailers and transport companies providing a diverse range of products and services in Belgium, France and UK. Cholette and Venkat (2009) complete a similar supply chain emissions analysis for the transport and storage activities in wine industry.

An important tool is visualization of the carbon implications of the supply chain. Supply chain carbon maps can be used as a tool to create industry-level benchmarks for environmental sustainability of a product. This benchmark offers the initial stage for firms to manage their performance with respect to environmental concerns, and to identify the areas across the supply chain with high carbon emissions with potential for cross-sectoral benchmarking (Acquaye, Genovese, Barrett, & Lenny Koh, 2014).

4.1 Life Cycle Assessment

As business competitions transform from “firm versus firm” to “supply chain versus supply chain”, there is a need to measure and account for environmental sustainability of products and services throughout their life cycle, from cradle to grave (raw materials extraction, manufacturing, distribution, usage and maintenance, recycling or disposal, etc.). To do so, organizations are required to assess the environmental performance of their entire supply chains including the processes within and outside the organization (i.e. those of their suppliers and customers). Such approach is often referred to as Life Cycle Assessment (LCA) in which the environmental impacts of a product or service is evaluated at all stages including raw material acquisition, processing, distribution, use, and disposal (Mälkki & Alanne, 2017).

Most LCA processes have been standardized (e.g., ISO 14044) and follow certain steps to define processes and the boundaries, identify material and energy flows, and environmental impact assessment of each process. LCA helps organizations avoid shifting environmental problems from one place to another and identify the key investment and improvement opportunities.

LCA and carbon emissions can occur at multiple levels of analysis related to supply chains. For example, Input-Output LCA (I-O LCA) can be used to evaluate inter-industrial macro-economic linkages (Egilmez, Mohamed Abdul Ghani, & Gedik, 2017). The use of LCA can expand the calculation of supply chain emissions from Scopes 1 to 3, to multiple layers, even up to six layers of emissions depending on the industry (Egilmez et al., 2017). But, these broader industry relationships are difficult to tie to specific company, product and brand supply chains. The level of analysis is usually quite general.

The LCA application studies that focused on specific supply chains include a breadth of industries. For example, the construction and built environment supply chains have seen significant investigation due to the emissions generated from building materials production (Akan, Dhavale, & Sarkis, 2017; Mohamed Abdul Ghani, Egilmez, Kucukvar, & S. Bhutta, 2017). These models have not only been used for decisions by supply chain partners, but also by policy makers to help identify measures that can broadly influence supply chains and industries. Additionally, various industries within the construction supply chain can be identified as the major culprits. Some results have indicated that "ready-mix concrete manufacturing", "electric power generation, transmission and distribution" and "lighting fixture manufacturing" sectors were found to be major contributors to carbon emissions stock in the construction supply chain.

Specific resources and inputs have also been investigated for measuring and reporting total supply chain carbon emissions. Take renewable jet fuels as an example (de Jong et al., 2017). In this case, the assessment covered "well-to-wake" carbon emissions including emissions from feedstock cultivation and pre-processing, upstream logistics, conversion to RJF, downstream distribution, and end use; the typical supply chain. Land change, byproducts, and general supply chain management were included in the analysis. That is, not only should supply chain operations be considered in a typical LCA and carbon emissions evaluation, but changes in the supply chain and various new residues and flows (de Jong, et al., 2017).

Given the changes in the retail industry significant work has also looked at shifting supply chain concerns as well. These industrial shifts for fast moving consumer goods from 'bricks and mortar' to online purchases may shift the carbon emissions from direct company to more indirect emissions evaluation (van Loon, Deketele, Dewaele, McKinnon, & Rutherford, 2015)Thus, the need for LCA and updated emissions values in various industries and products need to be carefully monitored.

A limitation of utilizing LCA is that some environmental dimensions are better developed than other dimensions. For example, much of LCA focused initially on hazardous wastes, carbon and water, along with newer metrics such as energy, are recent advances. Linking these various elements to supply chain management in general are all possibilities for further development and research.

4.2 Emissions Scoping and Double Counting of Emissions

Understanding the difference among emission types can help delineate different emission types, improve transparency, and set relevant types of emissions reduction policies and organizational goals (Fahimnia, Sarkis, et al., 2013). As mentioned earlier, GHG emissions can be classified into three different groups with respect to the degree of control an organization can have over the emission: Scope 1, Scope 2 and Scope 3 emissions. Companies need to account for and report on scopes 1 and 2 emissions at a minimum, whilst scope 3 remains an optional reporting category. However, for many organizations, the majority of their emissions and emissions reduction opportunities lie outside their own operations. Measuring scope 3 emissions would allow organizations to (1) identify the most polluting suppliers and outsource activities that pose significant risks to the supply chain, and (2) develop and implement new sustainability initiatives (win-win opportunities) in collaboration with suppliers.

The problem with scope 3 emissions reporting is a phenomenon called “carbon ownership”. When joint initiatives are implemented between companies and their suppliers, the ownership and reporting of the reduced emissions is a formidable challenge. Certain emission savings may be counted more than once by the participating organizations resulting in over-estimation of emissions generated at the state, national and international levels. While double counting of emissions have been long avoided in the LCA and carbon reporting literature, recent studies also show that double counting is usually necessary to encourage firms choose the optimal abatement efforts (Caro, Corbett, Tan, & Zuidwijk, 2013).

5. Conclusions

Carbon management in the supply chain has seen increased interest due to the many industries that play different roles in its management. Whether there are optimization designs and simulation approaches, policy disagreements, or industrial variations, the work in this area is evolving.

Multiple organizational functions are influenced by any planning and management of the sustainable supply chain. Marketing needs to worry about products where consumers might be demanding to know the carbon footprints of products. The supply chain carbon emissions valuations will be important in this regard. Finance is concerned about the financial implications of alternative answers across and within the supply chain. Monitoring of internal and external emission valuations in the supply chain have significant uncertainties (e.g. Dhavale and Sarkis (2018)). These uncertainties include accounting for actual emissions and the social and environmental costs of carbon emissions.

Organizational and supply chain behavioral changes, under the auspices of human resources management, for example, can have impacts on the way supply chain management practices may influence carbon emissions. As an example, transportation emissions can be greatly influenced by the behavior and training of truckers and transportation operators.

Purchasing and operations including the selection of suppliers, supplier development, and supplier monitoring and auditing can all influence the carbon emissions in a supply chain. Multiple tier investigation is necessary and tools such as LCA can prove valuable for consideration of the multiple layers of the supply chain and monitoring. Further development and investigation in this area is warranted.

Engineering, research and development are important for product development and design for the environment considering supply chain carbon emissions. This function, in collaboration with environmental health and safety are critical for long term strategic management of supply chain carbon emissions. Technical solutions, along with resourced financial and human resource behavior changes are all necessary for a broad perspective.

Given the impending issues to mitigate climate change concerns, managing the supply chain with a carbon reduction focus is necessary. Tools and perspectives are starting to gain momentum. Researchers and investigators from a broad variety of disciplines, relating to various organizational functions, have taken the lead in many efforts. A transdisciplinary approach ranging from the natural sciences, to social and management scientists, to practitioners and policy makers are all needed for a holistic solution to this pernicious problem.

References:

Acquaye, A., Genovese, A., Barrett, J., & Lenny Koh, S. C. (2014). Benchmarking carbon emissions performance in supply chains. *Supply Chain Management: An International Journal, 19*(3), 306-321. doi: doi:10.1108/SCM-11-2013-0419

Akan, M. Ö. A., Dhavale, D. G., & Sarkis, J. (2017). Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. *Journal of Cleaner Production, 167*, 1195-1207.

Andrew, B. (2008). Market failure, government failure and externalities in climate change mitigation: the case for a carbon tax. *Public Administration and Development, 28*(5), 393-401.

Atasu, A., Toktay, B., & Van Wassenhove, L. N. (2009). *The impact of collection cost structure on reverse channel choice.* Paper presented at the Georgia Institute of Technology Working Paper.

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I., & Omid, M. (2017). Green Supplier Selection Using Fuzzy Group Decision Making Methods. *Computers and Operations Research, in press*.

Bassi, A. M., Yudken, J. S., & Ruth, M. (2009). Climate policy impacts on the competitiveness of energy-intensive manufacturing sectors. *Energy Policy, 37*(8), 3052-3060. doi: 10.1016/j.enpol.2009.03.055

Benjaafar, S., Li, Y. Z., & Daskin, M. (2013). Carbon Footprint and the Management of Supply Chains: Insights From Simple Models. *Ieee Transactions on Automation Science and Engineering, 10*(1), 99-116. doi: 10.1109/Tase.2012.2203304

Benjaafar, S., Yanzhi Li, and Mark Daskin. (2013). Carbon footprint and the management of supply chains: Insights from simple models. *IEEE transactions on automation science and engineering, 10*(1), 17.

Böhringer, C., & Lange, A. (2005). On the design of optimal grandfathering schemes for emission allowances. *European Economic Review, 49*(8), 2041-2055.

Boyd, D. E., Spekman, R. E., Kamauff, J. W., & Werhane, P. (2007). Corporate social responsibility in global supply chains: A procedural justice perspective. *Long Range Planning, 40*(3), 341-356.

Burtraw, D., Palmer, K., Bharvirkar, R., & Paul, A. (2001). *The Effect of Allowance Allocation on the Cost of Carbon Emissions Trading*. Discussion Paper 01–30. Resources for the Future. Washington, DC.

C, B., B, F., & J, S. (2017). Sustainable Transport Fleet Appraisal Using A Hybrid Multi-Objective Decision Making Approach. *Annals of Operations Research, in press*.

Caro, F., Corbett, C. J., Tan, T., & Zuidwijk, R. (2013). Double Counting in Supply Chain Carbon Footprinting. *Manufacturing & Service Operations Management, 15*(4), 545–558.

Chaabane, A., Ramudhin, A., & Paquet, M. (2012). Design of sustainable supply chains under the emission trading scheme. *International Journal of Production Economics, 135*(37-49).

Cholette, S., & Venkat, K. (2009). The energy and carbon intensity of wine distribution: A study of logistical options for delivering wine to consumers. *Journal of Cleaner Production, 17*(16), 1401-1413.

Coglianese, C., & Carrigan, C. (2014). The Jobs and Regulation Debate. In C. Coglianese, A. M. Finkel & C. Carrigan (Eds.), *Does Regulation Kill Jobs?* Pennsylvania, USA: University of Pennsylvania Press.

Cramton, P., & Kerr, S. (2002). Tradeable carbon permit auctions: How and why to auction not grandfather. *Energy Policy, 30*(4), 333-345.

de Jong, S., Antonissen, K., Hoefnagels, R., Lonza, L., Wang, M., Faaij, A., & Junginger, M. (2017). Life-cycle analysis of greenhouse gas emissions from renewable jet fuel production. *Biotechnology for biofuels, 10*(1), 64.

Dhavale, D. G., & Sarkis, J. (2018). Stochastic internal rate of return on investments in sustainable assets generating carbon credits. *Computers & Operations Research, 89*, 324-336.

Egilmez, G., Mohamed Abdul Ghani, N. M. A., & Gedik, R. (2017). Layer analysis of CO2 sources in the US economic supply chains: an input output LCA study. *Industrial Management & Data Systems, 117*(10), 2171-2193.

Elhedhli, S., & Merrick, R. (2012). Green supply chain network design to reduce carbon emissions. *Transportation Research Part D: Transport and Environment, 17*, 370-379.

Fahimnia, B., Reisi, M., Paksoy, T., & Özceylan, E. (2013). The Implications of Carbon Pricing in Australia: An Industrial Logistics Planning Case Study. *Transportation Research Part D: Transport and Environment, 18*, 78–85.
Fahimnia, B., Sarkis, J., Boland, J., Reisi, M., & M, G. (2014). Policy Insights from a Green Supply Chain Optimization Model. *International Journal of Production Research, in press*.
Fahimnia, B., Sarkis, J., Choudhary, A., & Eshragh, A. (2014). Tactical Supply Chain Planning under a Carbon Tax Policy Scheme: A Case Study. *International Journal of Production Economics, 164*, 206-2015.
Fahimnia, B., Sarkis, J., Dehghanian, F., Banihashemi, N., & Rahman, S. (2013). The impact of carbon pricing on a closed-loop supply chain: an Australian case study. *Journal of Cleaner Production, 59*, 210-225. doi: http://dx.doi.org/10.1016/j.jclepro.2013.06.056
Fahimnia, B., Sarkis, J., & Eshragh, A. (2014). A Tradeoff Model for Green Supply Chain Planning: A Leanness-versus-Greenness Analysis. *OMEGA, 54*, 173-190.
Finkbeiner, M. (2009). Carbon footprinting—opportunities and threats. *The International Journal of Life Cycle Assessment, 14*(2), 91-94. doi: 10.1007/s11367-009-0064-x
Fleischmann, M., Bloemhof-Ruwaard, J. M., Dekker, R., Van der Laan, E., Van Nunen, J. A., & Van Wassenhove, L. N. (1997). Quantitative models for reverse logistics: A review. *European journal of operational research, 103*(1), 1-17.
Gopal, G. (2017). Pricing carbon dioxide into your supply chain Retrieved April 29, 2018, from http://www.iise.org/details.aspx?id=45034
Karl, T. R. (2009). *Global climate change impacts in the United States*: Cambridge University Press.
Lash, J., & Wellington, F. (2007). Competitive advantage on a warming planet.
Lee, K.-H. (2011). Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. *Journal of Cleaner Production, 19*(11), 1216-1223.
Mälkki, H., & Alanne, K. (2017). An overview of life cycle assessment (LCA) and research-based teaching in renewable and sustainable energy education. *Renewable and Sustainable Energy Reviews, 69*, 218-231.
Mohamed Abdul Ghani, N. M. A., Egilmez, G., Kucukvar, M., & S. Bhutta, M. K. (2017). From green buildings to green supply chains: an integrated input-output life cycle assessment and optimization framework for carbon footprint reduction policy making. *Management of Environmental Quality: An International Journal, 28*(4), 532-548.
Neto, J. Q. F., Bloemhof-Ruwaard, J. M., van Nunen, J. A., & van Heck, E. (2008). Designing and evaluating sustainable logistics networks. *International Journal of Production Economics, 111*(2), 195-208.
Oreskes, N. (2004). The scientific consensus on climate change. *Science, 306*(5702), 1686-1686.
Pachauri, R. K., Allen, M. R., Barros, V., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). *Climate change 2014: synthesis Report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change*: IPCC.
Pishvaee, M. S., Torabi, S. A., & Razmi, J. (2012). Credibility-based fuzzy mathematical programming model for green logistics design under uncertainty. *Computers and Industrial Engineering, 62*, 624-632.
Plambeck, E. L. (2012). Reducing greenhouse gas emissions through operations and supply chain management. *Energy Economics, 34*, S64-S74. doi: 10.1016/j.eneco.2012.08.031
Protocol, K. (1997). United Nations framework convention on climate change. *Kyoto Protocol, 19*.
Rezaee, A., Dehghanian, F., Fahimnia, B., & Beamon, B. (2015). Green Supply Chain Network Design with Stochastic Demand and Carbon Price. *Annals of Operations Research, in press*.
Rizet, C., Browne, M., Cornelis, E., & Leonardi, J. (2012). Assessing carbon footprint and energy efficiency in competing supply chains: Review – Case studies and benchmarking. *Transportation Research Part D: Transport and Environment, 17*(4), 293-300. doi: 10.1016/j.trd.2012.01.002
Sarkis, J., & Tamarkin, M. (2005). Real Options Analysis for "Green Trading": The Case of Greenhouse Gases. *The Engineering Economist, 50*, 273-294.
Savaskan, R. C., Bhattacharya, S., & Van Wassenhove, L. N. (2004). Closed-loop supply chain models with product remanufacturing. *Management science, 50*(2), 239-252.

Schaltegger, S., & Csutora, M. (2012). Carbon accounting for sustainability and management. Status quo and challenges. *Journal of Cleaner Production, 36*, 1-16.

Stechemesser, K., & Guenther, E. (2012). Carbon accounting: a systematic literature review. *Journal of Cleaner Production, 36*, 17-38.

Tseng, S. C., & Hung, S. W. (2014). A strategic decision-making model considering the social costs of carbon dioxide emissions for sustainable supply chain management. *J Environ Manage, 133*, 315-322. doi: 10.1016/j.jenvman.2013.11.023

van Loon, P., Deketele, L., Dewaele, J., McKinnon, A., & Rutherford, C. (2015). A comparative analysis of carbon emissions from online retailing of fast moving consumer goods. *Journal of Cleaner Production, 106*, 478-486.

Walmart. (2016). Walmart GLOBAL RESPONSIBILITY REPORT.

WBCSD, W. a. (2004). A corporate accounting and reporting standard. *World Resource Institute, Washington*.

Wiedmann, T., & Minx, J. (2008). A definition of 'carbon footprint'. *Ecological economics research trends, 1*, 1-11.

Zakeri, A., Dehghanian, F., Fahimnia, B., & Sarkis, J. (2015). Carbon pricing versus emissions trading: A supply chain planning perspective. *International Journal of Production Economics, in press*. doi: http://dx.doi.org/10.1016/j.ijpe.2014.11.012