A Study of Eco-Performane of Logistics Services in Food Supply Chains

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Abstract Transportation is one of the main contributors of greenhouse gases which give direct negatives impact on environment. Management of logistics services plays an important role in maintaining business competitiveness as well as social responsibility. Optimising logistics service with integrated economic and ecological objectives can help to reduce negative impact on the environment by reducing the amount of carbon emissions and improving operations efficiency. This study focuses on multimodal transportation planning and optimal strategies with a UK food supply chain case under carbon emissions control. The research investigates and identifies impact of the policies on logistics performance.

Keywords Multimodal transportation planning • Carbon emission policy • Fresh produce

1 Introduction

In the last decade, over 50% of fresh produce in the UK market were imported [1]. It has been a great challenge to achieve both economic and ecological objectives in the international transportation services. Research on transportation planning has been extensively reported in the literature [2–6]. Some research on logistics planning considering environmental impact has been reported [7–10].

However, research is still rare on interactions of supply chain economic and ecological performance with carbon control policies [11]. This study focuses on fresh produce supply chain case in the UK and investigates impact of different carbon emission control policies on operations of food logistics industry. The research aims to identify optimal strategies of multimodal transportation of supply

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networks under carbon policies, and provide a policy making reference to facilitate understanding of industrial reaction to government environmental policies on carbon emission. The research outcome is expected to have a generic contribution to multimodal transportation planning and government policy making in carbon emission control.

2 Eco-Logistics Planning

An optimisation model as seen in Eq. 1 is proposed to generate solutions and analyse behaviour of the supply network under different carbon control policies. Optimisation models are widely used in solving multimodal freight transportation problem [12–14].

In this paper, a mixed-integer programming is developed with four main elements: cost, time, distance, and mode of transportation, to analyse the economic and ecological performance of the logistics network, in particular the carbon emission policy impact on strategic options of supply chain design. The objective function of the model is to minimise the total cost (see Eq. 1), with consideration of policies of carbon emissions trading and carbon tax [15]. The modes of transportation in this study are road, rail, ship and their combinations.

Objective function:

$$\text{Min } CT = \sum_{k=1}^{p} \sum_{j=1}^{n} \sum_{i=1}^{m} \left(\left(TC_{i,j} * YT_{i,j,k} \right) + \left(CC_{i,j,k} * YT_{i,j,k} * YP_{i,j,k} \right) \right) * X_{i,j,k} \tag{1}$$

Subject to:

$$\sum_{k=1}^{p} \sum_{j=1}^{n} \sum_{i=1}^{m} CC_{i,j,k} * YT_{i,j,k} * YP_{i,j,k} * X_{i,j,k} = CL; \sum_{j=1}^{n} X_{i,j,k} = D_i;$$
$$\sum_{j=1}^{n} TT_{i,j} * YT_{i,j,k} \le RT_t; X_{i,j,k} \ge 0; YT_{i,j,k} \in \{0,1\}; \qquad YP_{i,j,k} \in \{0,1\}.$$

Notations: i – centre index; j – transportation mode; k – carbon emissions policies;

CL = carbon limit; TCi,j – transportation cost to centre (maritime port, rail freight terminal or a regional distribution centre) i with transportation mode j;

RTi – Required time for trip to a port or regional distribution centre i; TTi,j – time taken to centre i by transport mode j; CCi,j,k – carbon emissions cost to a centre i with transport mode j and carbon policy k; YTi,j,k – 1 if transportation mode j is used, 0 otherwise; YPi,j,k – 1 if policy k is chosen, 0 otherwise; Di – demand at centre i.

Interviews for data and business process mapping have been conducted with the case company which is a fresh produce logistics service provider. Some data such as carbon emission factor for transportation and carbon price are obtained from public sources [16]. At present, logistics companies have been mainly using road transportation for distribution of fresh produce in the UK. Road transportation has an advantage of door to door delivery with faster services. 40-ft refrigerated containers are normally used with heavy goods vehicles (HGVs) for the service. However, HGVs consumes enormous amount of fuels and creates environmental impact. Through the optimisation analysis, solutions of the logistics service network with different carbon policies can be identified with an insight into impacts of policies on shift between transportation modes and best strategies of logistics services.

3 Analysis and Finding

Firstly the model is analysed without considering carbon emission and associated costs. The model suggests distribution of fresh produce from all ports to all RDCs using road transportation. When carbon emission is considered, there is a significant impact on the present transportation practice. With carbon tax, multimodal options are selected (77% for road only and 23% for multimodal with rail plus road). On the other hand, with carbon emission trading, the best solution is suggesting road only and multimodal at 87 and 13% respectively. Carbon tax has a greater impact due to higher direct cost to the operations.

3.1 Carbon Tax vs. Carbon Emission Trading

Two common carbon control policies, Cap-and-trade (CT) for carbon emission trading scheme and carbon tax scheme, are involved in this research. CT scheme has an annual allowances allocated to the participants as a cap. Participants who face high abatement costs can continue emission by buying additional allowances, while those who face low abatement costs can take abatement action and sell their surplus allowances for a profit [15]. Carbon tax is based on consumption of fossil fuels.

To identify potential business behavior with government carbon control policies, the analysis is performed with different carbon charge rates as sensitivity analysis. Optimal carbon charges by carbon tax and carbon emission trading is investigated in the research as seen in Fig. 1. As carbon charges are highly dependent on government policies, the government enforcement plays a significant role in managing carbon emissions. The total cost includes transportation cost and carbon cost with consideration of transportation time limit. The analysis of total cost demonstrated optimum carbon charges with different carbon emission limit (CET in the Fig. 1) and carbon tax. It can be seen that, as cap increases, the optimal carbon charge for minimum total cost also increases. The carbon tax scheme in this case has the lowest optimal carbon charge.

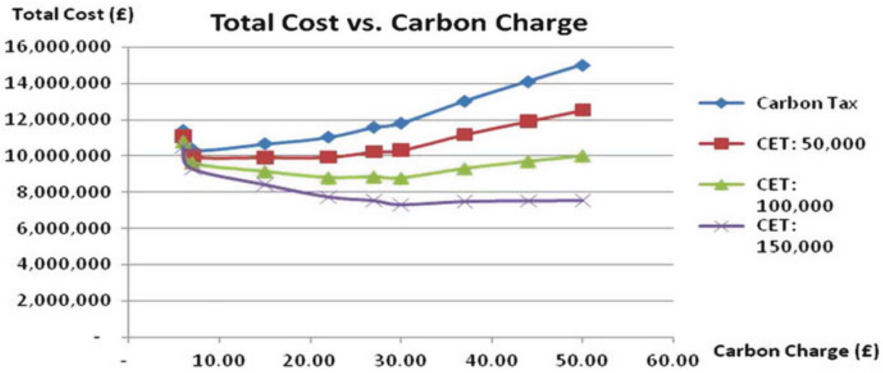

Fig. 1 Total cost fluctuations with different carbon charge

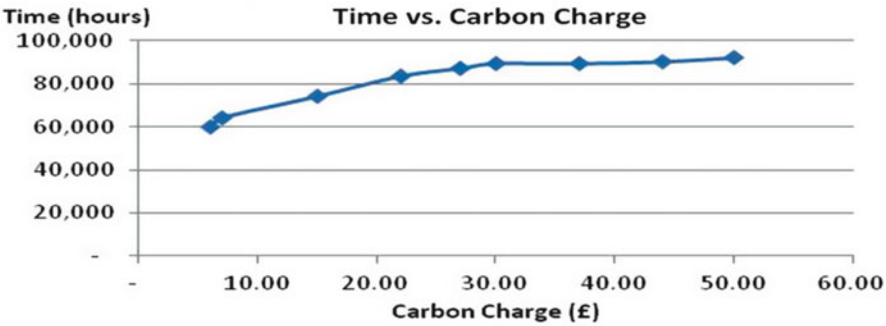

Fig. 2 Travel time with different carbon charge

3.2 Time Performance and Transportation Mode Selection

For fresh produce supply chains, time is an important factor. The performance in overall delivery time is analysed. The time spent in transportation processes with different carbon charging rates is shown in Fig. 2. In the analysis, time is a constraint for a trip to ensure food shelf-life requirements being met. As seen in Fig. 2, the travel time for each journey increases as the price of carbon mission increases. Therefore, the carbon charge is positively related to the logistics network performance in time.

To investigate impact of carbon control policy on transportation network configuration, the percentage of selected multimodal transportation routes with different carbon charges is analysed (see Fig. 3). Result shows that the higher the carbon price, the higher the percentage of multimodal transportation is chosen.

The optimal carbon charge is observed when carbon tax is chosen at the rate of £7 per ton of carbon emission, with a given travel time limit. Multimodal transportation accounted at 8 and 92% is for road only. If the CT scheme is chosen, with 50k

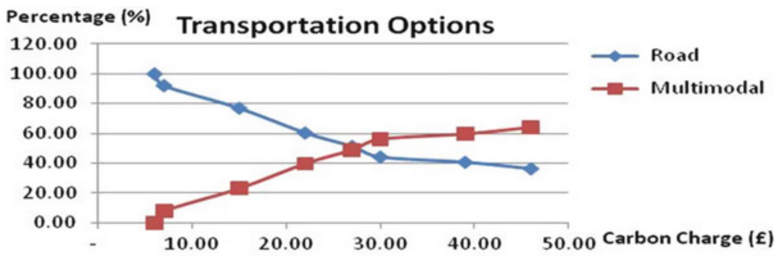

Fig. 3 Transportation options between road only and multimodal

ton of carbon limit, the optimum cost is at the price of £15 per ton of carbon emission. When the carbon limit is set at 100k ton and above, total cost is decreasing until the carbon price reaches £30. Higher than this charge, multimodal transportation becomes the favorable option.

4 Conclusion

This research has investigated impacts of the carbon emission policies on transportation operations for fresh produce industry. A network design approach for fresh produce logistics services under carbon emission control is proposed. With introduced carbon control policies, optimal decisions on transportation planning in fresh produce logistics will be affected by policies to be applied, carbon emission limits and carbon prices to be involved. The higher the charge on carbon emission, the more the allocation would be made to multimodal transportation routes. But the time spent may be increased in such cases, due to time spent in transportation mode transfer. The performance in costs can be optimised with given carbon charges and carbon policy through transportation mode selection. On the other hand, optimal carbon charges can be set to obtain lowest overall costs in the logistics operations. It can be seen that the policy to be applied by governments can play an effective role to shape the logistics network and affect economic and ecologic performance of businesses. This research outcome can be generalised to other industries for development of strategies with given carbon control policies, and for government to set up policies to encourage best business practice.

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