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Assessing the environmental impact of integrated inventory and warehouse management

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ABSTRACT

There has been considerable research on the environmental impact of supply chains but most of this has concentrated on the transport elements. The environmental impact of warehousing has received relatively little attention except within the context of distribution networks. A high proportion of total warehouse emissions emanate from heating, cooling, air conditioning and lighting and these aspects are largely related to warehouse size. This in turn is greatly influenced by inventory management, affecting stockholding levels, and warehouse design, affecting the footprint required for holding a given amount of stock. Other emissions, such as those caused by material handling equipment, are closely related to warehouse throughput and equipment choice. There is a substantial gap in the literature regarding this interaction between inventory and warehouse management and its environmental impact. The purpose of this paper is to contribute to filling this gap. Therefore, an integrated simulation model has been built to examine this interaction and the results highlight the key effects of inventory management on warehouse-related greenhouse gas emissions. In particular, it is found that decisions on supply lead times, reorder quantities, and storage equipment all have an impact on costs and emissions and therefore this integrated approach will inform practical decision making. Additionally, it is intended that the paper provides a framework for further research in this important area.

1. Introduction

In recent decades, there has been a continuing rise in global greenhouse gas (GHG) emissions which has led to a new peak of GHG in the atmosphere in 2013 (WMO, 2014). Among them, carbon dioxide (CO_2) emissions are considered as a major trigger of the greenhouse effect and are associated with substantial environmental damage. In the last decade alone, CO_2 emissions reached an average annual increase of about 3% which resulted in a new record of 34.5 billion tonnes of CO_2 being emitted in the year 2012 (Olivier et al., 2013). Taking into account all greenhouse gases, equivalent carbon dioxide (CO_2e) emissions reached a total amount of about 50 billion tonnes in the year 2012, and are forecasted to rise to 58 billion tonnes CO_2e in 2020 (UNEP, 2012; Olivier et al., 2013). While the consumption of energy and the consequent emissions have continually increased, transportation and storage are perceived as an essential driver of environmental pollution in global supply chains. It is estimated that about 2.8 billion tonnes of the overall GHG emissions, which is equivalent to about 5.5% of the total GHG emissions, are caused by the logistics and transport sector (WEF, 2009).

Meanwhile, the environmentally sustainable management of logistic activities has become an essential element of business strategy and competitive advantage (Sarkis, 2003; Dey et al., 2011). Besides the appreciable social and political pressure to reduce GHG emissions caused by an increasing public awareness of induced global warming and climate changes, many companies have realized that the sustainable use of resources may also be associated with substantial financial savings (Plambeck, 2012). However, most research into the environmental impact of logistics has concentrated on the GHG emissions associated with transport activities (see, for example, Piecyk and McKinnon, 2010 or Ubeda et al., 2011). This is understandable as the World Economic Forum (2009) estimates that, globally, most supply chain emissions emanate from road transport (57%), followed by ocean freight (17%). However, logistics buildings, comprising warehouses and sortation facilities, are significant, accounting for 13% of supply chain emissions. This is more than each of the remaining categories of air freight (8%) and rail freight (5%). National figures, which normally exclude the international element of transport movements, however, emphasise the significance of warehouse-related emissions. In

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United Kingdom, for example, the Department of Energy and Climate Change (2013) estimates that warehouses account for 2.1 million tonnes of oil equivalent energy usage (which equates to 4.0 million tonnes of primary energy, due to loss in electricity generation and transmission), compared to 7.7 million for heavy goods vehicles and 5.0 million for light goods vehicles. These figures clearly indicate that GHG emissions emanating from warehouses represent an important element in terms of overall supply chain emissions. The estimation of the overall environmental effect of logistic activities, and the potentially affordable reductions in emissions, requires a full life cycle analysis taking into account the carbon intensity of production, transportation, storage and handling operations (cf. Wu and Dunn, 1995; Dey et al., 2011). Otherwise, the underestimation of logistic-related emissions may lead to undesired effects. For example, the use of less carbon intensive offshore production could lead to higher overall emissions due to longer freight hauls, increased safety stocks and increasing warehouse capacities. Accordingly, the estimation of the overall environmental impact, requires a logistical trade-off analysis similar to those long applied in the economic optimisation of logistics systems, but now recalibrated with respect to emissions. This calls for an integrated approach where environmental considerations are implemented in all related areas throughout the logistic chain, with inventory management and warehousing playing a significant role.

The intention of this paper is therefore to contribute to closing this gap in the measurement of logistics-related emissions by developing a structured framework for the assessment of the environmental effects of inventory and warehousing activities. As inventory and warehouse management are closely related, with both affecting the storage space and materials handling activities within warehouses and thus the resulting GHG emissions, they will be considered in an integrated manner. For example, effective inventory management may reduce total inventory levels while guaranteeing an adequate customer service level, leading to reduced inventory costs as well as improved efficiency of the order picking operations as the travel distances are reduced. Similarly, effective warehouse management may improve storage and throughput capacities that would otherwise restrict inventory policy. Thus, both areas are closely interrelated and an integrated view on this topic may lead to substantial savings (Strack and Pochet, 2010). A closer look at the literature, however, reveals that incorporating sustainability considerations into integrated inventory and warehouse management has largely been overlooked. Consequently, as inventory management decisions determine warehouse operational requirements and vice versa (see Van den Berg and Zijm (1999), Strack and Pochet (2010) and Sainathuni et al. (2014)) an integrated model for warehouse and inventory planning is presented in this paper. This enables the systematic estimation of GHG emission influencing factors within inventory and warehouse management by the use of simulation (cf. Fig. 1).

The remainder of this paper is organised as follows: Section 2 provides a review of the relevant literature on energy consumption and GHG emissions related to inventory management and warehousing. Section 3 develops a structured framework for the assessment of the environmental impact of inventory management on warehouse emissions. It also outlines the assumptions and conditions used within the simulation model. The results of the model are presented in Section 4. Finally, the paper concludes with Section 5 presenting managerial implications and directions for future research.

2. Literature review

In recent years, there has been a considerable number of papers dealing with sustainability issues in logistics (e.g. Seuring and Müller (2008) and Brandenburg et al. (2014)), but there has been rather limited research into the environmental impact of warehousing and inventory management. This section explores the extent of the literature to date in these two areas.

2.1. Environmental impact of warehousing

The lack of extensive research to date manifests itself in the uncertainty as to exactly what the energy in warehouses is used for and, consequently, what contributes to warehouse emissions. In fact, even individual warehouse managers often only have knowledge of the total energy used by fuel type (e.g. electricity, gas or oil) from the invoices they receive. They therefore may not know how this is split by usage type (e.g. heat, light or equipment), as reported by Dhooma and Baker (2012). Contradictory figures result from this lack of information and research. For example, United Kingdom Warehouse Association (2010) reported the results of a survey that indicated that most energy is used for lighting (65% of energy used), followed by heating (12%). This contrasts with estimates published by the DECC (2013) indicating that lighting is only responsible for

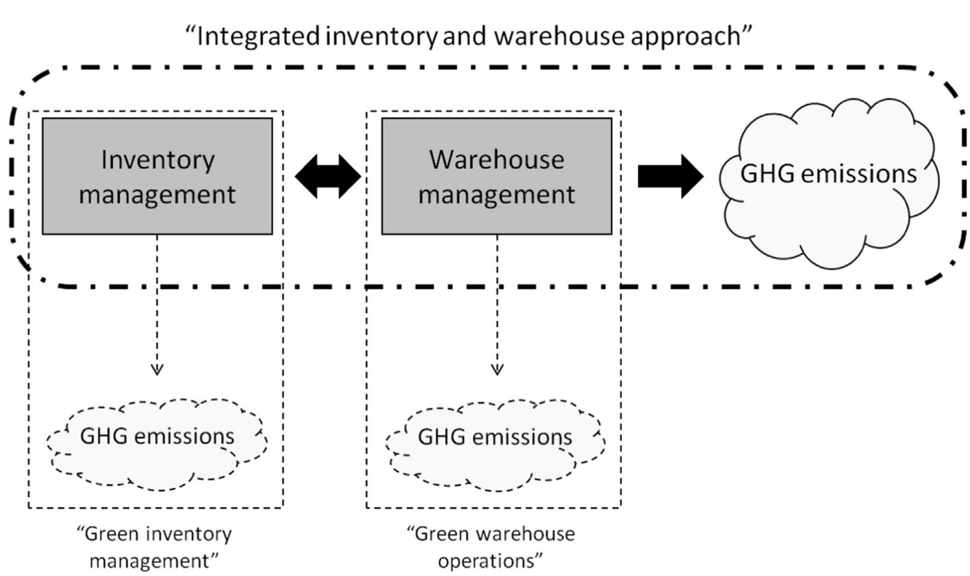

Fig. 1. Integrated inventory-warehouse approach for the estimation of GHG emissions.

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