Integrating Sustainability Performance Measurement into Logistics and Supply Networks: a Multi-Methodological Approach

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ABSTRACT

This paper seeks to address the way in which economic and environmental performance can be measured simultaneously, taking a multi-methodological approach to the logistics and supply chain management field in order to address sustainability challenges. The multi-methodological approach relies on the merits of different methodologies, provides more flexibility in tackling problems under investigation, and tolerates inaccurate estimation of parameters during the process. An illustrative case study (Westgate Ports) is undertaken in Australia in order to examine the ways in which the multi-methodological approach is applied, and how it assists during the decision making process in the adoption of green practices for freight transport logistics. The case validates the applicability and usefulness of the approach and highlights comparative outputs of costs and carbon emissions in freight transport logistics. Rail transport is identified as giving the opportunity to study the short

distance container and freight distribution network, although initially this does not appear to be the most cost-effective option. This study finds that it is better to simultaneously consider performance indicators from different perspectives and to integrate them into one model of system measurement in order for corporations to improve their sustainability performance.

Keywords: Sustainability performance measurement, Environmental and sustainability management accounting, Sustainable supply chain management, Green logistics, Eco-efficiency, Transportation, Carbon management, Australia

1. Introduction

Globalization and outsourcing have brought the means for companies to create vast networks of suppliers, distributors, logistics and transportation providers as they search for the efficiency promised by supply chains. It is inevitable that sustainability issues will arise from these activities. The interaction between sustainability and supply chains is important, both for a “licence to operate” and to keep companies competitive (Keindorfer, Singhal, & van Wassenhove, 2005; Lee & Kim, 2011). At a broad conceptual level, the term “sustainability” is defined as being that which meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). While sustainability at a firm level has multi-faceted meanings and implications (Etzion, 2007; Bebbington & Thomson, 2013), including corporate social responsibility, business ethics and environmental management, recent development focuses more on the environmental aspects of sustainability (e.g. global warming, energy efficiency) due to a heightened sense of urgency worldwide. Obviously there is much activity and ongoing development in the area of sustainability, therefore it is worthwhile for logisticians and supply chain management researchers and practitioners to consider the impacts of environmental sustainability on traditional assumptions and practices in the field of logistics and supply chain management (Vachon & Klassen, 2006; Linton, Klassen, & Jayaraman, 2007; Lee & Saen, 2012; Lee, 2013). However, it is not easy to utilise sustainability in logistics and supply chain management when companies try to meet lower costs and provide faster deliveries without compromising an improvement in sustainability performance and quality (Lee & Saen, 2012).

In the accounting community over the last three decades, there has been a discussion on the relationship between accounting and sustainability to understand how accounting tools and approaches can contribute for business community to achieve sustainability (Bebbington &

Thomson, 2013). With an emphasis on the managerial aspects of sustainability, sustainability management accounting, which adopts a more pragmatic approach to link sustainability accounting and business interests, has become popular in accounting and sustainability researches (Burritt & Schaltegger, 2010; Passetti, Cinquini, Marelli & Tenucci, 2014). With case studies in different contexts, sustainability management accounting has provided “business cases for sustainability” that may guide business communities to achieve sustainability in practice (Burritt & Schaltegger, 2010; Bebbington & Thomson, 2013). However, it has been also observed that measuring sustainability in business practice is a challenging task for managers and accounting researchers due to knowledge problems (Burritt & Tingey-Holroyd, 2012), methodological difference and limitations (Lee, 2012), and lack of applicable tools and understanding (Burritt & Schaltegger, 2010; Lee & Saen, 2012). In this paper, we would like to recognise and embrace the diversity of sustainability management accounting in sustainable supply chain management.

With a focus on sustainability in logistics and supply chain management, the related topics of sustainable supply chain management include environmental or green logistics (Murphy, Poist, & Braunschweig, 1996); environmental or green purchasing (Min & Galle, 1997); improvement of fuel efficiency (McKinnon, Stirling, & Kirkhope, 1993); and supplier selections in the green supply chain (Lee & Kim, 2009; Lee, 2013). The core idea of sustainable supply chain management is to ensure the long-term viability and continuity of a business, as well as contributing to the future well-being of society (Christopher, 2011; Klassen & Vereecke, 2012). That is, a sustainable supply chain which benefits the natural environment is likely to involve firms in cost leadership in the long-term as a result of better use of resources (Gimenez, Sierra, & Rodon, 2012).

Although all three aspects of sustainability (environmental, economic and social) ought to be

considered, most research into sustainability in the field of logistics and the supply chain is concerned with environmental aspects and how these aspects link to economic aspects (Seuring & Müller, 2008). Srivastava (2007), for example, provides an extensive literature review on green supply chain management. He identifies that there is a clear sign of increasing interest in green supply chain management among academics and practitioners of logistics and supply chain management. However, management has some challenges in adopting and implementing green supply chains in practice. He notices that “the problem is complex and challenging, as a very large number of parameters, decision variables and constraints are involved along with a large number of estimation requirements such as those of expected demands and returns and cost criteria associated with each decision” (Srivastava, 2007, p.71). The challenges of green supply chain management often result in superficial solutions which deliver insignificantly improved environmental and economic solutions (Srivastava, 2007; Brockhaus, Kersten, & Knemeyer, 2013).

Given the impact of industrial logistics and supply chain management on environmental and economic performance, green logistics - the main focus of this study - gives new opportunities for companies to significantly contribute to environmental sustainability. As Burritt, Schaltegger, Bennett, Pohjola, and Csutora (2011a) assert, “the interrelation and trade-off between dimensions of sustainability is a vitally important part of sustainable supply chain management, since sacrifices in one dimension can lead to disproportionate gains in other dimensions throughout the supply chain” (p.5). The challenge for managers of logistics and supply chains in embracing sustainability is how to link and to balance environmental performance and sound business practices (Lee, 2012). That is, how to identify preferred approaches or solutions balancing environmental and economic concerns (i.e. eco-efficiency). In order to tackle this challenge, sustainability-oriented performance measurement of green logistics helps to identify the trade-offs between the environmental aspects of carbon impacts

and the economic aspects of costs. In logistics and supply networks globally, there are rapidly increasing pressures to reduce carbon emissions for these networks. Therefore this study focuses on the impacts of carbon emissions on corporate decision making. From an environmental and economic perspective, the implementation of green logistic practices and performance measurement lacks a comprehensive structure (Lubin & Esty, 2010; Brockhaus et al., 2013). The identification and measurement of sustainability performance in logistics and supply chains is a new field of study, and well developed measurement tools are neither available to, nor applicable for, business practice (Gunasekaran, Patel, & McGaughey, 2004; Shaw, Grant, & Mangan, 2010; Lee & Saen, 2012). In the identification and measurement of sustainability performance for green logistics, sustainability accounting can provide an avenue for addressing environmental and economic activities. As recent accounting studies demonstrated, measuring sustainability performance is a challenging task for corporate accountants and managers (Bebbington, Brown, & Frame, 2007; Bebbington & Thomson, 2013; Christ & Burritt, 2013). In practice, sustainability performance issues are often neglected or partially addressed, and not fully integrated with information and management systems (Burritt & Tingey-Holyoak, 2012; Schaltegger & Burritt, 2014). Since this study takes an exploratory stance, we do not attempt to test theories; rather we explore multi-methodologies in order to identify solutions for eco-efficient logistics through the study of sustainability performance measurement in an Australian case.

In discussions of business performance and sustainability, the concept of eco-efficiency is a very popular concept to use in integrating the measurement of corporate environmental and economic performance (Callens & Tyteca, 1999; Ciroth, 2009; Figge & Hahn, 2013). Since the World Business Council for Sustainable Development coined the idea of eco-efficiency in the 1990s (Schmidheiny, 1992), the notion of eco-efficiency now provides a fundamental baseline in calling for the use of efficient environmental resources by linking environmental

issues and considerations of efficiency in corporate decision making. Utilizing eco-efficiency may bring a positive influence to environmental and economic performance. There is an ongoing debate about whether pro-environmental considerations contribute to economic performance. In this paper, we attempt to explore the integrated measurement of corporate environmental and economic performance in logistics and supply chain management. By using a multi-methodological approach in an illustrative case, we argue that the debate about a win-win environmental and economic improvement requires a better understanding of eco-efficiency in logistics and supply chain management. Since this study focuses on sustainability in accounting and supply chain management, furthermore, we argue the usefulness of identified, measured information about eco-efficiency in the management of the logistics and supply chains in supporting corporate decision making in regards to environmental and economic performance. By exploring and addressing the research topic “integrating sustainability performance measurement in logistics and the supply network”, this paper provides three main contributions. Firstly, since the provision of sustainable supply chains and green logistics is a rapidly developing area of research, this study provides an important insight into the linkage between environmental sustainability performance and economic performance in logistics. In particular, carbon emission is used for measuring environmental performance. Secondly, there are very few empirical studies which use ‘real-world’ cases and there is a need for case studies at the individual firm level (Lucas & Rafferty, 2008). The current study introduces the Australian case of Westgate Ports as the empirical context because the size and the impact of logistics industries have relatively huge impacts on the Australian economy and the environment. Industry practitioners in these or similar sectors will benefit from this case study which will help them in practicing green logistics in their own businesses. Thirdly, we explore multi-methodologies to identify carbon-focused, eco-efficient solutions to green logistics. Due to the lack of a comprehensive,

structured approach to identification and measurement of environmental and economic logistics performance, this study attempts to use a static process of mapping and cost/emission calculations, using mathematical modelling as well as complementary sensitivity analysis in order to gain a better understanding. As Murphy and Poist (2003) point out, green solutions will broaden the area of logistics as well as influencing logistics and supply chain managers to handle and operate their businesses in a sustainable way.

This study's underlying research question is to better understand "how companies identify cost effective, eco-efficient logistics and supply chain networks?" Although existing work and theories provide some insights in practice, only a limited amount of research has focused on "real world examples and cases" to apply and implement sustainable supply chain management in practice. This study is primarily concerned with green logistics management because logistics contribute major carbon emissions while playing an important role in financial performance (i.e. cost management). In this study, we focus on environmental sustainability, especially carbon emissions, to identify eco-efficient solutions for freight transport in logistics network using a case study of Westgate Ports, situated in Melbourne, Australia. While we focus mainly on green logistics and transportation, we take a broader supply chain perspective in discussion of theoretical and practical implications. Since there is no existing comprehensive structured literature concerning sustainability in logistics, we use a multi-methodological approach which helps firms to accurately capture and analyse different options in the use of eco-efficient logistics systems. This approach also increases the model's analytical capability and tolerates initial inaccurate estimation of parameters via sensitivity analysis. Depending on the systems under investigation, mathematical modelling and simulation can be applied to further explore the problem in order to support decision makers.

The structure of this paper is as follows. Firstly, we review the literature on sustainability performance measurement and its link to green logistics and sustainable supply chains. We then present the multi-methodological approach and illustrate its application using an Australian case. Next, we present and discuss our results. Lastly, we present our discussion and conclusions and suggest the limitations of this study and its implications for further research.

2. Literature and theoretical background

2.1. Linking Sustainability Performance Measurement to Green Logistics

As Milne (1996) pointed out, sustainability brings a number of challenges for management accounting and corporate decision making. For example, by ignoring environmental performance information, management accounting potentially provides insufficient information to corporate decision makers to make informed decisions (Milne, 1996; Milne, Kearins & Walton, 2006). Despite rapid growth of sustainability accounting over the four decades, current management accounting for supporting corporate decision making is incomplete as generally practiced. In particular, mainstream corporate accounting typically neglects a wide range of non-market activities such as carbon emission, environmental or social impacts (Milne, 1996; Burritt & Schaltegger, 2010; Lee, 2012; Figge & Hahn, 2013). With regard to the relationship between sustainability and corporate decision making in supply chain management, in their book, “Environmental Management Accounting and Supply Chain Management”, Burritt et al. (2011a) point out that one of the key challenges of sustainable supply chain management is cost-management and eco-efficiency. Cost savings through the employment of more efficient production and logistics measures can help to achieve sustainable supply chain management. Achieving both environmental and economic

efficiency (i.e. eco-efficiency) in logistics and the supply chain is not easy, but is very important in the implementation of sustainability.

In order to adopt sustainability management, the information provided by performance measurement will allow managers to make the “right” decisions about implementing sustainability performance in their logistics and their supply chains (Gunasekaran et al., 2004; Lee & Saen, 2012). Traditionally, logistics and supply chain performance measurement primarily focus on cost, time and accuracy (Shaw et al., 2010). In order to measure sustainability performance in logistics and supply chain management, we need to develop or select the most appropriate and effective performance measurement system. However, this is a difficult task because it is not easy to attribute performance outcomes to one specific entity within the supply chain network. In her study, Beamon (1999) notes that a generally applicable systematic approach to performance measurement in supply chain management has not been developed. She also finds that two factors, cost and a combination of cost and customer responsiveness, are predominantly utilised to measure performance in the supply chain. In evaluating performance measurement, cost is an important factor to consider but it should not be used as the sole measurement in evaluating performance in the supply chain (Beamon, 1999; Gunasekaran et al., 2004; Kennerley & Neely, 2003; Lee, 2011).

For many firms, the measurement of sustainability performance within logistics and supply chains is a hard challenge to overcome. For example, using the electricity utility sector, Weinhofer and Busch (2012) study the way in which climate risk impacts on a focal company and its supply chain partners. They categorise three different levels of activity including resource supply, production and product distribution in order to examine the climate risk impacts. They find that different measures can bring different levels of climate risk impact and outcomes which will not contribute fully to managers’ decision making concerning

sustainability in their supply chains. In a similar vein, Hervani, Helms, and Sarkis (2005) list the reasons that hinder performance measurement in the green supply chain network. These include non-standardised data, poor technological integration, geographical and cultural differences, differences in organisational policy, lack of agreement on metrics and poor understanding of the need for inter-organisational performance measurement.

Integrating environmental sustainability performance into logistics management is still a new phenomenon. Recently, Lai and Wong (2012) find that “green logistics management reflects ability to conserve resources, reduce waste, improve operational efficiency, and satisfy the social expectation for environmental protection” (p.268). Similarly Pazirandeh and Jafari (2013) characterise green logistics as that “which is designed not to only be environmentally friendly, but also economically functional” (p.891). The literature has a common key message which is that green logistics is minimising a firm’s environmental impact while improving operational efficiency including cost savings and better resource utilisation. Sustainability accounting, in particular environmental management accounting (EMA), can play a useful role in identification and measurement of the issues surrounding green logistics. Burritt, Schaltegger, and Zvezdov (2011b), for example, provide 16 decision making settings together with the related accounting tools regarding carbon management accounting. One of most useful aspects of EMA is to provide both types of information (physical and monetary) for managers to make short and long-term decisions concerning their organisations. As an approach, EMA can help to assess the environmental sustainability effects of the use of green logistics including identification (what aspects can be identified?) and measurement (what measurement units are to be applied to sustainability?).

Identification and measurement of a company’s environmental performance in logistics and supply chain management, in particular carbon performance, can be very important decision

making criteria for senior managers in order to select optimised transportation routes or channels which can simultaneously achieve cost and environmental impact reductions (Sanchez-Rodrigues, Potter, & Naim, 2010; Lee, 2011). Cuthbertson and Piotrowicz (2008) support this notion by suggesting that environmental criteria are increasingly important for sustainable business operations. More recently, Song, Wang, Jiang, Yang, and Wang (2012) address the urgent need for an improvement in energy efficiency in logistics management. They assert that in the area of green logistics (p.6) the focus on “how to reduce energy consumption” throughout logistics and the supply network and “how to foster sustainable competitive advantages” should be addressed and studied.

Although green logistics is a relatively new concept, reducing energy consumption resulting in carbon emission reduction is an increasingly important aspect of logistics, particularly in the area of transportation. In general, logistics includes transportation, warehousing and inventories. In regard to environmental concerns, transportation is probably the most visible aspect of logistics. According to Stern (2006), transportation is one of the main CO₂ emissions contributors with an amount of 14% of total emissions at both global and EU level. Zervas and Lazarou (2008) echo this by emphasising the fact that carbon emissions from transportation are a significant environmental threat, and Koroneos and Nanaki (2007) point out that road transport constitutes one of the main causes of CO₂ emissions. With the exception of the work by Golicic, Boerstler, and Ellram (2010), there are few empirical studies which focus on energy consumption or energy efficiency of logistics or transportation. With a focus on the environmental impact of transportation in supply chains, Golicic et al. (2010) study the extent to which a sample of Fortune 500 companies act to improve supply chain and transportation sustainability. They identify varying transportation-related sustainability practices in the form of a node, including mode, fuel, technology, volume, metric, fleet, partner, goals and benefits. They find that “only a very small percentage of

sample companies have tried to significantly reduce greenhouse gas (GHS) emissions from freight transportation in the supply chain” (p.51). In order to make the environment a sustainable priority in transportation and supply chains, they suggest (i) that supply chain transportation should be structured to focus on minimisation of the impacts of the transportation GHG emissions; (ii) that transportation technology be used to reduce fuel and therefore emissions; and (iii) that supply chains’ logistical network be optimised (Golicic et al., 2010).

Since many scholars have acknowledged that transportation is a main source of CO₂ emissions in the logistics and supply chain network, it is important to investigate more empirical cases of firms’ transportation and carbon emissions (Beresford, Pettit, & Liu, 2011; Sanchez-Rodrigues et al., 2010; Golicic et al., 2010). For example, Piecyk and McKinnon (2010) present the framework of relevant factors for CO₂ emissions in road transport, including structural factors (modal split), commercial factors (load factors), operational factors, functional factors and external factors (carbon intensity of fuel). In reality however, in business all of the above factors cannot be determined solely by study of the logistics or by the efforts of the transport manager. For example, shippers may prefer different transportation characteristics such as cost, quality and speed. The mode choice in transportation is the selection of air, sea/water, road, rail or pipeline. Each mode has different characteristics in terms of cost, lead-time, physical accessibility, fuel and energy consumption and environmental performance (Dekker, Bloemhof, & Mallidis, 2012). Also, transport by container ship has important impacts on carbon emissions, efficiency and fuel consumption. For example, fully or half laden and empty containers are lifted on and off ships at each port due to trade imbalances or dynamic operations. The movement of empty, half full or full containers of different sizes and types will affect transport utilisation and fuel consumption. Using an operational activity-based method, Song and Xu (2012) study CO₂ emissions in the

area of container shipping. They find that an improvement in port-handling rates and efficient empty repositioning may achieve economic and environmental benefits.

Notably, there is a gradually growing use of intermodal freight transport in order to reduce fuel and energy consumption, as well as to improve environmental impacts. Dekker et al. (2012) describe intermodal transport as “the use of a single transport load unit, like a container, over multiple transport modes” (p.673). The intermodal type of transportation option typically involves the combination of at least two different modes of transportation (e.g., rail, trucks, ships on inland waterways, aircraft) in a single transport chain, without a change of the goods’ containers (Bontekoning, Macharis, & Trip, 2004; Liao, Tseng, & Lu, 2010). There are *pros and cons* in the intermodal transport option, for example more coordination than the use of a single mode of transportation is required, which improves efficiency and on-time delivery. However few studies have been carried out exploring carbon emissions performance in the implementation of intermodal transport.

In sum, despite the importance of integrating environmental sustainability performance in green logistics and transportation, there is a lack of available approaches and tools to identify and to measure both environmental and economic performance in the area of logistics and transportation. Thus, there is an obvious need for environmental sustainability performance measurement to find eco-efficient solutions. We also find few empirical “real-world” cases which have analysed both carbon performance and financial performance simultaneously in the area of green logistics and transportation. This paper will shed some light on green logistics using a sustainability accounting approach, specifically focusing on carbon performance and economic performance in transportation, and will illustrate an Australian case as an exemplar.

3. Methodology

This section describes the multi-methodological approach that is to be followed to simultaneously measure economic and environment performance in logistics systems and supply chains. In the relationship between sustainability and accounting, Schaltegger and Burritt (2010) argue that the development of a pragmatic set of sustainability accounting tools for corporate sustainability practice is still an early stage of development, and is often hampered by insufficiently refined purposes and approaches. As Srivastava (2007) suggests, a combination of various tools and techniques may be useful for the purpose of formulation, approximation, analysis and solution of complex green logistics and supply chain problems. We accept his suggestion and adopt a multi-methodological approach to examine the case of Westgate Ports. The multi-methodological approach combines multiple research methodologies to explore research problems (Singhal & Singhal, 2012a, 2012b). Such research approaches have been recently applied to problems such as measuring stadium and theatre seat value (Veeraraghavan & Vaidyanathan, 2012) and assessing trust in the forecast of information sharing between suppliers and manufacturers (Özer, Zheng, & Chen, 2011).

In terms of the accounting approaches, we consider the activity-based costing approach is appropriate to fulfil the task at hand. In his study, Lamberton (2005) reviews the different methods of sustainability accounting and enumerates the general approaches for such a task including sustainable cost and full-cost accounting, natural capital inventory accounting, input-output analysis, and triple bottom line accounting. Considering the nature of services the case company provides in this study, an input-output analysis—through activity-based accounting approach—would enable the company to make confident cost analysis with carbon emission information for business decisions.

Figure 1 depicts the general steps involved in the multi-methodological approach, which lists

the necessary actions to be taken to effectively record and measure the inputs and outputs of logistics systems so that better informed decisions can be made. We begin with an activity-based “costing” approach which enables us to collect both cost and emissions at the same time for all activities via process mapping. This reflects the increasing trend suggested by the Global Reporting Initiative (GRI)’s Sustainability Reporting Guidelines (2013) that multiple units of measurement should be adopted to assess performance toward the environmental, economic, and social dimensions of sustainability. This will essentially allow an accurate “baseline” to be developed for further analysis. Various “to-be” scenarios can be constructed for performance analysis and comparison. Variables can be embedded during the modelling process, which enables sensitivity analysis of input variables and their impacts on outputs. Once a static model is developed, it can be tested by different methods, such as mathematical modelling, and subsystem optimisation. The general approach is underpinned by four major areas: 1) process mapping; 2) variable determination and data collection; 3) mathematical and simulation model construction; and 4) sensitivity analysis.

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3.1. Process mapping

Process mapping is “a valuable communication device to understand how processes operate and where responsibility lies” (Collier & Evans, 2007, p.273). Accurate process mapping, at the right level of granularity, facilitates the identification and recording of all related activities and thus ensures that proper data collection takes place. This subsequently enables the activity-based costing technique, which is defined by the Chartered Institute of Management

Accountants (CIMA, 2005) as “an approach to the costing and monitoring of activities which involves tracing resource consumption and costing final outputs. Resources are assigned to activities, and activities to cost objects based on consumption estimates. The latter utilise cost drivers to attach activity costs to outputs.” In the cases where an improvement or restructure will be made to the system, two scenarios can be constructed: the “as-is” and the “to-be” process maps. The “as-is” model serves two purposes: 1) to validate the “as-is” process map through comparison against practical operational data; and 2) to serve as the basis for development of the “to-be” process map. A comparison with the “as-is” process map allows for the detection of changes, and therefore better attention can be focused on those areas that are changing. The process components that are not changed can be “ignored”, as we are more interested in the net benefits brought by the processes changes. This is also helpful in reducing the errors introduced by parameter estimation for identical processes, and therefore will improve the accuracy of sensitivity analysis.

When the supply network or logistics system involves more than one company, which in reality is usually the case, the different actions and processes performed by different companies should be correctly recorded on the process maps so that the role (and hence impacts) a company plays in the system can be examined.

In supply networks and logistics systems, some changes such as modal switch and network re-design, have long-term impacts on the economic and environmental performance of the systems. These cases require careful and thorough analyses of the associated costs, benefits and other key performance indicators. Appropriate process maps would be the cornerstones in conducting meaningful analyses.

3.2. Variable determination and data collection

Once proper process maps are constructed, it is possible to determine the types of data to be

collected, as well as the way in which they will be collected. The challenges associated with environmental performance indicators were well documented, and using generalised scientific models to estimate emission levels and resource consumptions is recommended for environmental performance (Lamberton, 2005). The data collection uses a multi-methodological approach, e.g., it can be collected via any combination of literature reviews, surveys, experiments, interviews with staff members and operators, or even through a few Delphi research rounds. It is therefore essential to decide the variables that will facilitate data collection. For example, common data sets to be collected for transport systems include fuel or power consumption (and associated cost), time spent for each step in the process map and CO₂ emissions, etc. These data types will firstly need to be determined and subsequently used in the process maps to collect the corresponding data for performance analysis. It is important to note that some data collected at this stage are actually variables. For instance, if we are interested in the impacts made by CO₂ emissions of a particular type of equipment, the amount of emissions can be treated as a variable so that the impacts of changing the variables (hence different emission levels of the equipment) on the overall system can be clearly observed.

While determining the variables, the process map also provides an opportunity to identify the relationships among variables, and makes it possible to examine the interactions among them. To facilitate data collection, the role-based process maps can also be rearranged into linear process maps so that the data capture flow can be easily identified.

3.3. Mathematical/simulation model construction

Accurate data collection is essential for appropriate performance analysis and is the key in decision-making. However in reality, due to a variety of reasons, accurate data are not always readily available or are very difficult to capture. Other difficulties, such as the non-existence

of processes in the “to-be” scenarios also pose great challenges for performance analysis. Parameters provided by the industry or public domain data sometimes have to be used during the data collection phase. This gives no guarantee of the accuracy of the performance analysis due to the difference in terms of operational environment, operational efficiency, data consistency and even the accuracy of the data available. Sometimes, the data sources provided do not differentiate the types of equipment used and might be at a high aggregated level. One example is in Roso’s (2007) study where the CO₂ emission for trucks is estimated as 1 kg/km; while in the study by Liao, Tseng, and Lu (2009), CO₂ emission is estimated as 155 g/tonne km. Clearly, the second data source provides a more accurate measurement since it gauges both weight and distance.

To remedy such disadvantages brought by these types of data, mathematical or simulation models can be constructed to enable further investigation of the impacts of different variables. If we take container distribution as an illustrative example, we can see that in order to transport a certain number of containers, different types of trucks can be used (e.g., B-double, Super B-double, Super B-triple, etc.). It is possible to work out the number of trips that need to be taken to completely transport these containers and then treat the CO₂ emissions as a variable in mathematical models. This will facilitate the analysis of the impact of the variable on the overall system.

Sometimes, it is not enough to only look at the mathematical model, since a lot of other factors are also changing. Again using the container distribution example, it is important to take factors such as the volatile business environment (and therefore not constant container flows), fast moving fuel prices (therefore no fixed cost for each trip), seasonality demand of transport equipment (therefore a limitation to the available transport options) into consideration and assess the impacts of these factors on the decision making process of

transport network design. Mathematically modelling these types of changes would almost be impossible since the level of complexity increases significantly if such uncertainties are to be taken into account. Simulation models can be a substitute for mathematical models and allow the decision makers to play with a lot of combinations of different parameters. Variables can still be embedded into the simulation models to enable further analysis once the simulation runs are completed.

3.4. Sensitivity analysis

The purpose of constructing mathematical or simulation models is to conduct sensitivity analysis so that better informed decisions can be made. Sensitivity analysis compensates for the inaccuracies of available data and allows decision makers to see the interactions between different variables so that the system dynamics can be observed. In certain circumstances, a slight change in one variable might significantly change the overall system performance, and therefore sensitivity analysis will allow the identification of such variables and ensure that proper action is taken to address such scenarios. It is also helpful when the ranges of some input variables are only roughly known. Through the mathematical or simulation models, the variables can be viewed over their respective ranges, and once accurate values of these variables are determined, the decision maker can quickly locate the corresponding performance within the sensitivity analysis. This will significantly improve the effectiveness of communication between analysts and decision makers.

The ultimate objective of sensitivity analysis is to have a comprehensive understanding of the logistics system and supply chain under investigation. Whether mathematical modelling and/or simulation are employed will depend on the specific problem. But one thing that is clear for sensitivity analysis is that we need to admit that the business environments are not so static, and in some cases basic parameter changes will easily change the overall system

behaviour. A static point of view of logistics systems certainly is not enough anymore, and using the multi-methodological approach will provide different aspects of the problem. Therefore it is useful to combine them for decision making.

4. Illustrative Case

Case studies are “a strategy of inquiry in which the researcher explores in depth a program, event, activity, process, or one or more individuals” (Creswell, 2009, p.13). They can provide “rich descriptions, explorations and explanations of the phenomena being studied,” especially when there is little extant prior research, and case studies have been applied to a growing number of cases in environmental management accounting (Burritt & Saka, 2006, p.1266). We illustrate the application of the multi-methodological approach through an Australian case. In this illustrative case, we examine the container and freight distribution for one area in Melbourne, Australia. The company under investigation is Westgate Ports. With the vision of becoming the intermodal freight leader by introducing landside container logistics best practice to the Port of Melbourne and inland hubs, the company is actively looking into solutions for migration from road to rail to provide efficient container movement and freight services in a cost-effective, environmentally friendly and socially responsible manner.

The world has witnessed an increasing volatility in the oil price over the last five years or so and the oil price is most likely to maintain its current relatively high level, according to the International Energy Agency (IEA, 2010). The impact of such a change on transport mode selection is quite straightforward because of the percentage of fuel consumption in transportation operating costs. Generally speaking, fuel is over 30% of total long-distance road freight operating costs, while for rail it is about 20% (BITRE, 2009). In Australia, with the proposed introduction of the emission trading scheme, the proportion that fuel plays in overall transport operating costs is likely to increase in the coming years. An initial step, the

\$23/tonne carbon dioxide emission charge on about 500 companies in Australia, was announced by the government in July 2011 (Farr, 2011).

Recently the volume of container traffic in Melbourne has grown very rapidly. The Port of Melbourne Corporation (PoMC) handled about one million twenty-foot equivalent units (TEUs) in 1997 while in 2007 the number jumped to two million TEUs, and the container volume is projected to continue to increase about four-fold to eight million TEUs by 2035 (Victorian Government's *Freight Futures*, 2008). The Port of Melbourne is located in the west region of Melbourne, close to the central business district, while there is quite a lot of container and freight movement to the south east region of the city which must travel through already congested roads. As the container volume goes up, the traditional road based transport option for containers and freight will exert more pressure on roads.

In order to achieve sustainable competitive advantages through green logistics, Westgate Ports has initiated a project to investigate the intermodal (road/rail) solutions for container and freight distribution in Melbourne. This project incorporates the movement of containers as well as the final delivery of freight and empty container collections, which forms a complete circulation of containers as well as freight movement between the port and the end users. Therefore, the cost and benefit implications will be more thorough than simply looking into one section of the transport journey which merely deals with container movement. In this project, five factors including carbon emissions, cost, traffic congestion, community amenity and transport time are considered in sustainability and competitive transportation analysis, as the company wants to conduct the logistics tasks in a cost-effective, eco-friendly way, while taking community amenity and the pressure on and from traffic conditions into consideration.

4.1. Container and freight movement transportation options

Containerisation has significantly improved the efficiency of international freight handling

since its introduction in the mid-1950s (Coyle, Novack, Gibson, & Bardi, 2011). Although it is not uncommon for transport containers to be sent directly to end users, in practice containers are usually transported to an area for cross-docking or break bulk operations before freight can be delivered to the end users (such as retail stores), due to the volume of goods each container can take. The current practice for the movement of containers and freight in Melbourne is that trucks are used as the main means of transport. Due to historical development and transport practices, quite a lot of handling operations are involved during the entire journey of the post-port freight movement, and different equipment is used in the operations at various sections of the journey. Since different types of equipment have different capacities, in order to exploit economies of scale as well as to suit customer transportation needs, it is necessary for logistics service providers to look at two main problems of container and freight distribution:

- 1) At which place(s) should the cross-docking/ break bulk operations happen?
- 2) Which types of equipment should be utilised at different sections of the journey of the container and freight movement?

---- Insert Figure 2 here ---

In Melbourne, there are two possible ways for containers to be distributed under the current settings: road and rail. The “as-is” status for the case in this study is road transport, where semi-trailer/side-loader (1-2 TEUs), B-double (3 TEUs) and Super B-double (4 TEUs) trucks are used. There is also the possibility for Super B-triple trucks to carry up to 6 TEUs on dedicated roads. In the case of rail transport (one possibility in the “to-be” scenarios), to a

large extent the capacity depends on locomotive power, infrastructure (such as passing loops) and the siding of rail yards. Based on the geographical characteristics of the area and land availability, three channels can be proposed to accomplish the container and freight distribution task:

- 1) Channel A: This is the “as-is” scenario and is mainly a truck based transport option. In this option, containers are transported using semi-trailer/side-loaders/B-doubles from the marine container terminal to warehouses where the containers are unpacked. Subsequently the freight is transported to end users, or the containers are taken to end users directly. In either case, the empty containers are collected by another truck and transported to an empty container park. (In some cases, an already empty container is collected by the same truck that drops off the full container.) Later, another truck collects the empty containers that are then transported back to the empty container park, then to the marine container terminal. Due to traditional development, many cross docking and warehousing operations were established in areas close to the port but far away from the end users, as depicted in Figure 2. Therefore, the inclusion of ultimate freight distribution can significantly change the system dynamics when considering the travel time, road congestion, transport cost and greenhouse gas emissions for the whole chain of freight distribution.
- 2) Channel B: This is one option in the “to-be” scenarios where an inland container hub (ICH) is set up close to end users using super B-doubles/HPFVs (High Productivity Freight Vehicles) and B-triples to transport between the marine container terminal and the ICH; the “last kilometre” distribution is carried out with suitable container trucks/taut liners/tray trucks. The empty containers are consolidated in the ICH and transported back to the marine container terminal through the trunk road by super B-doubles/HPFVs in

fully loading mode. In this channel, warehouses can be sited at the hub with the empty container park which will greatly reduce movement/cost/carbon emissions, as internal movements can be conducted via container handling equipment.

- 3) Channel C: This is another “to-be” scenario which is the same as Channel B, with the exception of the use of freight trains for transportation between the marine container terminal and the ICH.

4.2. Application of the multi-methodological approach

The multi-methodological approach described in Section 3 is applied to the case under study. Based on the three transport channels discussed, process mapping of the container and freight movement is conducted for all three transport channels based on interactive meetings and discussions with managers and staff members from the company. The processes are divided into import and export flows so that the freight and container movement can be clearly examined. The roles of each site (the ICH, cross dock, empty container yard, etc.) are also separated for easy reference. Figure 3 presents one of the process maps where the import container and freight distribution for Channel A is illustrated. Once the process maps are confirmed with the company, they are subsequently rearranged in linear order to facilitate easy data capture.

An Excel-based cost and emission calculation model is subsequently constructed, where each process that is related to a cost and emission component is coded. Simply by changing the related information of the processes, the overall cost and emission of the whole system can be observed. The model enables users to examine the impact of any changes of variables used, such as transport cost and emission, travel distance, and number of containers to be handled, etc. Figure 4 provides a screenshot of part of the model where the left half summarises the total cost and emission for this particular process map and the right half presents (part of) the

coded elements in this process map. It is shown that the subtotal of cost and emission for each action can be immediately observed from the model, and parameters can be changed within the model to observe the system's reaction to these changes. For example, in Figure 4, the percentage of containers that are transported directly to the warehouse is 85% and the average distance transported is 45 km. This interactive model allows the users to play with the parameters in the system and fine tune these parameters to reflect the actual operations so that an accurate baseline can be developed, followed by similar models for “to-be” scenarios.

---- Insert Figure 3 here ---

---- Insert Figure 4 here ---

Mathematical models are also developed to compare the cost and emission differences between the three channels. The models are developed based on the process maps and instead of using parameters to calculate cost and emission, these parameters are replaced by variables. These variables include parameters such as unit handling cost for empty or full 20' or 40' containers, freight handling cost, unit transport costs for different types of transport equipment (laden and unladen), etc. The distances between different facilities are also treated as parameters so that the mathematical models can be applied to similar settings but with different geographical parameters. The following parameters and variables are used for the mathematical model:

A	‘average’ start point, A is not a specific location. Distance measured from ‘location’ A to any destination B means the average distance travelled to location B .
d_{BC}	distance between locations B and C .
T	container terminal.
D	cross dock.
H	inland container hub.
W	warehouse.
E	empty container park.
R	set of retailers.
Y	rail yard.
C_N	number of containers.
c_d	consolidation and break bulk cost for a 20’ container.
f_L	number of loose freight trucks for a 20’ container, $f_L = 1.3\sim 2.0$.
f_H	number of HPFV trips for a 20’ container, $f_H = 0.25$ means an HPFV takes 4 TEUs.
f_R	number of train trips for a 20’ container, $f_R = 0.02$ means a train takes 50 TEUs.
p_1	percentage of 20’ containers.
p_2	percentage of 40’ containers, $p_1 + p_2 = 1$.
p_d	percentage of containers transported to cross dock.
p_w	percentage of containers directly transported to warehouse from terminal, $p_d + p_w = 1$.
p_r	percentage of loose freight directly transported to retailer.
p_e	percentage of an export container requires picking up of an empty container at empty container park.
p_k	percentage of an export container requires picking up at warehouse.
p_c	percentage of an export container requiring transporting as loose freight trucks to cross dock.

p_t percentage of empty containers transported to terminal for export. $p_e + p_k + p_c + p_t = 1$.

$c_h^{f,e,l,p}$ handling cost for full container, empty container, full 20' container in the form of loose freight and pick and pack cost for a full 20' container in the form of loose freight.

$E_h^{f,e,l,p}$ handling emission for full container, empty container, full 20' container in the form of loose freight and pick and pack cost for a full 20' container in the form of loose freight.

$c_{T_1,T_2,L,H,R}^{f,e}$ the per kilometre transport cost of truck (T_1 , T_2 and L : one-TEU, two-TEU and loose freight truck, respectively), HPFV (H) and train (R), f , e refer to full and empty trips, respectively.

$E_{T_1,T_2,L,H,R}^{f,e}$ the per kilometre transport emission of truck (T_1 , T_2 and L : one-TEU, two-TEU and loose freight truck, respectively), HPFV (H) and train (R), f , e refer to full and empty trips, respectively.

Following the process maps and utilising the above parameters and variables, the total logistics cost and emission can be constructed. For example, the logistics cost using trucks (Channel A) to transport containers and freight would be:

$$\begin{aligned}
& C_N \{ c_{T_1}^f p_1 [d_{TW}(p_w + p_e + p_k) + d_{TD}(p_d + p_c)] + \\
& c_{T_1}^e p_1 [d_{AT} + d_{WE}p_w + d_{DE}p_d + (d_{AE} + d_{EW})p_e + d_{AW}p_k + d_{ET}p_t] + \\
& c_{T_2}^f p_2 [d_{WT}(p_e + p_k + p_w) + d_{DT}(p_c + p_d)] + \\
& c_{T_2}^e p_2 [d_{ET}p_t + (d_{AE} + d_{EW})p_e + d_{AW}p_k + d_{WE}p_w + d_{DE}p_d + d_{AT}] + \\
& c_L^f f_L (p_1 + 2p_2) [d_{WD}(p_c + p_d - p_r p_d) + d_{WR}(p_d - p_r p_d + p_w) + d_{DR}p_r p_d] + \\
& c_L^e d_{AW} p_c f_L (p_1 + 2p_2) + c_h^f (2 + 2p_e + 2p_k + 2p_c) + c_h^e (2 + 2p_e + 2p_t) + \\
& c_h^l (p_1 + 2p_2) [2p_d(1 - p_r) + 2 + 2p_c] + c_d (p_1 + 2p_2)(1 + p_c) +
\end{aligned}$$

$$c_h^p (p_1 + 2p_2)[(1 - p_r)p_d + p_w]\}$$

Cost and emission equations for other process maps are constructed in a similar way. Once these equations are constructed, parameters (such as distances between sites) can be fixed accordingly to actual operational settings and focus can be directed to variables that we want to examine. Sensitivity analysis can then be conducted to find more accurate baseline performance and to identify the ‘break-even’ point between any two channels with different scenarios. For example, Figure 5 shows the sensitivity analysis results for the cost difference between Channels B and C, demonstrating the impacts that occur when the transport unit price changes within the specified ranges.

---- Insert Figure 5 here ---

4.3. Key findings

Table 1 presents some of the cost and emission parameters we use in this research based on the operational data provided by Westgate Ports and the emission parameters collected from the literature (e.g., Liao et al., 2009; Roso, 2007). The transport time, cost and emission of the three transport channels are calculated and the cost and emission difference between different channels are compared with the truck transport mode without ICH (i.e., Channel A), which is the *status quo*. It is observed that the HPFV with ICH transport mode (Channel B) achieves the lowest transport cost for the time being, while the train with ICH transport mode (Channel C) incurs slightly higher cost compared with the HPFV option, but it is the most environmentally friendly option among all the three transport channels examined.

---- Insert Table 1 here ---

The key implications of each transport mode are listed in Table 2. It is observed that the train transport mode only incurs slightly higher cost than the HPFV transport mode in terms of cost per container, and there is no difference between the train and the HPFV mode for the delivery of freight from the ICH to end users, since the operations for these two modes are virtually the same. In terms of delivery time, the HPFVs are still affected by the trunk road traffic conditions. Considering the current road conditions in Melbourne, a dedicated freight road/lane would be very difficult; and even should such a road/lane be possible, it probably would be under access time restrictions. On the other hand, at the moment, rail transport can share with passenger trains and once the volume builds up, a dedicated track can be allocated.

---- Insert Table 2 here ---

Table 3 further provides the average cost and emission per TEU and the “savings” for HPFV and train transport compared with the current trucking option. It can be observed that in terms of average performance, the HPFV option reduces the transport cost by 33.5% and the train transport achieves a 26.1% cost saving. The savings on the emission for the train transport is more than doubled that of the HPFV option, which already achieves a 32.7% saving compared with the “as-is” trucking option. Assuming the carbon price is to be charged at \$23.0/tonne, the adjusted overall cost for each of the three options is listed in the last row of

the table. Although the adjusted cost with carbon price does not change the overall position of the three options, it does narrow the gap between the HPFV and the train transport.

---- Insert Table 3 here ---

The trains will operate according to schedules, which subsequently makes the operations management in the ICH more predictable and easier to handle. This result indicates that though the freight trains are used in relatively short distance transportation, they still prove to be a viable solution in terms of cost, and they provide the means to address the issues of CO₂ emissions, road congestion and community amenities. In the current container distribution model, container trucks are required to travel from the container terminal (PoMC) to the south east region of Melbourne, which generates heavy container truck traffic and CO₂ emissions due to the limited capacity of ordinary container trucks and the long journey from the port to the destination. The long distance travelled by the container trucks makes the scheduling of trucks, especially rescheduling of trucks and utilisation of the trucks' return journeys, difficult and hence results in a relatively low truck utilisation rate and high cost and CO₂ emissions. This can be illustrated by Figure 6, where the left side of the figure indicates the current "area coverage" for vehicle routing requirements, while the right side shows the two "to-be" scenarios. It can be observed that the area for the "as-is" scenario is much larger than that of the "to-be" scenarios and hence any inefficiency in vehicle routing would have a higher impact on the overall system performance. In the "to-be" scenarios, it can be guaranteed that the journeys from the port to the ICH are always fully utilised.

---- Insert Figure 6 here ---

In the proposed HPFV and train distribution options, the ICH can act as a buffer point so that scheduling and traffic control (night shifts for container transportation between container terminal and ICH) can be relatively easier to achieve. The “last kilometre” issue is also easier to address since the trucks only move within a relatively small region for the final delivery. Dispatch and communications between ICH and end users will be possible and the delivery times will be more predictable.

As mentioned earlier, the re-design of logistics systems and supply networks has long-term financial and environmental impacts. Therefore, time has to be taken into consideration when planning such systems. In terms of cost structure, road transport has higher percentages for labour and fuel consumption than rail transport (BITRE, 2009; Coyle, et al., 2011). With fuel price at its current level and the projection for future increase (IEA, 2010), the high labour costs in Australia, as well as the high increase in the rate of labour costs, the existing gap between the HPFV and rail transport options might be quickly narrowed down or even eroded over 5–10 years, not to mention the potential environmental benefits which will accrue from the use of rail transport.

5. Discussion and Conclusions

Logistics and supply chain activities may produce negative environmental impacts in a number of ways, including resource use in logistics and pollution created by the activities (Wu & Dunn, 1995; Shi, Koh, Baldwin, & Cucchiella, 2012; Björklund, Martinsen, & Abrahamsson, 2012). In order to integrate sustainability into logistics and supply chain

management, environmental advocates typically ask for a technology change. For example, switching the transportation of goods to electric or hybrid vehicles can substantially reduce the amount of fuel and energy consumed, and as a result, will contribute to the reduction of carbon emissions (McKinnon & Ge, 2004; Aronsson & Brodin, 2006; Björklund et al., 2012). However, the way companies are operated is an important determinant in the environmental performance. Despite negative environmental impacts from logistics and supply chains, there are a number of approaches that can be taken in order to reduce the use of finite resources and pollution without harming economic performance.

Importantly, integrating sustainability management into supply chain and logistics management requires not only an examination of the environmental impacts on financial performance, but also requires senior managers to better understand the impacts of the products, services and processes on the environment (Lee, 2012; Lee & Kim, 2011; Lee & Saen, 2012). In order to identify and measure sustainability performance in logistics and supply chains, it is necessary to link sustainability performance measurement to logistics and supply chains. However, it is not easy to uncover a link between sustainability performance and green logistics practice due to the lack of available tools and approaches. For example, Briassoulis (2001) in his sustainability measurement study finds that there is a shortfall in tools available to support sustainability management in operational terms. In a similar vein, Bhagwat and Sharma (2007) find that there is a lack of understanding of the number of performance measurement metrics, as well as lack of clear distinction between metrics at strategic, tactical and operational levels. In particular, they criticise the current financial measures which are based only on performance measurement of the supply chain, and they propose a “balanced approach” which includes financial and non-financial measurements. The present financial measure based performance evaluation practice is not well suited for use in logistics and supply chain management applications, nor does it present a clear picture

of the organisational performance (Bhagwat & Sharma, 2007; Chan, 2003; Shi et al., 2012). In particular, emerging areas of the supply chain network, such as green supply chain management and green logistics, have little or no performance measurement despite the importance of performance measurement in green supply chain management and green logistics (Hervani et al., 2005). Thus, there is a clear need to measure critical non-financial factors, such as environmental factors, in order to provide “useful” information for decision makers. As sustainability accounting is an interdisciplinary approach in nature, this study in particular provides an important finding to explain the relationship between sustainability and corporate decision making. As Milne (1996) argued, the relevance of decision making to environmental sustainability issues depends on the emphasis on economic and environmental values. When corporate decision makers put an emphasis on both economic and environmental values, then the collected environmental (carbon emission) and economic (cost) information should be integrated into information and management system to support corporate decisions.

For environmental and economic performance measurement, there are clear roles for sustainability accounting which provides a set of tools and approaches for addressing environmental, economic and social aspects of corporate activities (Schaltegger & Burritt, 2000). In particular, environmental management accounting (EMA) provides a useful approach to identify and measure environmental and economic performance units in physical and monetary information (Schaltegger & Burritt, 2010). In this study, we do not use traditional EMA tools such as life cycle assessment, input-output model, and material and energy flow accounting due to their limited applicability to logistics. Instead, we take EMA as an approach to identify and measure both environmental and economic performance in logistics management. Since there is no comprehensive structure or framework to measure environmental and economic performance in green logistics, we also adopt a multi-

methodological approach including process mapping, mathematical modelling, scenario analysis and sensitivity analysis.

In this study, we use an activity-based costing approach to collect transportation time, cost and carbon emission data for all activities in the logistics. Using scenario analysis, we present the comparative performance cases. Process mapping and mathematical modelling are used to provide a full analysis of environmental and economic performance. Furthermore, sensitivity analysis provides an additional resource to reduce the effect of the inaccuracies of available data. As this study uses model assumptions and a multi-methodology approach, sensitivity analysis adds credibility to our analysis. In this study, EMA provides a useful approach to collect the “relevant” information including activity-based cost and carbon emissions in the short-term. By using this process, EMA offers fundamental information to identify environmental and economic activity issues in both physical and monetary terms. Since sensitivity analysis in EMA is a very new issue, it is helpful to conduct this analysis when we collect both physical and monetary information to measure sustainability performance in logistics and supply chain management. This paper may offer an important step to open new approaches to the use of EMA in logistics and supply chain management.

With the case of Westgate Ports, we identified and measured cost per TEU and carbon emission per TEU under three operating conditions (truck, high productivity freight vehicles and rail). In addition, we identified and measured cost savings and carbon emission reductions in the operating conditions of high productivity freight vehicles (HPFV) and rail. We then measured each freight logistics option for cost including a carbon price. HPFV show the most eco-efficient (cost and carbon efficient) solution in the logistics frame. When we consider the environmental aspect only, the use of rail is the greenest option. In addition, transit time, logistics information systems, and cost and benefits sharing are identified as

important factors to take into consideration in future. Decision makers are also reminded of the long-term impacts of the time and cost structures of different options which they should take into consideration when planning and designing logistics systems and supply networks.

Using a multi-methodological approach, we analyse green logistics to measure both environmental and economic performance to assist in decision making. The greenest option for the organisation in this study is rail transportation; however, it is not the most cost-effective mode. This finding suggests that it is important to consider both the physical performance factor (CO₂ emissions) and monetary performance factor (cost) in “sustainable” corporate decision making in the area of logistics.

In light of the above reasoning, our argument provides three main contributions for the measurement and management of corporate sustainability performance in logistics and supply chain management. Firstly, this study contributes to a better understanding of sustainability performance measurement in logistics and supply chains. Our argument reveals that it is important to consider balancing the environmental and economic priorities of exemplars in green logistics management. As companies seek the trade-offs between cost savings and environmental outcomes, identification and measurement of both economic and environmental performance will provide the opportunity to redesign and reconceptualise logistics and supply networks, many of which create long-term competitiveness. Since there are few studies which measure and analyse environmental and economic performance in logistics and supply chain management, our study enhances understanding of green logistics and green supply chains as a part of sustainable supply chain management.

Secondly, this study makes a methodological contribution. Using EMA as an approach, this study extends performance measurement in supply chain management to green logistics and sustainable supply chain performance measurement. Also, it is one of the first attempts to

apply a multi-methodological approach using a real-world case study to examine physical performance information (carbon emissions) and monetary performance information (cost) simultaneously in logistics. Using one measurement only can provide relatively limited information to decision makers. The multi-methodological approach can offer short-term and long-term performance measurement, as well as operational-level and strategic-level performance measurement.

As a third and final contribution, our findings lead into the debate on the usefulness of information in corporate decision making for sustainability. As this study finds, it becomes clear that it is essential to consider both financial (monetary) and non-financial (physical, environmental) performance measurement in logistics and supply chain management in order to achieve sustainable supply chain management. Without linking financial and non-financial (environmental) performance to logistics, it is not possible to balance both environmental and financial performance goals in logistics and supply chain management. Since measures of eco-efficiency require physical and financial (or monetary) information, it is important to obtain both physical and financial information when considering the complexities of “real-world” logistics and supply chains. However, it is difficult to obtain accurate information about eco-efficiency due to a lack of available identification and measurement tools and approaches. As this study explores, a multi-methodological approach is a useful one to use in logistics business practices. Since a multi-methodological approach collects quantitative and qualitative data (also physical and monetary data), and uses various factors and scenarios to measure sustainability in logistics and supply chain management, this approach offers new insights into the improvement of sustainability performance measurement for sustainability accounting, particularly for EMA. When we consider that identifying and measuring physical and monetary information for corporate decision making is important in pursuing corporate sustainability, collecting “relevant” and “useful” information for measurement is an

especially important task. Therefore, we need to add new approaches (in this study, multi-methodological approaches) to develop frameworks and tools to make EMA more useful for managers of business practice. Since environmental sustainability and eco-efficiency are relatively new concepts in logistics and supply chain management, it is worth employing EMA to identify and measure sustainability performance in order to make relevant and useful corporate decisions to improve a firm's sustainability.

The approach presented in this paper does not aim to provide an all-encompassing and comprehensive response to corporate decision making towards sustainability in logistics and supply chains. The inherent methodological limitations of the approach include some model assumptions in order to measure environmental and economic performance in logistics and supply chain management. However, there are currently no comprehensively structured approaches to use; we attempted to use multi-methodologies to link sustainability performance measurement to green logistics. In order to supplement our approach, we conducted sensitivity analysis to allow decision makers to see the interactions between different variables. Since the analysis outcomes are dependent on the accuracy of these assumptions, further studies and analysis should be conducted to verify the analytical approach we propose here. In order to apply our proposed model to different sectors and countries, researchers may need to consider other factors which can play an important role in environmental and economic performance. These may include road and rail networks, fuel efficiency, carbon intensity, and vehicles carrying empty containers. Further, researchers may need to extend our approach to the supply network using more industry cases. Importantly, sustainability in logistics and supply chain management concerns all three dimensions of environmental, economic and social sustainability. This study, like many previous studies, focuses mainly on the environmental aspects and their link to traditional economic performance in logistics management. However, the argument presented here may offer an

important step towards more sustainable corporate decision making in logistics and supply chains, as compared to the status quo.

There are also important implications for researchers and practitioners. For further studies, a comprehensive analysis of sustainable logistics and supply chains should consider all three dimensions simultaneously. To this end, the role of sustainability accounting (particularly EMA) should be expanded to apply to logistics and supply chain management. As this study shows, EMA can provide not only a set of tools but also approaches to identify sustainability performance in logistics. It is suggested that researchers further examine the EMA roles and applications, taking into consideration logistics and supply chain management. It is also suggested that industry managers and practitioners employ and practice EMA for sustainability performance measurement within logistics and between business partners, in order to improve environmental and economic performance simultaneously (i.e. eco-efficiency). In order to do this, identification of the relevant information in physical and monetary terms will provide a basis for sustainability performance measurement. EMA can play an important role in providing this information. Third party logistics service providers could also consider eco-efficient transport logistics for customers who require “green logistics services” from business partners.

Acknowledgements

The authors would like to thank to anonymous referees and the special issue editors Roger Burritt and Stefan Schaltegger for their most constructive comments and suggestions to improve the paper. The authors alone are responsible for all limitations and errors that may relate to the paper.

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Table 1Estimation of parameters for cost and CO₂ emission

Item	Cost / km	Emission / km
Full one-TEU truck	\$2.40	1 kg
Empty one-TEU truck	\$0.96	0.7 kg
Full two-TEU truck	\$4.00	1.5 kg
Empty two-TEU truck	\$1.60	1 kg
Full HPFV	\$6.00	2.5 kg
Empty HPFV	\$2.40	1.5 kg
Full train	\$80.00	5 kg
Empty train	\$45.00	4 kg
Full loose freight truck	\$2.40	0.6 kg
Empty loose freight truck	\$0.96	0.4 kg
Item	Cost / lift	Emission / lift
Loading / unloading a full container	\$7.00	0.5 kg
Loading / unloading an empty container	\$4.00	0.3 kg
Shuffling a full container	\$7.00	0.5 kg
Shuffling an empty container	\$4.00	0.3 kg

Table 2

Key findings of each transport channel under current operating conditions

Category	Truck without ICH	HPFV with ICH	Train with ICH
<i>CO₂ Emissions</i>	Most	Moderate	Least
<i>Cost</i>	Most	Least	Slightly higher than HPFV
<i>Traffic Congestion</i>	Most	Moderate	Least
<i>Community Amenity</i>	Negative	Negative	Moderate
<i>Transport Time</i>	Depends on the handling efficiency of warehouses, cross docks, trunk road and local road traffic.	Depends on the handling efficiency of the ICH, trunk road and local road traffic.	Depends on the handling efficiency of the ICH, train schedules and local road traffic.

Table 3

Summary of cost, emission and savings per TEU

Item	Truck	HPFV	Train
Cost per TEU	\$252.70	\$168.07	\$186.69
Emission per TEU	104.98 kg	70.69 kg	36.00 kg
Savings based on truck transport			
Cost difference per TEU		\$84.63 (33.5%)	\$66.01 (26.1%)
Emission difference per TEU		34.29 kg (32.7%)	68.98 kg (65.7%)
Cost adjusted with carbon price	\$255.11	\$169.70	\$187.52

Fig. 1. The multi-methodological approach

Fig. 2. The “as-is” scenario for container and freight movement for one area of Melbourne

Fig. 3. Process map for import container and freight distribution operations

This scenario transports containers using one-TEU and two-TEU trucks

				Drive to Terminal			Load Container	
Item	Cost	Emission						
Drive to terminal	\$422,400.00	273000 kg		Avg Distance	15 km		Direct to W/H %	85%
Direct Tpt to warehouse	\$2,692,800.00	1032750 kg						
Tpt to cross dock	\$158,400.00	60750 kg		Subtotal Cost	\$422,400.00			
Unload cnt @ cross dock	\$21,000.00	1500 kg		Subtotal Emission	273000 kg			
							Tpt to Warehouse	
Tpt to warehouse from C/D	\$79,560.00	19890 kg					Avg Distance	45 km
Tpt to retailer	\$723,996.00	180999 kg						
Load empty cnt @ C/D	\$12,000.00	900 kg					Subtotal Cost	\$2,692,800.00
Tpt empty cnt to empty park	\$1,119,360.00	723450 kg					Subtotal Emission	1032750 kg
Unload empty cnt @ empty p	\$80,000.00	6000 kg						
Total cost	\$5,309,516.00	2299239 kg						

Fig. 4. The snapshot of part of the cost and emission calculation model

Fig. 5. Sensitivity analysis for cost difference between Channels B and C

Fig. 6. Change of impact of vehicle routing from Channel A to Channels B and C