Carbon Emission Policies Impact in Logistics Supply Chain Networks

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by

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ABSTRACT

Environmental issue is becoming a serious global concern. Human activities associate with industrial activities and households produce a great amount of greenhouse gases, particularly carbon dioxide, and gives significant impact on the environment. The legislation on carbon emissions has become an important agenda in order to control the amount of carbon emissions that might affect the world for future generations. In conjunction to this issue, therefore, the research was conducted to investigate the impact of the carbon emission policies on reverse and forward logistics strategies and operations and propose optimisation models for the paper recycling and fresh produce industry with cases in the UK. The optimal network design approach for both cases under carbon emission control is formulated. The research concluded that exporting the waste paper to Asia is a better option when pollution from the recycling is not charged. However, when considering the carbon emission in both the UK and the Asian country, the best strategy would depend on the amount of recycling and the differences between the costs of the recycling locally and overseas. For fresh produce case, with no carbon policies, road is a better transportation option. However, if the industry has to pay for carbon emission, consideration of multimodal transportation has to be made in order to remain optimal. The analysis of business strategies and configuration of reverse and forward logistics networks are carried out with quantitative optimisation modelling. The analysis for paper recycling and the fresh produce industry consider contributions to the environment and costs in relation to carbon emission. Mixed integer linear programming models were developed for both cases to obtain the optimal choice in strategic and operational decision making. Transportation industry is a main contributor of greenhouse gases that give direct impact to the environment. Multimodal transportation planning is important because it can help to reduce impact on the environment, by using a combination of at least two modes of transportation in a single transport chain, without a change of container for the goods, with most of the route travelled by road, rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road. Multimodal transportation planning is proposed in the fresh produce industry with another variable which is time. The analytical result derived from sensitivity analysis is discussed to draw academic and practical findings for carbon control policy making and logistics network configuration. The research outcome has a good generic contribution to eco-logistics management of other recycling materials and to generic logistics network configuration issues. The research is also significantly contributed to government policy making in carbon emission control.

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CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

The world population reached seven billion people by the end of 2011. With the increasing number of human beings, humankind has had a considerable impact on the environment. Environmental issues constitute the most serious problem in every part of the world. Global warming, which is mainly caused by the emissions of greenhouse gases (GHGs), is said to contribute significantly to these environmental problems. Although there are many types of GHGs that have an impact on the environment, such as water vapour, carbon dioxide, methane, nitrous oxide, ozone and chlorofluorocarbon (CFC), this study focuses on carbon dioxide emissions, which constitutes the largest portion of gas emissions.

In order to facilitate the control of carbon emission, environmental legislation has been extended. Since the Kyoto Protocol in 1997, most countries around the world have tried to reduce their carbon emission. Developed countries, which fall under Annex I of the Kyoto Protocol have to reduce their overall emissions by at least 5% below the 1990 level in the commitment period 2008-2012 (UNFCCC, 1998). In the United Kingdom (UK), according to the National Action Plan Phase II, the goal is to reduce carbon emission by 12.5% below base year over the same commitment period (Defra, 2007).

Humankind's actions produce waste that is generated from industrial and household activities. Such waste generates a significant impact on the environment. The logistics and recycling networks to reprocess waste products to reduce pollution and recover value have

been encouraged and widely implemented by industry. Consequently, reverse or waste logistics as a key business process dealing with disposed products plays a more significant role in supply chains today. Some materials that are widely recycled are paper, glass and metal. Paper is one of the most frequently used products with a very short life cycle. Among the waste products, paper recycling is crucial in the UK due to the lack of resources. Paper is a biodegradable product. Disposal of used paper by landfill creates a considerable amount of the greenhouse gas, methane, which contributes to climate change. Furthermore, paper is also a carbon-based product, resulting in a considerable amount of carbon emission if it is incinerated (CPI, 2009b). It was estimated that 13.2 million tonnes of paper and board products were consumed in the UK in 2008, and approximately 8.8 million tonnes, or around 67%, were recovered from the waste stream (WRAP, 2010). These amounts of recycling can prevent 11 million tonnes of CO_2 equivalent emissions. Therefore, efficient planning on paper recycling is crucial to reduce the negative environmental impact and increase the reuse of the materials. This will further reduce timber consumption in paper production. Such challenges have not been given sufficient attention in either research or practice, mainly due to the immature carbon emission control policies in different industrial sectors.

Reverse logistics activities in relation to recycling paper products involves the collection, sorting, reprocessing and redistribution processes. To minimize the carbon emission while maintaining the operational efficiency of the reverse logistics operations is a great challenge. With this challenge, operational decisions concerning the routing of recycling the disposed paper needs assessment not only on costs, but also on the environmental impact. The business strategies for waste paper recycling (e.g. Local reprocessing or export scrap paper and import recycled/new paper) also need to be considered in terms of environment impact and cost at a national level. To control carbon emissions, policies have been set up at different levels from

the global agreement, nationwide policies to the regulations of local councils. While the waste logistics and recycling activities help to reduce the negative impact on the environment, they also generate carbon emission and other pollution, for example, in transportation. In order to make recycling activities run smoothly, transportation has to be involved in the collection and transport of waste paper from houses to the material recycling facilities (MRFs) and paper mills.

Transportation is the biggest contributor to the world total carbon emissions, amounting to one quarter of global carbon emissions (IEA, 2009). Among transportation modes, road transportation shares more than half of the carbon emissions in transportation (Schipper et al., 2009). Since environmental impact is the main issue associated with the transportation industry, planning for transportation will have a significant impact on carbon emissions. A proactive management of environmental issues is required to identify the interactions among transportation activities that have a negative environmental impact and the types of environmental impact emanating from transportation operations and facilities (Rondinelli and Berry, 2000). Road-based freight transport generates problems, such as congestion, energy consumption and has a negative impact on the environment. With the increasing awareness in carbon emissions and the implementation of carbon emissions policies, multimodal transportation planning was introduced to reduce the impact on the environment. Multimodal transportation planning is defined as the carriage of goods by two or more modes of transport (ECMT, 1998).

Since multimodal transportation planning involves a change from different transportation mode, time is another parameter that has to be taken into consideration, especially when

dealing with the transportation of perishable products. Fresh produce is a perishable product and it is a big market in the UK.

Issues and challenges in reverse logistics and forward logistics have been proposed by many researchers. The research outcome provides a useful tool for the paper recycling business that enable the design of recycling networks that incorporate the environmental perspective, and for governments to set up appropriate policies concerning carbon emissions control.

This research investigates the impact of the carbon emission policies in reverse logistics and forward logistics supply chain networks. It focuses on the cases of the paper recycling industry and fresh produce industry, and proposes optimisation models for these industries. Optimisation models for the waste paper reverse logistics network assessment and optimal network design approach for the fresh produce industry are proposed with cases in the UK. The research outcome has a good generic contribution to the strategic and operational level planning for both industries. The research will also significantly contribute to government policy making in carbon emissions control.

1.2 RESEARCH NEED

The issue of global warming involves taking costly actions today to avoid adverse outcomes that will occur in the future. With the increasing importance of the impact of carbon emissions on the environment, the implementation of carbon emission policies is an important agenda. There are two main types of carbon emission policy, namely, carbon emission trading and carbon tax. Since the implementation of the carbon emissions policy is

still at an early stage, this research is useful in finding a better option policy for both reverse logistics and forward logistics to minimise the negative impact on the environment.

1.3 RESEARCH QUESTIONS

Following the research needs, this study investigates the impact of carbon emission policies in the cases of reverse logistics and forward logistics. Thus, the following research questions have been formulated:

With the increasing awareness of carbon emission policy, what would be the impact of carbon policies on the behaviour of logistics in a supply chain strategy and operations in the paper recycling industry?

and

Multimodal transportation planning is hoped to help in reducing carbon emissions, how can this planning help in the fresh produce industry as multimodal transportation will increase the delivery time, which is crucial in respect of perishable products?

1.4 RESEARCH OBJECTIVES

The objectives of the research can be obtained by employing logistics for both the reverse and forward logistics supply chains. The paper recycling industry is a case that represents the reverse logistics supply chain. It is a closed-loop supply chain because the network of paper recycling in this study involves exporting the waste paper, and importing it back in order to meet the demand. Paper is selected because it can be generalised to other types of recycling,

such as metal, plastic and glass. The fresh produce industry is chosen to represent the logistics in the forward logistics supply chain because it involves importing fresh produce to the UK and its distribution to local regional distribution centres. It is a perishable product, and, hence, the time factor is included in the network. It is a more complicated industry because of the perishable products, and, therefore, the fresh produce network model can be simplified for other types of forward logistics. Hence, the aims and objectives of this study are:

1. To construct a new business model to help the logistics industry optimises their business in the context of carbon emissions.
2. To propose a mathematical model for designing a reverse logistics network that handles paper recycling activities.
3. To propose a mathematical model for a forward logistics network that handles a fresh produce transportation network with an additional carbon emissions element.
4. To evaluate the impact of carbon emissions policy on reverse logistics and forward logistics networks.
5. To reduce the total costs in the network of reverse logistics and reduce the total costs and time in forward logistics with consideration of carbon emissions.

1.5 SCOPE OF THE RESEARCH

In this paper, the study of both forward and reverse flows is proposed and illustrated with numerical examples. The first case study of reverse logistics is the paper recycling industry. The study focuses on the allocation of waste paper in the UK paper recycling industry starting from material recycling facilities (MRFs) until the waste paper is sent to both local

paper mills as well as those in China. China is used as an export market because China is the largest paper importer from the UK (CPI, 2010).

In the case of the forward supply chain network, the fresh produce industry is used. The fresh produce is imported to the UK market from Spain, Holland, South Africa, Chile, Brazil and Argentina and via six main UK ports. The focus is on the distribution of fresh produce to the UK market by considering multimodal transportation from these UK ports to fresh produce regional distribution centres (RDCs) in the UK.

1.6 RESEARCH CONTRIBUTIONS

This research makes three contributions to the body of knowledge:

For academics: This research contributes to the literature by enriching the literature on the study regarding carbon emissions policy impact on strategic and operations level, while also considering multimodal transportation planning. This study further incorporates the aspect of carbon emission trading and carbon tax in trying to minimise the cost for overall logistics network. Besides, this research also introduces the utilisation of mathematical models that takes into consideration the elements on carbon emission policy in logistics supply chain network.

To the government: The findings of this research are expected to be a useful guideline for the government in making decisions on the rate of carbon to be charged, especially for carbon tax as the government is responsible for the carbon charge rate. With the increasing awareness of environmental related issues and push factors from international agreement, sooner or later, carbon policy will be implemented not only by developed countries. Therefore, this study

contributes as a foundation in helping the government in making an efficient strategic decision making in the policy option for implementation.

For practitioners: The research presents two case studies where the impact of carbon policy implementation on transportation planning is taken into consideration. The case study on paper recycling can be generalised to other types of recycling materials. Fresh produce industry on the other hand considers time as another factor since time is an important factor in perishable products. Furthermore, multimodal transportation planning is also included in the fresh produce case. This study shows the impact of carbon emission policy implementation on the operations of these industries.

1.7 THESIS ORGANISATION

This thesis consists of six chapters. Chapter 1 introduces the research background, research needs, research questions, research objectives, scope of research and research contributions. Chapter 2 reviews the existing studies that have been conducted and are relevant to the research area. First, the review of reverse logistics focus on paper recycling is made, followed by the review of forward logistics, which is the fresh produce industry. In relation to that, multimodal transportation planning comes into the picture as transportation is the second biggest contributor to the world's carbon emissions. Finally, Chapter 2 reviews the research that has been conducted in relation to carbon emissions. White papers are the source of information most referred to, as most of the references on carbon emissions policies originate from the government or companies.

Chapter 3 presents the research methodology, discusses the details of the overall research design and describes the formulations for the optimisation models in this study. The optimisation-sensitivity analysis approach is used in carrying out the research. Data collection strategies are also demonstrated in this chapter. Chapter 4 describes how the analysis was performed. The locations of material recycling facilities, paper mills and regional distribution centres for both cases are divided according to the UK regions.

Chapter 5 compares the impact of carbon emissions policies on both networks. The optimisation models are tested with different carbon charges. Finally, Chapter 6 draws the conclusions of the study, including the overview of the findings, the limitations and recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter generates the conceptual framework of the study, based on the review of literature that is relevant to the subject matter. It contains five sections including the introduction and summary.

Section 2.2 presents a review about previous studies in the reverse supply chain network. The sense of closed-loop in this study is related to selling (export) and buying back (import) in a reverse logistics network focusing on the paper recycling industry in the UK.

Section 2.3 reviews the literature on the forward logistics supply chain network. The consideration of multimodal transportation planning in a fresh produce industry is added to the analysis in order to determine the impact of carbon emissions on the operational level of the fresh produce industry. The overview of the fresh produce industry in the UK is also provided.

Section 2.4 provides a background to the carbon emissions policies that have been established since the Kyoto Protocol 1997. With the increase in environmental awareness, carbon emission is an important issue nowadays. Different types of carbon policies that are essential to mitigate global warming are explained.

Finally, section 2.5 presents a summary and discussion of the whole body of literature reviewed in this chapter with the contribution of this research compared to the earlier research that has been done.

2.2 REVERSE LOGISTICS SUPPLY CHAIN NETWORK

In the past, when there were no regulations or concerns expressed by the public, most companies did not take any responsibility after their products were sold. Now, because of the growing concerns from the public around the world and regulation from the governments and agencies, reverse logistics is a good way to deal with this issue. Reverse logistics concerns those activities associated with the handling and management of equipment, products, components, materials or even entire technical systems to be recovered (De Brito and Dekker, 2002). Reverse logistics is a significant field of study since it deals with waste that might end up in landfill. By exploring reverse logistics, some wastes can be taken back into the supply chain and can cause less harm to the environment. The reprocessed products will be brought back into the market and redistributed to customers. Reverse logistics has become a key competence in a modern supply chain (De Brito and Dekker, 2003). Although reverse logistics is a fine approach in taking back the recyclable materials from the waste stream, not all products can be reprocessed or recycled.

Reverse logistics or product recovery can be divided into three classes, namely, reuse, remanufacture and recycle (Fleischmann et al., 2000). Among the waste that can be reused are the materials that can be used by the second customer without prior repair operations, for instance, clothes, household items and construction materials. Reusable parts can be extracted from the products sold in the second hand market or assembled into a new product. The remanufacturing process is suitable for materials that are worn out or obsolete. Car parts

(Dekker et al., 1998; Kumar and Putnam, 2008; Cruz-Rivera and Ertel, 2009) and electrical and electronic products (Spengler et al., 2003; Bian and Yu, 2006; Dat et al., 2012) are important materials addressed in reverse logistics associated with end-of-life products that fall under remanufacturing. Electrical and electronic products present major concerns regarding the disposal of the products, especially at this time of rapid technological innovation where many electronic products become obsolete faster than before. Some electrical and electronic products are hazardous to human health and eco-system if they are transferred to landfill because of the contents, which contain toxic and hazardous contents. Therefore, these products have to be properly handled, processed, disposed, and, if applicable, remanufactured, recycled or reused. An example of Waste of Electrical and Electronic Equipment (WEEEs) is household appliances (Kumar and Putnam, 2008), machine tools and mobile phones (Chan et al., 2006; Hanafi et al., 2008). End-of life products are normally under the company's responsibility to promote the collection and recycling of products and proper disposal of any chemical contents.

The most common product recovery is recycling and the materials that are usually recycled are paper (Bystrom and Lonnstedt, 1997; Fleischmann, 2001), plastic (Pohlen and Farris II, 1992), glass and metal (Gossling-Reisemann, 2008). Sand recycling is studied by Dekker et al. (1998) in the context of reuse in the operational research perspective.

2.2.1 Reverse logistics network

Hu et al. (2002) defined reverse logistics as a type of business process that involves planning, managing, and controlling the flow of waste for either reuse or final disposal. It is a logistic structure of goods flow from users towards producers. It turns out to be important because it can capture value from used products instead of sending to landfill. From an environmental perspective, reverse logistics support practices in relation to various levels of product and materials reuse (Meade and Sarkis, 2002).

Reverse logistics became known back in the 1970s, as Schary (1977) dealt with the recovery of waste after consumption. He also stressed the movement of recycled materials. In 1992, Pohlen and Farris II identified different reverse logistics channel structures and described the details of the functions of the channels with a discussion of the issues affecting the structure of the reverse logistics channels used in recycling. Recycling has become widely practiced in the effort to reduce greenhouse gases to the atmosphere.

Barker and Zabinsky (2008) addressed two main challenges in reverse logistics network design. The first one is on how to build product recovery activities into traditional forward logistics networks. Logistics systems are typically not designed to accommodate reverse logistics efficiently because traditional supply chains are designed to provide a certain quantity of product to the customer at a certain time. The second challenge is how to manage the impact of uncertainty in the reverse logistics supply chain. The uncertainties in reverse logistics involve uncertainty in volume and condition of the returned products. The crucial challenge is that producers are facing much higher uncertainty in the supply and demand of returned products.

Reverse logistics can be used in the treatment of hazardous waste as well. A discrete–time linear analytical model was formulated by Hu et al. (2002) who proposed a model consisting of four critical activities – collection, storage, treatment and distribution – that minimise the total reverse logistics operating costs subject to the constraints that take into account such internal and external factors as business operating strategies and governmental regulations. By using their proposed model, they found that total reverse logistics costs can be reduced by more than 49%. Their research is a good support for the benefits of reverse logistics.

Lee and Dong (2009) explored a stochastic approach for the dynamic reverse logistics network design under uncertainty. The uncertainty observed by them was in terms of demand on forward products and supply of used products by customers. They introduced a hybrid processing facility, which can handle both forward products and returned products. In a traditional reverse logistics network, a facility can handle either forward products or returned products. The network that represents both forward and returned products has an advantage in strategic level decision making.

2.2.2 Optimisation model in reverse logistics

Numerous researches on logistics operations management and optimisation have been reported in the literature. Optimisation models are used by many researchers in optimising cases in reverse logistics, such as mixed integer linear programming (MILP) (Fleischmann, 2001; Lourenco and Soto, 2002; Spengler et al., 2003), analytic hierarchy process (AHP) (Meade and Sarkis, 2002), genetic algorithm and fuzzy programming (Qin and Ji, 2010). Since optimisation deals with the quantitative approach of decision making, generally, optimisation is essential in order to quantify the benefit of reverse logistics to the society.

Fleischmann et al. (2000) used quantitative model in reverse logistics by focusing on the highlight of the key strategic issues for each stage of the recycling operation with three different supply chain contexts for product recycling. They are mandated product take-back, value added recovery and take-back for remanufacturing for testing how the structure and design of the framework could be modified in order to address the changes. In 2001, Fleischmann et al. proposed an MILP recovery network design model to analyse the impact of product return flows on the logistics network. They found that product recovery can, in many cases, be implemented without requiring major changes in existing forward production-distribution networks.

Product recovery under remanufacture has been investigated by Spengler (2003) in which the interaction between scrap from discarded electronic equipment is optimised. The focus of his study is production planning.

Optimisation modelling is used in optimising reverse logistics network in this study. Mutha and Pokharel (2009) used mathematical modelling in an optimising reverse logistics network using new and old product modules. The design of their network is strategic as it involves a decision on the number, location and capacities of various facilities and allocation of material flows between them. The network diagram involves nine echelons with five main echelons representing the network from retailers, warehouses, reprocessing centres, factories to distribution centres. From reprocessing centres, some of the processed materials are sent to disposal sites, recycling centres and spare markets. Suppliers are another echelon for sending raw materials to the factories. Scenario analysis is then conducted to reflect the situation on changes in capacities at the processing centres and receipt of returned products from the

customer. Mathematical modelling is suitable for network optimisation because quantitative analysis for product recovery network is still not fully developed (Fleischmann et al., 2000). They performed a study of logistics network for product recovery in different industries. The recovery chain from end user consists of five activities which are collection, selection, reprocessing, redistribution and disposal. They used MILP and the cases are grouped into three categories namely bulk recycling network, assembly product remanufacturing network and reusable item network. Hu et al. (2002) applied the cost minimisation model in a study in multi-type hazardous-waste reverse logistics systems. They minimised the total reverse logistics operating costs with internal and external factors as business operating strategies and governmental regulations. The objective of the proposed model is to minimize the total reverse logistics cost for a given multi-time-step period. The total reverse logistics cost involved in the objective function includes five major time-varying cost items: total collection cost, total storage cost, total treatment cost, total transportation cost for reusing processed wastes, and total transportation cost for disposing processed wastes.

2.2.3 Paper recycling in reverse logistics supply chain network

Paper recycling is used in this study because paper is a carbon-based product, and, hence, releases a considerable amount of carbon emissions when incinerated. When the paper is disposed into the landfill, it will create a powerful greenhouse gas called methane, which contributes to climate change. Recycling is a sustainable way to manage waste paper. CPI (2009b) has stated that recycling one tonne of paper will produce 1.4 tonnes and 0.62 tonnes of carbon emissions equivalent compared to landfill and incineration, respectively. Recycling reduces the need for extraction and processing of new resources; therefore, it saves fossil-fuel energy, and avoids the climate impact of alternative waste treatment systems. These include

the release of fossil-fuel derived carbon dioxide (CO_2) from incineration and the release of methane, a much stronger climate change gas, from landfill (FOE, 2009). Among the waste products, paper recycling is crucial in the UK due to the lack of forests. Disposal of used paper by landfill will create a considerable amount of the greenhouse gases, which contributes to climate change. Therefore, efficient paper recycling becomes crucial to reduce the negative environmental impact and increases the reuse of the materials. This will further reduce timber consumption in paper production.

In the UK, waste paper is collected from the municipal waste stream for recycling. More than half of the waste paper is collected via kerbside collection schemes (WRAP, 2010). Paper is used a lot at home and in the office, such as in printing and writing, packaging, newsprint, and direct or junk mail. These used papers are then recycled to be used again. Paper is the most recycled material besides plastic, glass and other recycled items. The UK industry is proud of its recycling heritage, which started over 100 years ago. There are more than 60 grades of waste paper in Europe, which have been categorized into five main groups – ordinary grades, medium grades, high grades, Kraft grades and special grades (CPI, 2009a). Although it is said that paper recycling could reduce the adverse effects to the environment, not all paper can be recycled. For instance, cigarette paper and paper that is put to permanent use in books and for artistic purposes are non-recoverable because their end-use results in them being bonded with materials that make them unsuitable for recycling. Therefore, this kind of paper has to go to landfill or incineration.

In 2008, 13.2 million tonnes of paper were consumed in the UK (WRAP, 2010); of which 67% of the paper consumed was recovered from the waste stream for the purpose of recycling. This means that the rest, 33%, was sent to landfill. Recycling paper can store

carbon; on the other hand, landfill or incineration of paper breaks down the paper and releases carbon to the atmosphere. Therefore, papers that are not recycled have an adverse impact on the environment, which leads to global warming. Besides carbon, the cost for landfill is not cheap as the landfill tax has to be paid. In 2009, the landfill tax was £40 per tonne, which is higher than recycling a tonne of paper (Seely, 2009).

There are three types of collection system in the UK, namely, co-mingled, segregated and the twin or dual stream (CPI, 2009b). A key challenge facing the paper recycling sector is how to maintain the quality of paper collected in the face of the trend towards single stream (co-mingled) collection. The co-mingled collection system is a system in which all recyclables, like paper, glass, plastic and cans, are placed and sent together to material recycling facilities (MRFs) for the sorting process. Segregated collection is a system in which recyclables are sorted into different compartments of a collection vehicle depending on the material, thereby removing the need for sorting at the MRFs. Segregated collections tend to produce cleaner waste paper than the co-mingled process. Twin or dual stream is the collection of material in two batches: typically with paper and card being segregated from other recyclables at the point of collection. In this way, the paper can be kept clean and free of contaminants whilst the remaining recyclables are sent to an MRF for resorting. There are pros and cons in determining the collection system. The segregated and twin system produces less contaminated paper than using the co-mingled system. However, from the consumer's point of view, the co-mingled collection system is easier, especially for residential consumers, and, hence, could result in a higher amount of recyclable materials.

In the UK, waste paper is collected from residential and office areas and sent to the MRFs. After finishing the sorting, balling and inspection process, recovered papers are then sent to paper mills for the next process. The first process in a paper mill is re-pulping and screening, which turns the waste paper into a mushy mixture and removes small contaminants, such as bits of plastic and globs of glue. The following processes are cleaning, deinking, and refining, bleaching and colour stripping. Finally, when the clean pulp is ready to be made into paper, the process is called papermaking (TAPPI, 2001). The recovered paper contains some fibres that become smaller as the paper is recycled. Some recycled paper may contain fibres that have been recycled before. These fibres can be recycled up to seven times before they become too short and brittle to be transferred into a new paper (TAPPI, 2001).

Some recovered papers are sent to local paper mills while the rest are exported to overseas paper mills. Out of the 8.8 million tonnes paper recovered from the UK waste streams in 2008, 4.8 million tonnes was exported (CPI, 2009a). Currently, the export from the UK waste stream is sent to destinations, such as Asia including India, Indonesia and China, as well as some European countries. China is the biggest market for waste paper export from the UK with 61% of the export going to this country (CPI, 2010). Based on this fact, in this study, only China is used as the export destination.

2.3 FORWARD LOGISTICS SUPPLY CHAIN NETWORK

Forward logistics has been an important issue for a long time. Forward logistics refers to the management of the flow of resources from one place to another. In a forward logistics network, the raw material is normally at the starting point of the network and ends with the

end customer. Transportation is a major player in market integration and becomes a key factor in economic connection. With transportation, the economy can grow, since the goods and services can be sent from and to every part of the world. Logistics has a relationship with operational and cost performance.

2.3.1 Multimodal transportation planning

The transportation industry is fundamental to the current economy and society. The goods are produced in a certain part of the world and sent to meet demands from all over the world, and, therefore, transportation is a key process. The development of a country has a close relationship with transportation because it is one of the factors taken into account in determining the development of a country.

Macharis and Bontekoning (2004) defined intermodal transport as the combination of at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route travelled by rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road. The increasing importance of multimodal infrastructure and intermodal services will intensify the environmental impact of transportation activities in the future (Rondinelli and Berry, 2000). Multimodal transportation infrastructure adds value in logistics as an integrated system managed holistically. With multimodal freight transportation planning, the goods can be distributed effectively to the right place at the right time whilst considering the environmental impact.

2.3.2 Freight transportation network with multimodal transportation planning

With the increasing awareness of environmental impact, it may have a major impact on the traditional supply chain schedules. International freight transportation is largely demanded as the goods are being sent all over the world. Truck, rail, ship and aeroplane are common modes of transportation. This study focuses on freight transportation and does not consider aeroplanes as a transportation mode. A number of researches have been conducted on the freight transportation network (Southworth and Peterson, 2000; Hasan, 2009; Yang et al., 2011).

Multimodal transportation was first electronically reported in 1988 (Macharis and Bontekoning, 2004). After that, it was widely developed in the 1990s. Multimodal or intermodal transport uses a combination of at least two modes of transportation in a single transport chain, without a change of container for the goods, with most of the route travelled by rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road (Macharis and Bontekoning, 2004). The demand for multimodal transportation infrastructure rose due to a number of factors, such as economic globalisation, agile manufacturing, speed-to-market delivery, and supply chain management. As transportation systems expand and become more integrated, their impact on the physical environment will become more complex (Rondinelli and Berry, 2000).

Several studies have been conducted regarding transportation planning. Kim and Van Wee (2009) developed a model to compare the intermodal freight system and truck-only freight system. Their research concluded that regardless of the type of locomotive, the rail-based intermodal freight system emits less carbon than the truck-only systems. In a traditional

supply chain, road transportation is widely used for most of the transportation process, because of its flexibility. In multimodal transportation planning, roads still play an important role in the transferring of goods to the final destinations. Therefore, Janic (2007) developed a model for comparing the internal and external cost of the road freight transport network. The finding from the study is that the costs of the road transport network are constant and the intermodal transport network decrease as the volume of units increases. In order to neutralise the effect of higher prices, the service frequencies in the medium-distance market must be increased.

Multimodal freight transportation planning can be used at different levels. Inland distribution is the main focus of this study. An economic logistic model has been conducted by Iannone and Thore (2010) to highlight and measure the advantages that logistic agents can enjoy in routing maritime containers through the interports in Southern Italy. They formulate and solve an economic optimization model for the inland logistics of containers imported through the seaports located in the Campania region in Southern Italy. The programming problem minimizes the total generalized logistic cost of the container distribution operations over the inland network, subject to flow balancing conditions at all origin, intermediate and destination nodes, as well as to capacity constraints over railway links. Their results demonstrate that it is possible to improve the competitiveness of railway services over short distances only by adopting an extended gateway system based both on the possibility of carrier haulage by railway under customs bond without any accompanying inland transit document over seaport-interport routes, and on customs clearance at the interports. A cost model of multimodal transport for garment exporters was produced by Banomyong and Beresford (2001) with five main elements – cost, time, distance, transport, mode and intermodal transfer. The transport mode examples are road, rail, inland waterways and sea

while intermodal transfers are ports, rail freight terminals and clearance depot. A confidence index is introduced for each route, transport modes and nodal links. Bangkok is used as a main hub. The results obtained show that when considering time and cost, Bangkok is not the most competitive as compared to Port Klang route which can give a better alternative for Lao garment exporters. Moccia et al. (2011) added shipment consolidation options in a transportation problem with a multimodal network. They included flexible time and scheduled services in the operations of a logistics company. An origin-destination integer multi-commodity flow formulation with non-convex piecewise linear costs, time windows, and side constraints is used in carried out the study. Column generation algorithms are designed to compute lower bounds. These column generation algorithms are also embedded within heuristics aimed at finding feasible integer solutions. The computational experiments conducted showed the efficacy of the proposed heuristic algorithm based on decomposition, even though their representation of the virtual network can sometimes result in very large digraphs. A study on the international multimodal freight network has been conducted by Southworth and Peterson (2000). They described the development and application of a single, integrated digital representation of a multimodal and transcontinental freight transportation network focusing on the routing of the tens of thousands of intermodal freight movements. Geographic information systems (GIS) technology was invaluable in the cost effective construction and maintenance of the network. Among the benefits of the approach, it allows different mode specific line haul networks to be linked together via more than one data representation for transportation terminals, and using more than one approach to defining local network access and egress.

Multimodal transportation can help in reducing carbon emission in the transportation industry. With increasing awareness and the current charge on carbon emission, it can help in reducing the cost in the supply chain. Few researches have been conducted on the environment related to freight transportation (Facanha and Horwath, 2006; Lopez et al., 2009; Hoen et al., 2011). Facanha and Horwath (2006) concluded that air transportation emits the highest carbon compared to road and rail transportation with rail producing the lowest emissions.

2.3.3 Optimisation model in transportation planning

Optimisation models are widely used in solving freight transportation problems. Optimisation using simplex iteration has been done by many researchers to develop a planning model to minimise redistribution using different modes of transportation. Yamada et al. (2009) used a heuristic approach in proposing a model for strategic transport planning in the freight terminal development and interregional freight transport network design. Their combination of optimisation and heuristics approach determines a suitable set of actions from a number of possible actions, such as improving the existing infrastructure or establishing new roads, railways, sea links, and freight terminals. Empirical results of the model as applied to an actual large-sized interregional intermodal freight transport network show that genetic local search could provide better performance as compared to other genetic algorithm-based, as well as tabu search-based, heuristics. The model is successfully applied to transport network planning in the Philippines, where the development of a freight transport network is necessary to increase the utilisation of other transportation modes rather than road-based vehicles. A heuristic approach that can be applied in the tactical and the operational planning phase was used in studying a long-haul freight transportation problem by Caramia and Guerrioro (2009). They minimised the travel time and the route cost and maximised the

transportation mean sharing index related to the capability of the transportation system of generating economy scale solutions.

2.3.4 Fresh produce industry in the UK

The beginning of the chapter covered the reverse logistics of a supply chain. However the forward supply chain is included in the study in order to evaluate the performance of multimodal transportation planning. Since the last decade, the supply of fresh produce in the UK market has increased significantly because of the increase in consumption over this period. However domestic production has declined, which shows a trend of increase in import volumes. In 2008, 58% of the supplies in the UK market were imported and the rest, 42%, were domestic production (EFFP, 2010). The UK has to rely on imports in order to meet the demand for fresh produce that cannot be produced in the UK and also to meet the demand of the produce that is out of season in the UK. Although domestic production has increased, it is still low compared to the total demand for fresh produce. Currently the fresh produce is imported from Northern Hemisphere countries, such as Spain, Holland and New Europe, and from Southern Hemisphere countries like Argentina, Brazil, Chile and South Africa.

In the structure of the fresh produce supply chain, intermediary marketing business acts as a middle person between the grower and the customer. This study plays a role as an intermediary marketing business in organising the import of fruits for the UK market by considering the cost and carbon emissions. Fresh produce is quite a complex industry and can be divided into several sectors. These sectors are quite complex because each sector has different characteristics, especially in terms of perishability. This study focuses on the fruit sector alone. Fruit sector can be divided into two main sectors – top fruit and soft fruit. Top

fruit is any fruit that grows on a tree like apples and oranges while soft fruit is the fruit growing on the ground, such as strawberries, raspberries and blackberries. Soft fruit is more perishable than top fruit. In the UK, a greater volume of fruit is imported compared to vegetables, with 85% of the demand for fruit in the UK being fulfilled from imports (EFFP, 2010).

The large volume of imports has an impact on the cost in the supply chain. Transportation cost plays an important role in the cost structure. The transportation industry is also a main contributor of greenhouse gases that have a direct negative impact on the environment. Hence the transportation planning is crucial. Road-based freight transport generates problems, such as congestion, energy consumption and a negative impact on the environment. With the increasing awareness in carbon emissions and the implementation of carbon emissions policies, multimodal transportation planning was introduced to reduce the impact on the environment. Multimodal transportation planning is defined as the carriage of goods by two or more modes of transport (ECMT, 1998). The environmental impact is the main issue today, especially in the transportation industry, where it has a big impact on the traditional supply chain schedules. Therefore, a proactive management of environmental issues is required to identify the interactions among the transportation activities that have a negative environmental impact and the type of environmental impact emanating from the transportation operations and facilities (Rondinelli and Berry, 2000).

2.4 CARBON EMISSIONS

The increasing amount of carbon emissions due to human activities contribute to the global warming problems. Transportation has a close relationship with carbon emissions since it is one of the main contributors of global carbon emissions. In the UK, transportation is the second largest source of carbon emissions (Watters and Tight, 2007). Globally, transportation predominates with 23% of carbon emissions (EOCD, 2010). Reverse logistics and fresh produce distribution activities contribute a significant share in the transportation industry. Without any policy to complicate the activities, people will keep on emitting carbon and greenhouse gases. Therefore, carbon emissions policy is an important agenda in order to slow the harmful impact on the environment.

The Kyoto Protocol, which was adopted in 1997, was the first international agreement to mitigate climate change and aims to reduce carbon emissions by 5% from the 1990 carbon level over a 5-year period for industrialised countries (UNFCCC, 1998). Under the Kyoto Protocol, all industrialised countries are grouped under Annex I countries with a commitment to reduce carbon emission targets contained in Annex B. The UK's commitment under the first five year commitment period (2008-2012) is to achieve a reduction of 12.5% CO_2 from the 1990 levels by 2012. During the first commitment period, the countries must meet the targets set under the Kyoto Protocol through its national measures.

In approaching the end of the first commitment period, the Kyoto Protocol, which has been in force since 2008, has been criticised because of its weakness. The carbon market has been adversely affected by low prices that are failing to drive the necessary investment in low-carbon technology and a series of scandals about the integrity (Newell, 2012). The scandals include fraud and gaming by unscrupulous actors (Green, 2008). Newell (2012) also states

that the governance touches on the deeper politics of carbon markets, and, therefore, the role politics plays in response to climate change has to be addressed. This study, however, does not focus on the political side but on the impact of carbon emissions by quantifying the carbon emissions cost in monetary value.

Another issue concerns the participating countries. The United States is the biggest industrialised country but has not ratified the agreement even though it has the largest share of global emissions with almost 19% (IEA, 2011). The two next largest emitters – China and India – are not industrialised countries, and, therefore, not included in the Annex I countries. China has overtaken the United States as the world's largest annual emitter in terms of energy related CO_2. These three main emitters contribute to almost half of the world emissions. There are arguments between developed countries and developing countries. Some developing countries like China and India do not want to sacrifice their development by cutting the emissions. These countries have said that the developed countries should be responsible for the high level of emissions. On the other hand, the developed countries want to make sure that developing countries also participate in reducing the world carbon emissions.

The aim of reducing total carbon emissions under the Kyoto Protocol has a loophole due to the issue known as emissions leakage, which can reduce the cost effectiveness and environmental performance of the agreement. Another weakness is found in the incapacity of the targets to deal with the uncertainties surrounding climate change, especially on the side of abatement cost (Philibert, 2004). In this rapidly changing world, the emissions of some fast growing non-Annex I countries have become more than the emissions from some poor Annex I countries. The Kyoto Protocol, with a five-year time horizon (2008-2012), is said to be

using a short-term approach to solve a long-term problem (Olmstead and Stavins, 2011). The environmental issue is a long-term problem, and, therefore, the Kyoto Protocol does not stop at 2012. The next commitment period after 2012 will be introduced with a new international framework that can deliver stringent reductions in emissions.

Despite the weaknesses, the Kyoto Protocol has the strength for using a market-based approach in reducing the global emissions cost. The carbon emission trading that has been implemented among Annex I countries helps to trade the costs between the members in the same emissions trading scheme. Philibert (2004) mentioned that the Kyoto Protocol's main strength lies in its emissions trading feature, which is the key for cost-effectiveness, environmental effectiveness and equity. The involvement of developing countries through CDM can reduce emissions in comparison to business-as-usual trends in non-regulated areas.

The carbon emissions policies aimed to achieve effective environmental control. The implementation of carbon emissions policies requires continuous accurate monitoring in order to ensure that the environmental targets are achieved. In protecting the environment through legislation, it is crucial to ensure that these policies do not entail a high administrative and financial burden to the participating bodies. There are many levels of carbon emissions policies, for instance, at the regional, national and local carbon emission control policies. The different characteristics of the cost structure and carbon emission in different logistics processes will lead to different responses of the business performance to the control policies applied to the business.

The design of the carbon emissions system is affected by the point where emissions are regulated. The system can be upstream, downstream or a hybrid system. The proposals range from far upstream, such as the sale of fossil fuels, to far downstream, such as the purchase of manufactured products and energy by ultimate consumers. In the power industry, the upstream versus downstream discussion has focused on whether to place the burden of compliance on plants that produce electricity, on the companies that distribute power, or even individual consumers. In designing the carbon markets, the principal thing is to ensure that the carbon markets are constructed as a balancing act between the various elements in the loose coalition with three sorts of tension (Paterson, 2012). These tensions are over the stringency of the targets to be pursued, the environmental integrity and the tension regarding the questions between different carbon markets. The first and second tensions are more problematic compared to the third one.

There are two main environmental policies with the main objective being to slow down global warming. The first policy, which employs the market-based approach, is carbon emissions trading. Another important instrument is the taxation of energy according to its carbon content, which is referred to as carbon tax (Ekins and Barker, 2001). The main difference between carbon emissions trading and carbon tax is the price and quantity adjustment. In carbon emissions trading, the quantity of carbon emitted is fixed, and the price of emissions permit adjusts whereby with carbon tax, it is the price of carbon that is fixed, and the quantity of the carbon emitted that is adjusted (Ekins and Barker, 2001). Different policies will have a different impact on the business and all industries, and, therefore, the policy enforcement plays a significant role in managing carbon emissions. Government involvement is the main issue in implementing carbon emission policies since the carbon price and tax rate are highly dependent on government policies. The policies will therefore

significantly affect the cost structure and business performance of reverse logistics as transportation and manufacturing involve a large amount of energy consumption.

Both carbon emission policies are explained in detail in the next part of this chapter.

2.4.1 Carbon Emissions Trading

Carbon emission trading is a trade market mechanism used to control carbon emissions under the Kyoto Protocol. Svendsen and Vesterdal (2003) outlined four main issues in designing a carbon permit trading, which is targeted group, allocation of emission allowances, how to mix emission trading with other instruments and enforcement. In addition, other issues arise regarding monitoring, enforcement and penalties for non-compliance of participants to meet the allowed emissions limit. The carbon market acts as a policy instrument and is politically useful in the response to climate change (Paterson, 2012).

Carbon emissions trading can be divided into various types, such as cap-and-trade, baseline-and-credit and offset (UNEP, 2002). The most widely used is the cap-and-trade system. This system has been widely proposed and implemented in many regions and countries, such as Australia, Japan, New Zealand and the European Union. The European Union Emission Trading System (EU ETS) is the largest emissions system in the world, and, currently, the global frontrunner for a cap-and-trade mechanism (Sorrell, 2010; Haupt and Ismer, 2011).

In the cap-and-trade, an overall carbon emissions limit is defined and allocated by the regulator to each participant in a given period of time (Tietenberg, 2003). The crucial concern in a cap-and-trade system is the carbon permit allocation. There are three main methods to allocate carbon limit, which are grandfathering, benchmarking and public auction (Edwards

and Hutton, 2001). Grandfathering, which is based on historical emissions, is said to be a feasible approach in allocating the emissions permit to each industry sector (Lee et al., 2008). The carbon limit is free and allocated after examining the history of the carbon emissions of a company. Benchmarking is the carbon limit that is calculated based on regulator's judgment. This method is more bureaucratic and difficult to apply in less homogeneous sectors. The public auction is a fairer method and could raise revenue (Edwards and Hutton, 2001). In practice many schemes are likely to use a combination of the carbon permit allocation methods.

The participants in a trading scheme are free to emit the carbon as long as their emissions amount is within their limit, or sometimes referred to as a cap. Participants who face high abatement costs need to buy additional allowances, while participants who face low abatement costs can take abatement action and sell their surplus allowances for a profit (Sorrell and Sijm, 2003). The carbon emission trading market is the place where the participants who have an additional allowance can sell these surplus allowances to the participants who need to buy these allowances. A tradable permit can provide an incentive to reduce total emissions below the allocation in order to benefit from selling excess permits on the open market. The advantage of carbon trading is that some participants can reduce carbon emissions more economically. Other participants that are facing higher costs of reducing emissions can purchase from those participants whose emissions reductions can be made inexpensively (Nordhaus, 2007). The trade, which can be either free or with restrictions, is based on the price of the carbon emission permit according to the demand and supply of carbon emission allowance at the trade market (Lutter and Shogren, 2002).

When a trading programme is restricted to specific participants it is referred to as a closed system, while a trading programme that allows participants to use emission reductions from sources other than the original participants is known as an open system (UNEP, 2002). In an open system, non-participants can earn credits for emission in the emission reduction projects, such as the Clean Development Mechanism (CDM) and Joint Implementation (JI). The aim of the CDM is to assist non-Annex I countries to achieve sustainable development and contribute to the objective of the Protocol, and to support Annex I countries in achieving compliance with their quantified emission limitation and reduction commitments (UNFCCC, 1998). CDM benefits non-Annex I countries, which is normally developing countries to participate in CDM projects to earn carbon emission reductions (CERs) in contributing to sustainable development. These countries have the right to sell their CERs generated to other Annex I countries. The benefit of CDM to Annex I countries may use their CERs for such projects to contribute in compliance with their reduction commitments. A body is needed to monitor these emission reduction projects between Annex I and non-Annex I countries. JI is another mechanism where any party may transfer to, or acquire from any other country's emission reduction units resulting from the emission reduction projects within Annex I countries (UNFCCC, 1998). Any emission reduction unit (ERUs) that is awarded has to be subtracted from the original emission cap to avoid double counting. Therefore, JI has the advantage of being easier to implement since it is within Annex I countries, and, hence, does not require a centralised monitoring body as long as the country complies with international requirements.

According to Droge (2009), pricing instruments can work through two separate channels. The first is by giving incentives for a more efficient production. The second channel is by

changing relative prices further down the value chain. However, carbon leakage can occur through international trade in energy goods, and a shift in production (Droge, 2009).

Carbon emission trading (referred to as cap-and-trade) is an effective approach to combat the negative impact on the environment. A cap-and-trade system sets a clear limit for greenhouse gas emissions and minimises the cost of achieving this target. The cap or carbon limit plays an important role as a reduction target. This cap is created to decline from time to time. A declining cap can provide a firm reduction target and a system for measuring carbon emissions. It can provide an affordable environmental guarantee. With a strong emissions reduction target and clear rules, this policy can achieve environmental goals. Therefore, good planning on carbon caps is a crucial matter.

There are a few drawbacks that have been identified in as much as the cap-and-trade system can have a high fluctuating spot price. The opponents of cap-and-trade said that this policy can never succeed in limiting carbon emissions because a hard cap on emissions would inevitably lead to increases in the cost of energy, which will lead to increasing costs throughout the economy. In a cap-and-trade system, a decision on the cap is the main factor in ensuring the effectiveness of the system. Reyes and Gilbertson (2009) have shown that the decision of cap size can determine whether a cap-and-trade system will be a success or failure.

2.4.2 Carbon Tax

The carbon tax is another policy in which the emitters need to pay for carbon emissions based on the tax rate imposed by the government. The idea of an environmental tax was started 70

years ago by a British economist, Arthur Pigou, with the concept of internalising the economic externality; Pigovian policy responses to the tax on carbon emissions (Mankiw, 2008).

Designing a tax policy is a big challenge. Metcalf and Weisbach (2009) considered three central design issues – tax rate, tax base, and international trade concerns. The main issue in carbon tax designing is configuring the appropriate tax size (Mankiw, 2008). Several researches have been conducted on the size of the tax. Generally, the tax rate is based on different fossil fuels and according to their carbon content. Coal is taxed at a lower rate than petrol and gasoline, which normally has the heaviest tax per tonne of carbon dioxide emitted than other fuels (Pearson and Smith, 1991). According to Herber and Raga (1995) carbon tax calculation is based on a specific tax, including primary and final carbon tax for fossil fuels and for end users in energy production, respectively.

Galinato and Yoder (2010) developed and examined a tax and subsidy regime, which is a compromise between a standard Pigovian tax and traditional indirect subsidy. The revenue from taxes on high-emitting energy sources are used to fund subsidies on low-emitting energy sources. They found that compared to a no tax scenario, with a constrained tax/subsidy from the general tax fund, there is an impact of carbon tax on the participants in terms of the overall amount of tax paid to the government. The implementation of a carbon tax policy should be made by adjustment to the income tax to ensure that a carbon tax is revenue neutral and distributed neutrally.

Komanoff, as published by Yale (2009), said carbon tax can quickly drive across the board transition. For example carbon tax nations can easily offset import price with the border tax adjustment, which cannot be offered by cap-and-trade. The carbon tax system has advantages, for example, this system puts a clear price on carbon emissions for many years ahead since the tax rate is known for a specific period of time. A straight carbon tax at whatever level would be politically acceptable. The straight carbon tax applied in upstream in the energy economy is a more preferable approach to help bring about the long-term decarbonisation of the global economy.

As cap-and-trade, carbon tax also has its opponents. Some drawbacks that were identified from a carbon tax system are about guessing what level of tax might drive the pollution cuts to avert runaway climate change. The amount of carbon emissions that will be reduced is estimated as well, and it may not be sufficient to change the course of global warming. With this scenario, carbon tax cannot guarantee that it can achieve the emissions targets. This model is still untested compared to the cap-and-trade that has been implemented by big emission trading schemes. The simplicity in carbon tax is seen as a different dimension, as, in reality, any tax legislation will be complex and vulnerable to loopholes. With the involvement of politics, the pressure on a carbon tax system will most likely lead to exemptions of sectors and firms, which reduces the environmental effectiveness and drives up costs, as some low cost emission reduction opportunities are left off the table.

2.4.3 Theoretical Background of the Policies

There are some arguments between environmentalists, economists and academics about their preferred policy be it carbon emissions trading (specifically cap-and-trade) or carbon tax.

Each group of supporters tries to emphasise the benefits and drawbacks of each type of policy. Overall, the main advantage of carbon emissions trading is in its clarity concerning emissions reduction while the main advantage of carbon tax is because of its overriding benefit, which is simplicity. In principle, both policies can achieve cost-effective reductions, depending upon the design. An interview was conducted with experts concerning their views on cap-and-trade vs. carbon trading. The difference is summarised in the following table.

Table 2.1: The difference between cap-and-trade and carbon tax (Yale, 2009)

Elements	**Cap-and-trade**	**Carbon tax**
Goal	Clear goal of emissions reduction	Clear goal of using less energy and has direct responses
Revenue	Revenue is likely to be bargained away well before the first trade ever takes place	Clear amount of revenue
Politics	Political pressure will lead to different allocations of allowances, which affect distribution, but not environmental effectiveness and cost effectiveness	Political pressure will most likely lead to exemptions of sectors and firms, which reduces environmental effectiveness and drives up costs, as some low-cost emission reduction opportunities are left off the table
Economy	Specific on high emissions industry	Covers entire economy
Certainty	Delivers emissions certainty by establishing a declining emissions limit based on assessment of the reduction levels required to protect the climate	Cost certainty by setting up a fixed cost on emissions – would not provide the same level of emissions certainty during any given compliance period
Carbon limit	Sets a clear limit – legal limit on pollution	Does not have a carbon limit – guessing the level of tax

Elements	Cap-and-trade	Carbon tax
Environmental effectiveness	Can guarantee achievement of emission target	Provides greater certainty regarding costs
Price	Lets market forces set a price on emissions	A clear price of carbon for years ahead

While many researches focus only on one carbon policy at one time, some researchers use a hybrid policy, which is a combination of carbon emissions trading and carbon tax (Pizer, 2002; Eichner and Pethig, 2009). Pizer (2002) argued that the price controlled by the regulatory body is more efficient than the quantity control in terms of welfare gains. According to him, taxes are much more efficient than permits for controlling GHG emissions. He uses alternative hybrid policies that combine quantity control with an efficiency of prices, by using a tradable permits target but allowing additional permits to be purchased at a fixed trigger price. The results suggest that a hybrid policy is an attractive alternative compared to either a pure price or quantity system. Crals and Vereeck (2005) conducted a research and concluded that a cap-and-trade programme is likely to involve fewer transaction costs than carbon tax if carbon permits are distributed freely, traded on a brokered market and monitored upstream. They mentioned that most countries rely on carbon tax instead of carbon emissions trading.

Zhao et al. (2010) predicted that a self-organized free-market approach at the level of a sector, state, country or continent can provide better control than a top-down regulated scheme in terms of market volatility and monthly pollution peaks. They uncovered a complex trade-off that arises between average emissions (affecting the global climate), peak pollution levels (affecting citizens' everyday health), industrial efficiency (affecting the nation's

economy), frequency of institutional intervention (affecting governmental costs), common information (affecting trading behaviour) and market volatility (affecting financial stability).

Symons et al. (1994) conducted a research regarding the social effects of carbon tax for reducing carbon emissions for the UK economy on the purchasing power and economic behaviour of the household. They considered the distribution of the increased tax burden across consumers. Their analysis was divided into four stages. First, input-output framework was used to assess the likely impact of carbon taxes on fossil fuels upon the prices on consumer goods. Second, the change in price was used to estimate the effect of consumer demand using simulation. Third, carbon emission was calculated and finally the distributional implications of the carbon tax was analysed. Various levels of carbon tax were used and the lowest carbon tax found was £240.50 per tonne.

As a conclusion, cap-and-trade and carbon tax are both good policies, depending on the perspective. Since there are benefits and drawbacks to each, if any policy is chosen to be implemented, the regulating body has to make sure that the benefits are focused on so that the drawbacks can be minimised. A well designed cap-and-trade policy should not be overlooked while a straight carbon tax is preferable in exercising the chosen policy. Different policies can impose various impacts on the logistics service cost structure and decisions of the transportation operations. Therefore the policy enforcement plays a significant role in controlling carbon emissions and transportation performance. The existing research has not presented sufficient quantitative evidence of such impacts of the policies on industry, in particular, on transportation strategies in the food logistics context in which time and perishability is key performance indicator (KPI) (Kageson, 2001; Kampman, 2008). This

research therefore focuses on food logistics service performance in the context of multimodal transportation and application of carbon control policies. The research quantitatively investigates food supply chain speed, as a KPI of performance in time, for delivering foods through selected transportation modes in supply chains, while maintaining cost and environment benefits with various potential carbon control policies.

2.5 GREEN SUPPLY CHAINS

Green supply chain and eco-logistic strategies have attracted greater attention in academic research and industrial practice (Schaper, 2002). Such changes can be seen in intensive research on the multimodal transportation infrastructure and intermodal services to reduce the environmental impacts of transportation activities (Rondinelli and Berry, 2000). In supply chains, however, road transportation is still widely used for most of the transportation process, as it is easier to handle. In multimodal transportation, roads still play an important role in transferring goods to final destinations. Many studies have investigated the cost structure and associated performance in logistics networks. Janic (2007) found that unit costs of the road transportation network are relatively stable with volume. However, the cost with intermodal transportation network decreases as the volume increases. His research concluded that in order to neutralise the effect of higher prices, the service frequencies in medium-distance market must be increased. The above research on the cost performance of logistics services has not considered impact of carbon emission and associated costs. With the increasing concern over business and environmental sustainability, emphasis in research and practice should be given to designing processes that reduce carbon gas emissions and energy consumption (Linton et al., 2007). How the sustainability issue affects the food supply chain design needs more in depth studies. Van der, et al. (2009) studied food supply chain

performance considering food perishability and sustainability. The research simulated a supply chain process considering food quality changes, travel time, and carbon emissions for sustainable food supply chain design. However, when carbon emissions impose cost pressure on business operations, how the strategies and behaviour change in the supply chain and logistics operations has not been sufficiently studied.

Potential policies as legislation with the aim of achieving effective environmental control will exert cost pressure on logistics operations and potentially drive strategic changes in transportation planning (Li et al., 2010). With the potential impacts or pressure, the development of effective carbon control policies would play a significant role in the innovation of logistics services towards sustainable sector specific transportation systems (in this research, the food supply chains). The existing research has not presented sufficient contribution to this purpose. At present, there are many levels of carbon emission policies, from local, regional to global policies. Different characteristics of cost structures and carbon emission in different logistics processes will lead to different responses of the business performance to the control policies applied to the business.

Dealing with multimodal transport emissions is a complex issue because multiple actors with sometimes conflicting interests are involved. Agusdinata et al. (2011) carried out a research with the main objective being to develop an approach to evaluate the overall policy options to reduce CO_2 emissions within the transportation sector by including air and ground modes of transport. An examination and comparison of carbon dioxide emissions of truck-only transportation with intermodal coastal shipping and truck movements was performed by Liao et al. (2009). The results reveal that replacing long-haul truck transport with the intermodal

can significantly reduce carbon dioxide emissions because of the efficiency of maritime fuel. A research was conducted by Li (2011) in which the effectiveness of rail freight transport in reducing logistics costs and carbon dioxide emissions was evaluated. Compared to his work, this research is different in optimising the overall cost and time. In addition, a comparison between two main carbon emission policies and the impact of these policies on both reverse and forward supply chain networks is also investigated in this study.

2.6 CONCLUSION

This chapter has reviewed the literature related to reverse logistics, forward logistics with multimodal transportation planning. It has also investigated the different types of carbon emission policies that have become a major factor after the Kyoto Protocol in 1997. A considerable amount of literature has been reported on reverse logistics, and multimodal transportation planning. Carbon emission policies, however, has not been widely reported in the literature due to the debates on the carbon policies. There are critics concerning the implementation of carbon policies, as discussed in the global carbon market forum.

Reverse and forward logistics supply chain networks are directly involved with transportation, which, therefore, has a positive impact on the environment. Since the carbon emissions policies have been legislated in order to reduce the impact of carbon emissions on the environment, the study of the network of reverse and forward logistics is an important issue. The benefits and drawbacks for both policies is reported in this chapter.

To help in filling the gap in the literature, this study will investigate the impact of carbon emissions policies on the network of reverse and forward logistics specifically in paper recycling and fresh produce industry in the UK. Although abundant research has been done on the paper recycling network and multimodal transportation planning, this study looks at the implementation of carbon emissions policies and the impact of these policies on the cost and time that might affect the strategic and operational decision making. This study contributes by quantifying the value of carbon emissions in monetary value and minimises carbon emission cost together with other costs involved in the supply chain network.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter shows the methodological part of the thesis. It starts with the research design of the study followed by the method used for analysis. The chapter then continues with methods employed for data collection strategies for both the reverse and forward logistics supply chain networks. Finally, this chapter explains about the research process involved in both cases.

3.2 RESEARCH DESIGN

This research is a quantitative research that uses mathematical models to optimise the network performance. Prior data collection and analysis techniques can be determined with the consideration of several issues to be completed beforehand (Limpanitgul, 2009). A research can be conducted by using the analytical or descriptive method; analytical methods are used in this analysis.

The problem of the research is first identified in designing the research. A plan or research design is an important initial step in the research process. A research design is a logical plan for getting from defining the initial set of questions to be answered, to drawing some set of conclusion (Yin, 2003). According to Churchill (1979) research design can provide the overall guidance for the next step, such as data collection and the analysis of data in a study.

Figure 3.1 illustrates the process involved in conducting this study. After the research problem is identified, a review of the literature is prepared in order to ascertain the research that has been conducted in the same field of study. This research combines several research areas for instance reverse logistics, forward logistics, multimodal transportation planning and carbon emissions. Based on the literature, the research questions were developed. After that several interviews were conducted with paper recycling and fresh produce companies. Then the optimisation models for both reverse logistics and forward logistics were formulated. In order to run these mathematical models, data were needed. The data collection included both primary and secondary data. After the results were obtained, another interview was conducted with the company for validation. Finally, the conclusions were made with the suggestions for future research.

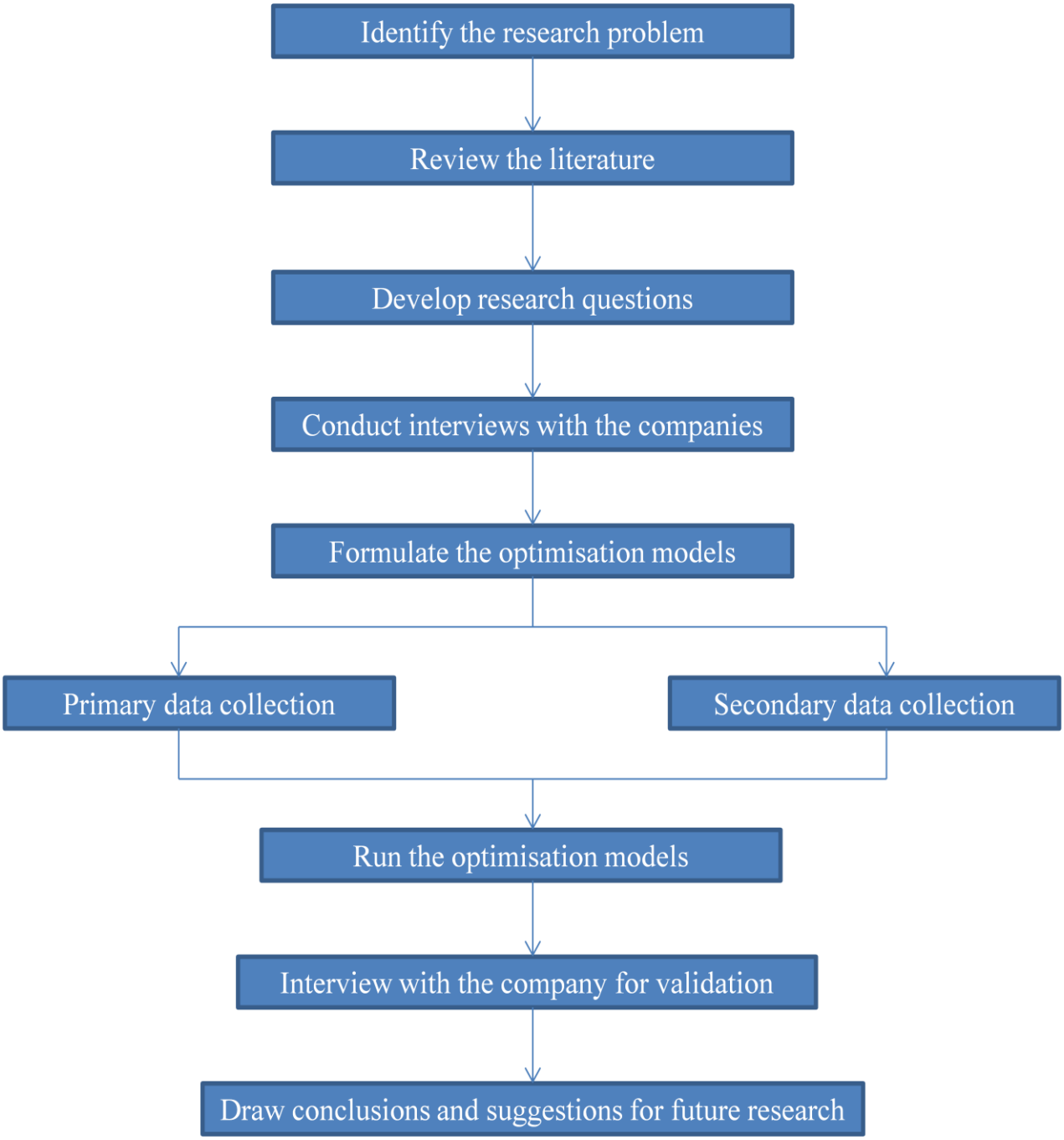

Figure 3.1: Research design

3.3 MATHEMATICAL MODELLING METHODOLOGY

The methodology that has been selected for conducting this research is mathematical modelling. Two models are used, representing the reverse and forward logistics supply chain networks. The advantage of mathematical modelling is the capability of having the required degree of precision because the results generated are in an exact and precise form (Pacut, 1980). Two optimisation models are developed using mixed integer linear programming (MILP). Optimisation models are widely used in solving network design and strategic planning related studies (Luathep et al., 2011; Singh et al., 2012; Liu et al., 2011) and multimodal freight transportation problem (Yamada, 2009; Caramia and Guerrioro, 2009).

Several interview sessions were conducted with the companies for the purpose of obtaining the information and primary data as well as for validation. The initial stage of interviews is about the general background information of the company and the overall strategy. For the forward logistics case, this information is transportation costs, the location of regional distribution centres with the capacity and the ports that have facilities to handle fresh produce.

3.4 SOURCE OF DATA

The methodological choice in terms of source of data is broadly between primary and secondary data. Churchill (1979), and Iacobucci and Churchill (2005), provided a definition of primary data and secondary data. Primary data are originated by the researcher for the purpose of the intermediate investigation in hand while secondary data are defined as the existing data and statistics, and, therefore, provide advantages over primary data in terms of

cost and time. The disadvantage of secondary data is that it may have problems with accuracy because the data were collected for other research purposes.

3.4.1 Primary Data

The primary data constitute the information that is collected through direct observation, personal interviews, and questionnaires or through conversations. Generally, these data are collected by the researcher in a research work and collected during the research time. This data are very important in creating the understanding for the researchers on the project.

In this study, primary data were obtained from interview sessions with both companies – a paper recycling company in Kent and a fresh produce company in Liverpool. Four emails and telephone communications with paper recycling company and five interview sessions with fresh produce company were conducted. The managers were kind enough to answer most of the questions and provide a lot of valuable information. The primary data that were obtained from the paper recycling company for the reverse logistics case study concern the general operations and carbon emissions. For the forward logistics case, the primary data collected from the company include the locations of the regional distribution centres (RDCs), the demands for each RDC and road transportation cost. Based on these locations, the distance and time between each port and RDC were obtained using Google maps. The time between each port to the RDC was established from the National Rail website. Since there was no distance between the ports to RDCs from the website, the distance was estimated to be 10% less than the distance for road transportation because, generally, railways follow a straight line compared to roads. The process involved and details of the operations are given through the interviews. Most of the data for forward logistics are primary data.

3.4.2 Secondary Data

Secondary data are the data that come from documents, books, scientific articles, white papers, websites and other historical records that are relevant to the research conducted. The secondary data about the research area were mainly gathered from white papers that have been published by the government and the companies in related industries. Other sources are from numerous scientific articles, books and annual reports, as well as online company information that is published on the websites. The advantage of secondary data is that it can save cost and time (Iacobucci and Churchill, 2010).

The data about paper recycling in the UK, such as demand, total paper consumption, paper price, and types of paper were obtained from the white paper published by WRAP (2007 and 2010). The material recycling facilities, paper mills, locations and capacity for each paper mill were obtained from online company information. There are many material recycling facilities and paper mills in the UK. Out of all material recycling facilities and paper mills, some of them were manually selected in the study based on their location throughout the United Kingdom. The selection of these material recycling facilities and paper mills covers Northern Ireland, Scotland, Wales, North England, Midlands and South England. The total capacity of the chosen paper mills amounted to half of the capacity mentioned by WRAP 2010. The carbon emissions trading price was obtained by daily monitoring of the carbon price on the website from December 2009 to August 2012. The average of these prices was used in the analysis.

Carbon emissions data is one of the key elements in this study. The paper recycling company is paying for carbon charges but is reluctant or does not really understand the carbon charge

in detail. The fresh produce company that we are dealing with does not use any carbon emissions data in their operations. Therefore, in order to run the optimisation models with carbon cost, carbon emissions data were obtained from secondary sources. Carbon auditing is a relatively new science and still evolving. To obtain carbon emissions data is quite challenging. Since this is quite a sensitive issue, probably due to the errors that have been made in the past, there is a tendency not to publicise the statistics (McKinnon and Piecyk, 2009). Generally, the reverse logistics case uses more secondary data than the forward logistics case in this research project.

3.5 OPTIMISATION – SENSITIVITY ANALYSIS

The optimisation model is formulated and minimises the total cost. These costs are the transportation cost, production cost, carbon emission cost related to transportation and production, purchase cost. Sales revenue is taken into consideration because of the income from the export of waste paper.

In order to employ an efficient transportation network and the impact of carbon policies, sensitivity analysis was used to see the impact of changes in the network behaviour. Therefore, the combination of optimisation-sensitivity analysis procedure was used. Lourenco and Soto (2002) employed optimisation and simulation for a recoverable production planning system for a production environment within an integrated logistics network. The simulation model evaluated the results obtained from the optimisation model. His study was used as a reference for the optimisation-sensitivity analysis. Sensitivity analysis was done in order to determine the impact of carbon policies on the network. Since

there is limited historical data, sensitivity analysis is an appropriate tool for modelling for this kind of problem.

The design of the paper recycling network is at a strategic level and concerns decisions in respect of the location, capacity, the number of material recycling facilities and the number of paper mills. The processes considered in the network are sorting, reprocessing, and remanufacturing.

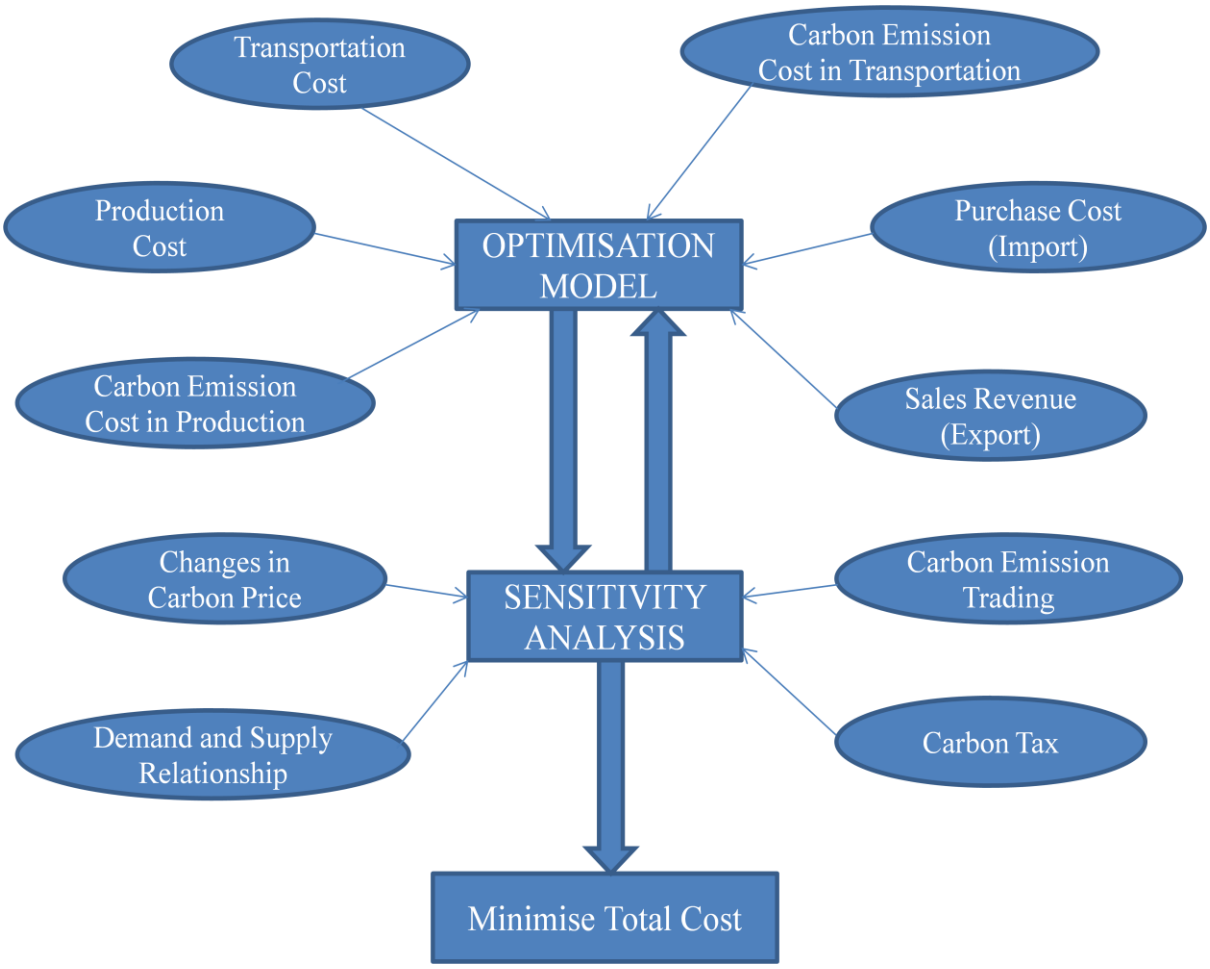

Figure 3.2: Optimisation – sensitivity analysis process for reverse logistics

The optimisation-sensitivity analysis process, as in Figure 3.2, was modified based on the process proposed by Cheung (2001) and has been used by Lourenco and Soto (2002). Lourenco and Soto (2002) developed a model that takes advantage of the synergies of integration, developing a model for global production planning that generates the optimal production and purchasing schedule for all the companies integrating a logistic chain. Then, they incorporate products returns to the model proposed, and analyse the implications. They use some examples with different configurations of supply chains varying the number of production plants, distribution centres and recovery plants. The combination of optimisation and simulation give insights on the relationship between the several elements of the production process in terms of the quantity of product on inventory, the production and purchasing schedule, and the total costs of the systems.

In this research, a mathematical model, namely, mixed integer linear programming (MILP) model is used to find the optimal solution. MILP is an established operational research method for finding an optimal solution in allocation problems. Agha (2006) minimises the total distance travelled by the collection vehicles. Results show that the application of the model improves the collection system by reducing the total distance by 23.47% thus saving around US$1140 per month. Fleischmann et al. (2001) used MILP facility location model to analyse the impact of product return flows on logistics networks. They found that the impact of the return flows increases with the economic incentive for product recovery. Spengler et al. (2003) consider the interactions between choice of scrap to be recovered, disassembly and bulk recycling using a mixed-integer linear programming model to determine the daily allocation of products to processes for a major electronic scrap recovery centre that faces limited processing capacities and market restrictions. The optimisation calculations covering

typical discarded electronic products to be recycled in the related centre lead to a relevant improvement of the economic success.

Based on the literature and the nature of this problem, MILP is selected to be used in this study. The objective of the model is to minimise the total cost with constraints on carbon limit and the capacity of the local paper mills. Sensitivity analysis was subsequently conducted in order to observe the impact of the carbon charge on the network behaviour using both carbon emissions trading and carbon tax policies.

Optimisation models are widely used in solving the forward logistics supply chain network case as well. In this case, sensitivity analysis was also applied. However, the focus is more on the operational level of decision making. The difference between the forward logistics and reverse logistics case in the research study is that the forward logistics includes another variable, which is time, and the impact of carbon policies on different modes of transportation. Banomyong and Beresford (2000) used four main elements in their MILP model: cost, time, distance, and mode of transportation. The optimisation modelling minimises the total cost and travel time for the fresh produce industry in the UK.

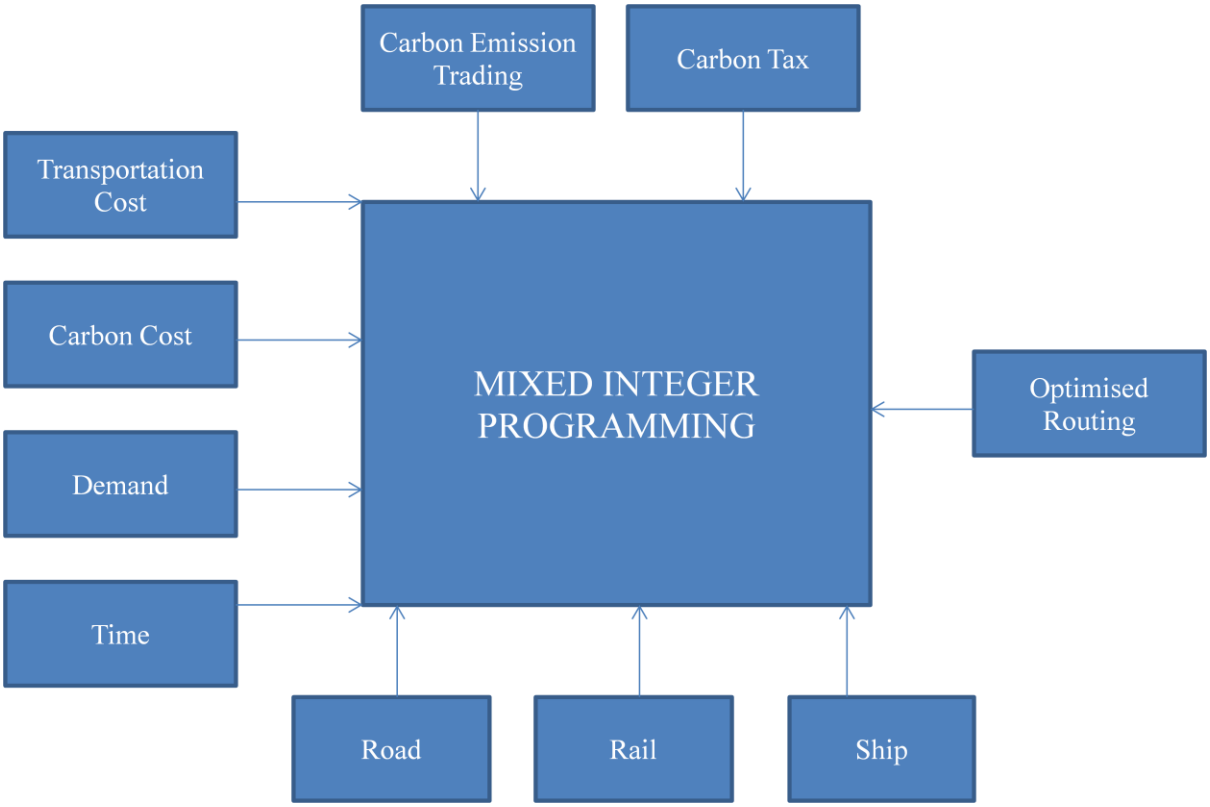

Figure 3.3: Optimisation model for forward logistics

Figure 3.3 shows the optimisation model that has been formulated for the fresh produce industry in forward logistics. Four variables – transportation cost; carbon cost; demand, which refers to the capacity of all regional distribution centres; and travel time between the ports and regional distribution centres – are included. The two arrows from above show that the impact was tested with two carbon policies. The arrows from below demonstrate the different transportation modes, which are road, rail (plus road as a multimodal transportation planning) and ship for sending fresh produce to Northern Ireland. The model was optimised to find an optimal routing that minimises the total cost and travel time.

3.5 SUMMARY

The aim of this chapter was to present a discussion about the research methodology that has been adopted in this research study. The presentation of the overall research design described the steps involved in this research process. The source of data was described for both the primary and secondary data. The optimisation-sensitivity analysis was the approach applied in carrying out the analysis.

Two case studies were employed in this research, namely, paper recycling and the fresh produce industry in the UK. Both cases represent reverse and forward logistics supply chain networks. The models were optimised using MILP and the sensitivity analysis is carried out in order to see the impact of carbon emission policies on both networks.

CHAPTER FOUR

MODEL DEVELOPMENT

4.1 INTRODUCTION

This chapter shows the models developed in both the logistics – closed-loop and open supply chain networks. The impact of carbon emission policies on these logistics is examined. Logistics in a closed-loop supply chain is based on the paper recycling industry. In the UK, paper is collected from the home and office and sent to material recycling facilities (MRFs), and after that to paper mills. These recycled papers are made into new products to enter the market again. Some of the waste paper is processed locally and the rest is exported overseas for recycling activities. In this study, the different categories of paper grades are not used, and, instead, the average is used.

For the open supply chain, a forward supply chain is investigated, which is the fresh produce industry. Fresh produce is imported from overseas and distributed to the UK market using different modes of transportation.

4.2 REVERSE LOGISTICS SUPPLY CHAIN NETWORK

Reverse logistics activities mainly include collection, sorting, reprocessing and redistribution. To optimally design a reverse logistics network, the primary factors involved in the decision making would be the locations of the processing (or recovery with which the disposed products are remanufactured to regain the product value) and sorting centres, collection and distribution routes and transportation modes (Mutha and Pokharel, 2008). In this paper, the

research mainly focuses on the impact of carbon emission control policies on the design of the reverse logistics network and the performance in relation to both the environment and operational efficiency. For this purpose, a network optimisation model is built to evaluate the logistics performance under various scenarios in relation to the strategic arrangements of a reverse logistics network in the waste paper recycling context in the UK.

As a strategic analysis, the network design will not elaborate on the detailed cost components in operations, such as fixed costs, differences of processing costs and handling costs between different centres, etc. Instead, the research focuses on the impact of different carbon emission policies and recycling strategies (e.g. Selecting different local and overseas recovering centres) on the environment (carbon emissions) and operational performance, with the diversity in delivery distance and transportation routes. The investigation particularly looks at how the selection of carbon emission policies shapes the recycling strategies and network configurations differently. Figure 4.1 illustrates the problem scope that this part of the research focuses on. The paper recycling industry is used to represent the reverse logistics case.

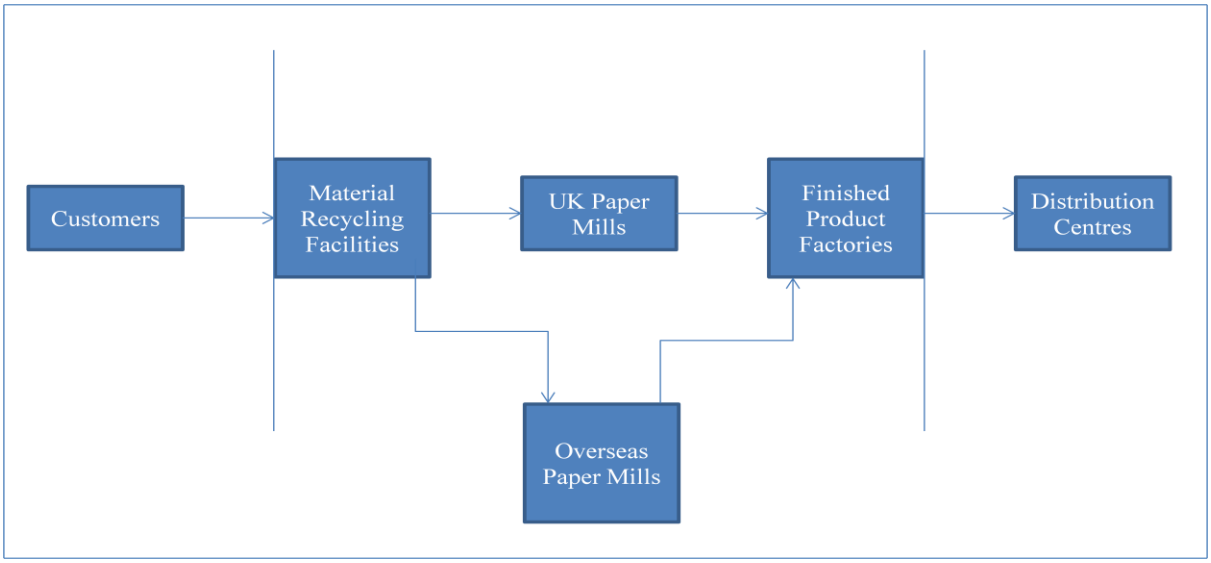

Figure 4.1: Reverse logistics network for paper recycling in the UK

The optimisation model has been developed through the commonly used mixed integer linear programming. The objective function targets to minimise the total cost, which involves two parts: environmental costs and logistics operational costs. The environmental costs include tax, penalty and carbon credit purchase in relation to carbon emission from the recycling activities. The operational costs include production costs, and transportation costs. Some recycling costs, such as collection and sorting costs are not included in the model, as the costs will not contribute to or differentiate the decision process and results – they are incurred anyway, no matter what recycling strategy (i.e. Select local or overseas recovery centres) is adopted or which transportation modes and routes are selected. Costs associated with business opportunities (e.g. Shipping options lead to a much longer lead-time for customers when compared with rail freight) are also ignored in the modelling.

Binary variables are used in the model to select the transportation modes, routes and locations of the paper mills that recover the scrap paper. The most commonly used tax and cap-and-

trade carbon emission control policies are used to investigate the impacts of the environmental incentives on business performance, and simulate business reactions to policy changes. In this research, it is assumed that under the specified carbon emission limit of the carbon emission trading scheme, there is no cost incurred. The businesses will only pay when their overall carbon emission exceeds the limit. On the other hand, carbon emission tax has to be paid for all carbon emissions in the business. The constraints of the model include the UK demand on paper, processing capacity and carbon emission limit. The optimisation model is described as follows:

Objective function = Minimise total cost

Subject to constraints:

(1) Local processing + export = Total supply

(2) Amount sent from MRF ≤ Capacity in a MRF

(3) Amount sent to paper mill ≤ Capacity in a paper mill

(4) Import = Demand –Local recovered paper

Total cost = Local transportation cost + paper mill operation cost – selling profit + import cost + import transportation cost + carbon emissions cost from local transportation, operation in paper mill and import transportation.

In mathematical form:

$$Min\ C =$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m}\left(TC_{i,j} * YM_j * X_{i,j}\right) + \sum_{k=1}^{p}\sum_{i=1}^{m}(TC_{i,k} + YT_k * X_{i,k}) + \sum_{j=1}^{n}\sum_{i=1}^{m}(OC_j * YM_j * X_{i,j}) -$$

$$\sum_{k=1}^{p}\sum_{i=1}^{m}\left(SV_{i,k} * SP\right) +$$

$$k=1pIMk * PP+k=1pTCk*YTk*IMk+$$

$$(((j=1ni=1mCEi,j*YMj*Xi,j)+(k=1pi=1mCEi,k*YTi,k*Xi,k)+(k=1pCEk*YTk*IMk))$$

$$+-CL)*CC \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n}\sum_{i=1}^{m} X_{ij} + \sum_{k=1}^{p}\sum_{i=1}^{m} X_{i,k} = SSi \qquad (2)$$

$$\sum_{i=1}^{m} SS_i \leq M_i \qquad (3)$$

$$\sum_{j=1}^{n} DD_j = N_j \qquad (4)$$

$$\sum_{k=1}^{p} IM_k = D - \sum_{j=1}^{n} RV_j \qquad (5)$$

$$X_{i,j}, X_{i,k}, SV_{i,k}, IM_k \geq 0 \qquad (6)$$

$$YM_j, YT_i \in \{0,1\} \qquad (7)$$

Parameters:

i = Paper mills index

j = MRF index

p = Port index.

X_{ij} = Quantity sent from MRF i to paper mill j

X_{ik} = Quantity sent from MRF i to port k

TC_{ij} = Transportation cost from MRF i to paper mill j

TC_{ik} = Transportation cost from MRF i to port k

OC_j = Operation cost at paper mill j

SV_{ik} = Quantity exported from MRF i through port k

SP = Selling price

IM_k = Quantity import through port k

PP = Purchasing price

TC_k = Import transportation cost through port k

$CE_{i,j}$ = Carbon emissions for transportation from MRF i to paper mill j

$CE_{i,k}$ = Carbon emissions for transportation from MRF i to port p

CE_k = Carbon emissions for import transportation through port k

CL= Carbon limit

CC = Carbon charge

YM_j = 1 if paper mill i is employed, 0 otherwise

YT_k = 1 if port k is employed, 0 otherwise

SS_i = Total supply from MRF i

M_i = Capacity in MRF i

DD_j = Total demand at paper mill j

N_j = Capacity in paper mill j

D = Demand

RV_j = Total recovered paper from paper mill j

Assumptions in this model:

i. The demand for recovered paper in this model is about 50% of the overall paper demand in the UK, which is 14 million tonnes (WRAP, 2007).

ii. The carbon limit for this model is arbitrarily used at 100 tonnes.

iii. Carbon tax is used at £17 per tonne, an estimated value based on the French tax rate (Library of Congress, 2012).

iv. The transportation cost and carbon emission cost for export transportation is at the seller's expense.

v. The amount of carbon emission over the given limit can be either charged with a penalty (carbon emission tax) or covered by purchasing credits from the market at the current price by the cap-and-trade scheme (Kageson, 2001).

4.2.1 Paper recycling network development

Paper recycling is one of the common recycled materials nowadays. In designing the paper recycling network, material recycling facilities (MRFs) and paper mills in the UK are

identified. There are eleven MRFs and nine paper mills selected in the model. These MRFs and paper mills are chosen in every region of the UK – Northern Ireland, Scotland, Wales and England– from the main paper recycling companies. The locations of the MRFs, together with their capacity, were obtained from the company websites and are shown in Table 4.1.

Table 4.1: MRFs location and capacity

Region	**MRFs**	**Capacity (tonnes)**
Northern Ireland	Craigavon	50,000
Scotland	Kirkcaldy	30,000
	Inverness	10,000
	Irvine	30,000
Wales	Chester	30,000
	Caerphilly	1,700,000
England	Kent	1,300,000
	Southampton	200,000
	Tilbury	312,000
	Coalville	45,000
	Dewsbury	70,000

Table 4.2 shows the locations of paper mills located in Scotland, Wales and England. There is no paper mill in Northern Ireland because all the waste paper is sent to Great Britain or the UK mainland for recycling activities. The capacity is obtained through a secondary source and is summarised as in Table 4.2.

Table 4.2: Paper mill location and capacity

Region	Paper Mill	Capacity (tonnes)
Scotland	North Ayrshire	280,000
	Croy	96,000

Wales	Deeside	520,000
England	Sittingbourne	325,000
	Watchet	325,000
	Darwen	325,000
	Cullompton	325,000
	Birmingham	250,000
	Kent	250,000

Some of the waste paper from the UK is exported to be recycled overseas. In this model, China is considered as the overseas market because China is the largest foreign buyer of recycled paper from the UK. In 2010, the Confederation of Paper Industries (CPI) mentioned in their annual report that 61% of waste paper from the UK are exported to China. The main UK ports are chosen for export routes, namely, Grangemouth, Liverpool, Southampton, and Felixstowe.

The distance between each MRF to each paper mill for local processing and from each MRF to each port for export were obtained using Google maps. The carbon emission cost was calculated based on the distance from MRFs to paper mills and ports. Only road transportation is used for transportation from MRFs to paper mills and ports. From the interviews with a paper recycling company, rail is not practical for delivering waste paper because the UK has a restricted loading gauge and the network is over-loaded with passenger traffic. Further, rail is unable to backhaul finished goods and raw materials making it uncompetitive for paper and waste paper products. For sea transportation, ships are used to deliver waste paper from Northern Ireland to the British mainland and for export to other countries.

4.2.2 Carbon emission cost in road transportation

The calculations of carbon emissions in the road freight network have to be defined with respect to the type of vehicle used, type of trucking and geography (McKinnon and Piecyk, 2009). Heavy goods vehicles (HGV) are used for delivering the waste paper from the MRFs to the paper mills or to the port. For types of trucking, since we are interested in total cost, trucking could be hired and reward or own account. Geographic position determines how the carbon is charged, as different regions have different ways of dealing with the carbon emissions cost structure. However, in the UK the carbon charge is considered to be uniform throughout the nation.

Waste paper is distributed using containers. The standard weight of the container is 4 tonnes whereas the loaded paper is restricted to around 25 tonnes per container, and the typical vehicle used is a 44-tonne articulated diesel truck (WRAP, 2008). The emission factor for a 29 tonne truck is 47.1g CO_2/tkm (WRAP, 2008). With the emission factor in tonne kilometre, the calculations of carbon emissions for each journey are calculated by multiplying the weight transported and distance travelled (McKinnon, 2007). The overall amount of carbon emissions resulting from delivering one truck load of paper is calculated, as in the table below, with the example from North Ayrshire to Kirkcaldy:

Table 4.3: Carbon emissions from delivering paper from MRFs to paper mills

Route	Emission Factor (kg CO_2/tkm)	Distance (km)	Emission (kg CO_2/t)	Weight of Paper (tonne)	Total Emission (kg)
North Ayrshire to Kirkcaldy	0.0471	137	6.42	25	161.32

4.2.3 Transportation cost for delivering waste paper from MRFs

i) MRFs to the local paper mill and ports using road transportation

Waste paper that has been collected and sorted is sent from the MRFs to the local and overseas paper mills using road transportation. The fixed and variable transportation costs are obtained from the company. Since the paper mills are located in different regions, the road delivery is mainly undertaken through national motorways.

ii) UK ports to the overseas port using sea transportation

The typical maritime container used to store paper has a self-weight of 4 tonnes, with an inside capacity of 25 tonnes, which is the same type of container that has been mentioned before. The first step in planning such an international movement of goods is to transport the sorted paper from the MRFs to UK ports by using the road.

The majority of paper mills in China are concentrated in Guangdong Province, which is located on the south coast of China. Thus, this research focuses on measuring the amount of carbon emissions based on the assumption that ships leaving the UK are destined to arrive in China via Shekou port, Guangdong Province. The transportation cost is obtained from the Hapag-Lloyd website, one of the largest container shipping lines in the world. The transportation cost from all UK Ports to Shekou Port incurs the same amount of cost. Details of the freight charges and total transportation costs are illustrated below:

Table 4.4: Freight charges between China Port to UK Port and vice versa

Freight Charges from China Port to UK Port	20’ (Per Container)	Currency	20’ (£) / TEU
Terminal handling charge origin	141	USD	85

Seafreight	1025	USD	616
Document charge	150	CNY	13
Bunker charge (BAF)	487	USD	293
Low sulphur fuel surcharge sea	15	USD	9
Emergency surcharge	25	USD	15
Suez Canal transit charge	9	USD	5
Emergency bunker surcharge	92	USD	55
CAF seafreight	16	%	98.56
Carrier security fee	8	USD	5
Terminal handling charge destination	120	GBP	175
Administration fee destination	17	GBP	17
TOTAL			1386.56

4.2.4 Operational cost

The operational cost includes all costs, such as fixed costs (machinery and capital investment), and variable costs (labour cost, electricity usage, carbon emission cost). The operational cost is assumed to be uniform with respect to all paper mills.

Other data used in the model are the total paper consumption in the UK, which amounted to 13.2 million tonnes in 2008 (WRAP, 2010). The price of recovered paper varies according to the grade and ranges from £52 to £69 per tonne. The price used in the model is £60 per tonne (WRAP, 2010).

4.3 FORWARD LOGISTICS SUPPLY CHAIN NETWORK

The logistics used in the open supply chain is forward logistics for the fresh produce industry in the UK, which is the opposite way of reverse logistics, as explained in Section 4.2. The fresh produce is brought into the UK market from major UK ports and distributed to local regional distribution centres.

A mathematical model has been developed with the objective function being to minimise the total cost, which covers transportation cost, carbon emissions cost and time with the consideration of two policies, which is carbon emissions trading and carbon tax. The different modes of transportation used in this study are road, rail and ship. Road and road plus rail options are used for distribution in the UK mainland while the ship is used for distribution to Northern Ireland. The optimisation model transports fresh produce in a full 40-foot refrigerated container.

Objective function = Minimise total cost and time

$$Min\ C = \sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{i=1}^{m}\left(TC_{i,j} + YT_{i,j,k} + X_{i,j,k}\right) + \sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{i=1}^{m}(CE_{i,j} * YT_{i,j,k} * YP_{i,j,k} - CL)^{+} * CC + \sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{i=1}^{m}(TT_{i,j} * YT_{i,j,k} + HT_{i,j} * YT_{i,j,k} * X_{i,j,k}) \quad (8)$$

Subject to:

$$\sum_{j=1}^{n} TT_{i,j} * YT_{i,j} \leq RT_i \quad (9)$$

$$\sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{i=1}^{m} X_{i,j,k} = D_i \quad (10)$$

$$X_{i,j,k} \geq 0 \quad (11)$$

$$YT_{i,j,k} \in \{0,1\} \quad (12)$$

$$YP_{i,j,k} \in \{0,1\} \quad (13)$$

Total cost = Transportation cost + carbon emissions cost

Parameters:

i = Cluster index

j = Transportation mode

k = Carbon emissions policies

$X_{i,j,k}$ = Quantity sent to cluster i using transportation mode j at the time t

$TC_{i,j}$ = Transportation cost to cluster i with transportation mode j

$TT_{i,j}$ = Travel time to cluster i with transportation mode j

$HT_{i,j}$ = Handling time to cluster i with transportation mode j

$CC_{i,j,k}$ = Carbon emissions cost to cluster i with transportation mode j and carbon policy k

$YT_{i,j,k}$ = 1 if transportation mode j is used, 0 otherwise

$YP_{i,j,k}$ = 1 if policy k is chosen, 0 otherwise

RT_i = Required time for sending to cluster i

CE = Carbon emission

CC = Carbon charge

D_i = Demand at cluster i

The objective function is normalised before the model is run because of different units for cost and time. Excel Solver is used as the optimisation tool. There are four constraints involved in this model. Constraint (9) is travel time to each cluster must not be more than required time so that it does not have an impact on the shelf life. Constraint (10) which is that the demand at regional distribution centres (RDCs) must be fulfilled. Constraint (11) is a non-negativity constraint while constraints (12) and (13) are binary constraints referring to transportation mode and types of carbon policy.

4.3.1 Multimodal transportation network development

Multimodal options used fresh produce distributions from all processing facilities that located at the UK Ports to RDCs are road only and road plus rail options. For the second option which is road plus rail, rail in the main transportation mode with road at the end of the network in order to reach the final destinations. Due to the geographic difference, RDCs Northern Ireland has a different transportation route from the other RDCs located on the UK mainland. The fresh produce is sent through the ship to Belfast Port before they are sent by road to RDCs. Therefore the multimodal option is ship plus road.

Six ports are used as distribution points for the UK market – Southampton, Felixstowe, Tilbury, Bristol, Immingham and Liverpool. The UK's regional distribution centres (RDCs) are located throughout the UK. The RDCs that are located next to each other are grouped into a cluster and divided into sixteen clusters according to the location of the RDCs given by the

company. The location and capacity of cases per week for each cluster is described in the following table.

Table 4.5: UK regions with clusters division and capacity

Clusters	Regions	Capacity (cases per week)
Cluster 1	All Northern Ireland	118,145
Cluster 2	All Scotland	4,465,531
Cluster 3	All Wales and close area	4,616,345
Cluster 4	All North East	2,681,395
Cluster 5	All Yorkshire & Humber	4,041,583
Cluster 6	Liverpool, Manchester	4,757,744
Cluster 7	Crewe, Stoke	1,976,509
Cluster 8	Birmingham, Coventry, Lutterworth, Alfreton	5,746,442
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	8,676,619
Cluster 10	Bristol, Trowbridge, Wellington, Tewkesbury	2,000,476
Cluster 11	Plymouth	92,310
Cluster 12	Cambridge, Thetford, Peterborough	673,633
Cluster 13	Southampton, Portsmouth	1,771,416
Cluster 14	Andover, Didcot, Bracknell, Farmborough	5,105,216
Cluster 15	Brent, Weybridge, St Albans, Harlow	2,470,750
Cluster 16	Maidstone, Crawley, Grays	7,213,865

A virtual location is created based on the location of all RDCs in each cluster. This location is calculated using the concept of the gravity model. The average distance is calculated between

the ports to all RDCs with the weighted capacity. This concept is applied in the calculation of the short road distance in multimodal transportation (rail plus road), as well as time average for both road and multimodal options. Cluster 7 is used as an example of the calculations.

Table 4.6: Distance (km) between ports to all RDCs in Cluster 7

Port \ RDC postcode	CW10 0TE	ST7 5UH	ST21 6SL
Southampton	201	190	173
Felixstowe	223	213	196
Tilbury	201	191	174
Bristol	116	133	116
Immingham	143	137	135
Liverpool	47.5	55.9	73.2
Capacity	1,450,674	363,461	162,374

There are three RDCs in Cluster 7. The distance was obtained using Google map. The virtual point calculation uses this formula.

Virtual point distance from Port *i*,

$$\frac{\sum_{i=1}^{3} d_i * c_i}{\sum_{i=1}^{3} c_i}$$

Where *d* = distance, *c* = capacity.

Therefore, the distance between each port to a virtual point in Cluster 7 is calculated as in the next table.

Table 4.7: Distance between ports to virtual point in Cluster 7

Port	Distance (km)
Southampton	197
Felixstowe	219
Tilbury	197
Bristol	119
Immingham	141
Liverpool	51

The travel time from all ports to each cluster is obtained using the same approach. The virtual point time for Cluster 7 is as shown in Table 4.8.

Table 4.8: Travel time (hours) between ports to all RDCs in Cluster 7

Port \ RDC postcode	CW10 0TE	ST7 5UH	ST21 6SL
Southampton	3.5	3.42	3.13
Felixstowe	3.83	3.77	3.47
Tilbury	3.37	3.3	3
Bristol	2.07	2.37	2.07
Immingham	2.52	2.63	2.63
Liverpool	0.98	1.17	1.45
Capacity	1,450,674	363,461	162,374

Travel time to virtual point from Port *i*,

$$\frac{\sum_{i=1}^{3} t_i * c_i}{\sum_{i=1}^{3} c_i}$$

Where *t* = time, *c* = capacity.

Therefore, the travel time between each port to a virtual point in Cluster 7 is calculated as in the next table.

Table 4.9: Travel time between ports to virtual point in Cluster 7

Port	Time (hour)
Southampton	3.45
Felixstowe	3.79
Tilbury	3.33
Bristol	2.13
Immingham	2.55
Liverpool	1.05

Road transportation is the traditional form of transportation network while rail and ship transportation in this study are for multimodal transportation planning with a combination of rail plus road and ship plus road. In multimodal transportation, road is considered to reach the final destination. We did not include road transportation in the beginning of the multimodal transportation planning because most of the ports have access to rail.

The weight of loaded fresh produce provided by the company is 24 tonnes. Adding the standard weight of empty containers of 4 tonnes makes 28 tonnes in a journey. The emission factor for a 29 tonne truck is 47.1g CO_2/tkm (WRAP, 2008). Therefore 47.1 times 28 tonnes and divided by a 29 tonne truck gives the emission factor for road transportation to be 45.5g CO_2/tkm. The calculation of total carbon emission per container is shown for Cluster 7 as an example.

Table 4.10: Carbon emission for delivering fresh produce from the Ports to Cluster 7 using road

Cluster 7 from Port	Road Emission Factor (kg CO_2/tkm)	Road Distance (km)	Road Emission (kg CO_2/tkm)	Weight of goods (per container)	Total Emission (kg)
Southampton	0.0455	315	14.33	24	343.98
Felixstowe	0.0455	350	15.93	24	382.2
Tilbury	0.0455	315	14.33	24	343.98
Bristol	0.0455	191	8.69	24	208.57
Immingham	0.0455	226	10.28	24	246.79
Liverpool	0.0455	82	3.73	24	89.54

According to WRAP (2008), the rail emission factor ranges from 13.9g CO_2/tkm to 49g CO_2/tkm. The emission factor used in this study is the mid-point of the range, which is 32g CO_2/tkm.

Table 4.11: Carbon emission for delivering fresh produce from Ports to Cluster 7 using rail

Cluster 7 from Port	Rail Emission Factor (kg CO_2/tkm)	Rail Distance (km)	Rail Emission (kg CO_2/tkm)	Weight of goods (per container)	Road Emission Factor (kg CO_2/tkm)	Road Distance (km)	Road Emissions (kg CO_2/tkm)	Total Emissions (kg)
Southampton	0.032	315	10.08	24	0.0455	4.87	0.22	247.24
Felixstowe	0.032	350	11.2	24	0.0455	4.87	0.22	274.12
Tilbury	0.032	315	10.08	24	0.0455	4.87	0.22	247.24
Bristol	0.032	191	6.11	24	0.0455	4.87	0.22	152.01
Immingham	0.032	226	7.23	24	0.0455	4.87	0.22	178.89
Liverpool	0.032	82	2.62	24	0.0455	4.87	0.22	68.29

The ship emission factor varies according to vessel size. Practically, vessels that serve Northern Ireland from the British Mainland are less than 2000 TEU. The carbon emission factor for this vessel size is 11.9g CO_2/tkm (WRAP, 2008).

Table 4.12: Carbon emission for delivering fresh produce from UK Ports to Belfast Port using feeder ship

Belfast Port from Port	Ship Emission Factor (kg CO_2/tkm)	Ship Distance (km)	Ship Emission (kg CO_2/tkm)	Weight of goods (per container)	Total Emissions (kg)
Southampton	0.0119	510	6.07	24	145.66
Felixstowe	0.0119	633	7.53	24	180.78
Tilbury	0.0119	545	6.49	24	155.65
Bristol	0.0119	413	4.91	24	117.95
Immingham	0.0119	842	10.02	24	240.48
Liverpool	0.0119	231	2.75	24	65.97

Currently the fresh produce company in this study uses road transportation for distribution of fresh produce in the UK. Road transportation has an advantage of door to door transportation with no handling cost in the middle. This company uses 40-foot refrigerated containers using heavy goods vehicles (HGVs). HGVs consume enormous amounts of fuel and create various social and environmental issues. The transportation cost is calculated based on the fixed cost and variable cost. These costs are given by the company. The fixed cost for road transportation is £108.12 per container for 40-foot refrigerated container truck while the variable cost is £1.08 per kilometre.

Rail transportation is not yet in practice in this company. However, we have secondary data about rail transportation costs from EOCD (2005). The rail transportation costs are also

divided into fixed and variable cost. The fixed cost is the handling cost from the port to the train station and from the train station to the truck. The fixed cost used in this model is £135 per container (Garratt, 2003). The variable cost consists of maintenance, renewals and congestion and scarcity costs. The variable cost for freight rail transportation is £1.57 per freight train-km from various sources (EOCD, 2005). With the mean train length of 22 wagons (Woodburn, 2009), the calculated variable cost is £0.07 per container per kilometre. Shipping in this study is dealing with short sea shipping from the UK ports to Northern Ireland, specifically to Belfast Port. The cost structure of short sea shipping for the Irish Sea is also summarised into fixed cost and variable cost. Fixed cost includes a terminal handling charge (THC), which is given by £175 for the UK ports (Maerskline, 2009). Since this route is between two UK ports, the THC is doubled to £350. The freight rate per kilometre is £0.055 per container (Chen, 2009).

4.4 SUMMARY

This chapter has shown the optimisation models that have been formulated for both the reverse and forward logistics supply chain networks. The optimisation models with the notations were explained. The details of the data were shown, such as the location and capacity of the material recycling facilities and paper mills as well as the regional distribution centres and ports used in this research study.

The steps for the calculations that have been done are presented in this chapter. This includes the calculation of transportation cost, carbon emissions amount and carbon emissions cost. The virtual points that have been used as an average of regional distribution clusters were determined.

CHAPTER FIVE

ANALYSIS FINDINGS

5.1 INTRODUCTION

As a continuation from Chapter 4, the impact of carbon emissions policies on the reverse logistics network and forward logistics are presented. Both models were run using Excel Solver.

This research investigates the impact of the carbon emission policies on operations in the logistics of closed-loop and open supply chains. Optimal network design approaches for these industries under carbon emission control are proposed with strategies based on policy impact. To identify potential business reactions or behaviour with government carbon control policies, the analysis is performed with different carbon charge rates as sensitivity analysis through the optimisation models.

5.2 REVERSE LOGISTICS SUPPLY CHAIN NETWORK

The reverse logistics supply chain network is investigated with the paper recycling industry in the UK. Waste paper is collected from the residential or offices and sent to material recycling facilities before being sent for the next stage to be processed at the paper mills. There are different types of waste paper, such as cardboard, newspapers and magazines. This study does not focus on each type of paper, but uses average data obtained from the confederation of paper industries. Local and overseas paper mills are considered for reprocessing destinations for this supply chain network. In order to fulfil the demand for

paper in the UK, the import of paper is also included in the model. Since this model considers sending out the waste paper and buying back paper to meet the demand, this network constitutes closed-loop logistics. This case of closed-loop logistics in a paper recycling industry focuses on the strategic issues at the national level.

Initially, the optimisation model is run without carbon charge. The results show that local processing is 59% of the overall output of material recycling facilities (MRFs). The rest, 41%, are sent overseas in order to optimise the model with minimum cost. Only road transportation is used in the paper recycling industry. An interview conducted with a paper recycling company shows that, currently, rail is not a practical solution in this country as the UK has restricted loading gauge and the network is over-loaded with passenger traffic. In addition, rail is not competitive for paper and waste products because it is unable to backhaul finished goods and raw materials.

The optimisation model is exercised in order to see the impact of carbon policies on the network of the supply chain. Both carbon policies are used, namely, carbon tax and carbon emission trading. Carbon tax is examined with the approximation tax at £17 per tonne. The optimal solution has no impact on the network behaviour. However, the total cost with the addition of carbon cost is increased by 1%. The carbon tax is then increased in order to see the impact on the network. At £211 of carbon tax per tonne, there is an impact on the network. The local processing is increased to 1.19% while the export is reduced from 100% to 98.81% of the output from MRFs. If the tax keeps increasing, the total cost will increase as well. Local processing increases as the carbon charge are increased. At the rate of £214 per tonne, the total cost increased by 0.5% from the total cost at the rate of £211 per tonne. Local

processing allocation increased to 6.49% and export decreased to 93.51%. This is the impact of reducing the amount of carbon emissions from 553 tonnes to 533 tonnes for the network. This pattern appears to be the same as the carbon charge, which increased to £293 per tonne.

If the carbon charge increase is too high, the optimisation model suggests that the export will be reduced because local processing will incur less carbon emissions compared to export. There are two options in this model – to send for local recycling or export. If export is chosen, the import has to be considered in the network as well because total consumption in the UK is taken into consideration. This is why when the carbon charge is high, more allocation for local processing is done. The assumption for shipping cost of export and import is under the responsibility of the buyer. Although when the export is chosen, the UK does not have to pay for carbon emissions, when considering the import, the UK still has to pay for the carbon emissions charge. Generally, the higher the tax rate, the greater the allocation to the local paper mills in order to remain optimal.

Table 5.1: Paper recycling industry behaviour under carbon tax

Carbon price (£)	Total Cost (£)	Carbon Emission (tonne)	Local Processing (%)	Export (%)
-	262,847,923	557	-	100.00
17	274,265,899	557	-	100.00
211	404,562,603	553	1.19	98.81
214	406,557,965	533	6.49	93.51
249	429,304,334	499	15.89	84.11
256	433,632,278	469	24.49	75.51
261	436,555,741	444	31.11	68.89

Carbon price (£)	Total Cost (£)	Carbon Emission (tonne)	Local Processing (%)	Export (%)
269	441,151,712	438	32.75	67.25
270	441,721,306	435	33.55	66.45
272	442,846,256	404	42.15	57.85
274	443,923,653	392	45.46	54.54
293	453,998,984	391	45.72	54.28

Table 5.1 shows that when the carbon tax rate is increased, the total carbon emission decreases with a greater allocation for local processing.

Table 5.2: Paper recycling industry behaviour with cost fractions under carbon tax

Carbon price (£)	Transportation Cost	Operation Cost	Purchasing Cost	Selling Profit
-	43,570,215	-	420,090,000	215,289,000
17	43,570,215	-	442,200,000	225,990,500
211	43,276,397	2,249,999	688,533,477	343,965,970
214	42,022,868	12,250,000	665,671,676	327,298,667
249	40,779,893	30,000,000	658,520,047	312,934,500
256	39,851,953	46,250,000	619,745,422	284,249,333
261	39,208,673	58,750,000	588,760,459	261,501,000
269	39,099,900	61,850,000	587,690,693	258,656,667
270	39,051,185	63,350,000	584,255,796	256,019,977
272	38,567,869	79,600,000	538,098,680	223,596,531
274	38,404,814	85,850,000	521,334,569	211,493,333
293	38,406,876	86,350,000	536,393,342	216,958,325

Table 5.2 shows the impact of the carbon charge on different types of costs. As the carbon charge becomes higher, all the costs increase but the rate of increase is more for purchasing cost and selling profit. This scenario happens because of the greater allocation being made to local paper recycling, and, therefore, more imports have to be considered, which results in an increasing pattern in purchasing costs.

After that, the impact of carbon policy on a reverse logistics supply chain network is tested by using the carbon emissions trading policy. The trading price of £14 per tonne is used. The impact of carbon emissions trading policy on a reverse logistics supply chain is almost the same as the impact of carbon tax policy. Although the allocation of local processing and export is the same, the total cost is slightly different because carbon emission trading has a carbon limit. This limit is set up by the government or any regulatory body. In this analysis, the carbon limit used is 100 tonnes. If the carbon emission is below this limit, there is no charge on carbon emission. However if the carbon emission produced by any industry or company is more than the carbon limit, then the carbon charge is applicable. Table 5.3 and Table 5.4 show the summary of the impact of carbon emissions trading policy on a reverse logistics supply chain of the paper recycling industry. The impact on costs is the same as under carbon tax because there is no difference in allocation of local processing and export as the carbon charged is increased, however, the carbon emission cost is lower due to the carbon limit, and, therefore, carbon emission trading has an impact on the small amount of total cost compared to carbon tax.

Table 5.3: Paper recycling industry behaviour under carbon emissions trading

Carbon price (£)	Total Cost (£)	Carbon Emissions (tonne)	Local Processing (%)	Export (%)
-	262,847,923	557	-	100.00
14	272,249,562	557	-	100.00
211	404,541,479	553	1.19	98.81
214	406,536,565	533	6.49	93.51
249	429,279,434	499	15.89	84.11
256	433,606,678	469	24.49	75.51
261	436,529,641	444	31.11	68.89
269	441,124,812	438	32.75	67.25
270	441,694,306	435	33.55	66.45
272	442,817,599	404	42.15	57.85
274	443,896,253	392	45.46	54.54
293	453,969,678	391	45.72	54.28

Table 5.3 shows the behaviour of the paper recycling industry with the impact of carbon charge under carbon emissions trading policy. The impact of carbon charge under carbon emissions trading is almost the same as the impact of charge under carbon tax, specifically, in allocations of local processing and export. The model gives the first impact on allocation at the rate of charge of £211 per tonne. Since carbon emissions trading has a different charging structure, the total cost and carbon emissions cost are different. At £211 per tonne of carbon charge, the total cost is £404,541,479 instead of £404,562,603, which shows a difference of more than £21,000 under the carbon tax. After that, the increasing pattern is the same and the test sensitivity analysis on the model ends with the carbon charge of £293, with a total cost of 453,969,678 under carbon emissions trading and £453,998,984 under carbon tax.

The other cost structures under both policies are the same. Among all the costs involved in the network, only carbon emissions cost is affected, and, hence, it has an impact on the total cost.

Due to the difference in carbon emissions cost between the carbon tax and carbon emissions trading policies, Figure 5.1 is constructed to illustrate the comparison of carbon emissions cost between both policies. The highest carbon emissions cost is under carbon tax because the charge is on all carbon emissions. Carbon emission trading with a higher carbon limit gives less carbon emissions cost because the quantity of carbon emissions charged is less compared to the lower carbon limit. The model is tested with another carbon limit, which is 200 tonnes. The impact of carbon charge under carbon tax, carbon emissions trading with carbon limits of 100 tonnes and 200 tonnes is demonstrated.

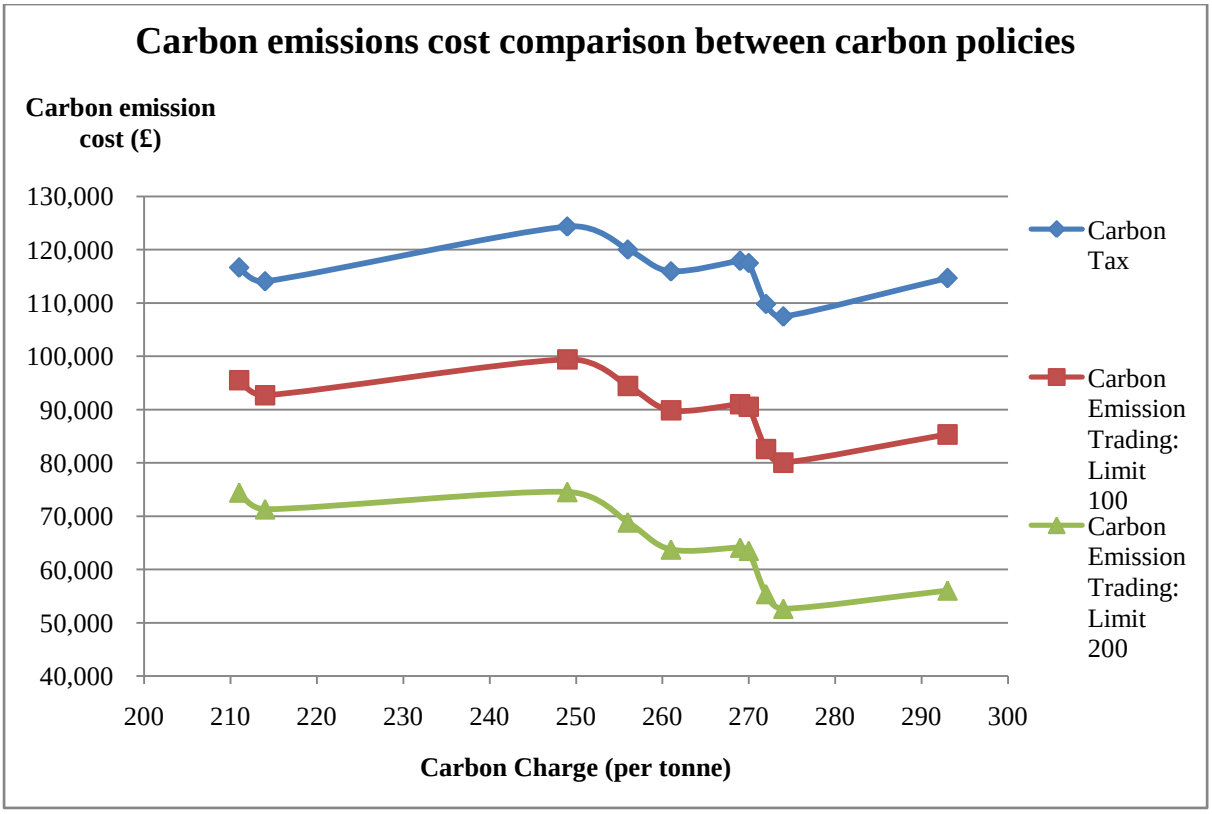

Figure 5.1: Carbon emissions cost comparison with different carbon policies for reverse logistics supply chain

As explained before, both policies have the same impact on the pattern of carbon emissions. The carbon tax is affected more by a higher carbon emissions cost. Under carbon emissions trading, the impact of having a different carbon limit is illustrated in Figure 5.1 above with less carbon cost with the bigger carbon limit. The pattern of carbon emissions cost movement fluctuates with the highest cost when the carbon charge is £249 per tonne and the lowest carbon emissions cost at £274 per tonne.

Table 5.4: Allocation to local paper mill as carbon price is increased

Carbon Price (£)	From MRFs	To Local Paper Mill	Distance(km)	Amount (tonne)
211	Kent	Kent	5	45,000
214	Coalville	Birmingham	54	200,000
249	Irvine	North Ayrshire	13	30,000
	Caerphilly	Watchet	136	325,000
256	Caerphilly	Cullompton	151	325,000
261	Tilbury	Sittingbourne	62	250,000
269	Tilbury	Kent	81	62,000
270	Chester	Deeside	12	30,000
272	Dewsbury	Darwen	81	325,000
274	Caerphilly	Birmingham	187	125,000
293	Inverness	Croy	256	10,000

Table 5.4 shows the changes in allocation to local paper mills at the specific carbon charge. When the price is less than £211 per tonne, the optimal solution suggests that all the waste paper has to be sent to overseas' paper mills for recycling. At the rate of £211 per tonne, only the MRF located in Kent, which is located 5 miles from the Kent paper mill. The amount of waste paper involved in this allocation is 45,000 tonnes, which is the amount of Kent MRF's waste paper supply. When the carbon charge is increased to £214 per tonne, the affected MRF is Coalville and the local paper mill that will receive the waste paper from this MRF is Birmingham. The location for this paper mill from Coalville is 54 km with an amount of 200,000 tonnes of waste paper. Instead of exporting the waste paper, by sending to the local paper mill when the carbon emission is charged at £214 per tonne, the carbon emission cost decreases from the overall carbon emission cost when the carbon is charged at the rate of

£211 per tonne. When the carbon is charged at £249 per tonne, two MRFs are affected. Instead of sending for export, Irvine and Caerphilly MRFs have to send waste paper to local paper mills, which are located in North Ayrshire and Watchet, respectively. The distance from Irvine, North Ayrshire, is 13 km with 30,000 tonnes of waste paper. Caerphilly, Watchet, has a distance of 136 km and total amount of waste paper of 325,000 tonnes. The overall 355,000 tonnes of waste paper that have been changed from export to local processing has reduced the total cost in the overall network. However, the carbon emission when the carbon is charged at £249 is more than the total carbon emissions cost when the carbon is charged at £214 per tonne. The next carbon charge that affects the behaviour in the reverse logistics network is when the carbon charge is £256 per tonne. The affected route is from MRF Caerphilly to the Cullompton paper mill. The distance for this route is 151 km and the amount that needs to be sent is 325,000 tonnes of waste paper. MRF Caerphilly is affected when the carbon charge is £249 per tonne. Since the demand for the Watchet's paper mill is less than the supply from MRF Caerphilly, the maximum amount that can be sent is just up to the maximum capacity of the Watchet paper mill. The amount of each affected route determines the fluctuations of the pattern in carbon emissions cost, as shown in Figure 5.1.

Figure 5.2 demonstrates the impact of carbon policies on the allocation from the material recycling facilities for local processing, export and the consideration of import in order to meet the local demand for waste paper. With no carbon charge, the optimal solution is sending all the waste paper that has been sorted in MRFs for export. As the carbon charge increases, more allocations are made to local processing and export decreases. Since export produces more carbon emissions because of long distance travelling, the optimal solution with less cost is to allocate more for local processing. The more expensive the carbon charge, the more the carbon emission cost will be, and, to compensate this, more allocation to local

paper mills is considered in order to remain optimal. As illustrated in Figure 5.2, the quantity of export shows a decreasing pattern. On the other hand, local processing shows an increasing pattern when the carbon charge becomes higher and higher. The quantity of import follows the pattern of export because if the waste paper is sent to be reprocessed overseas, the UK demand for paper has to be met by importing paper from overseas.

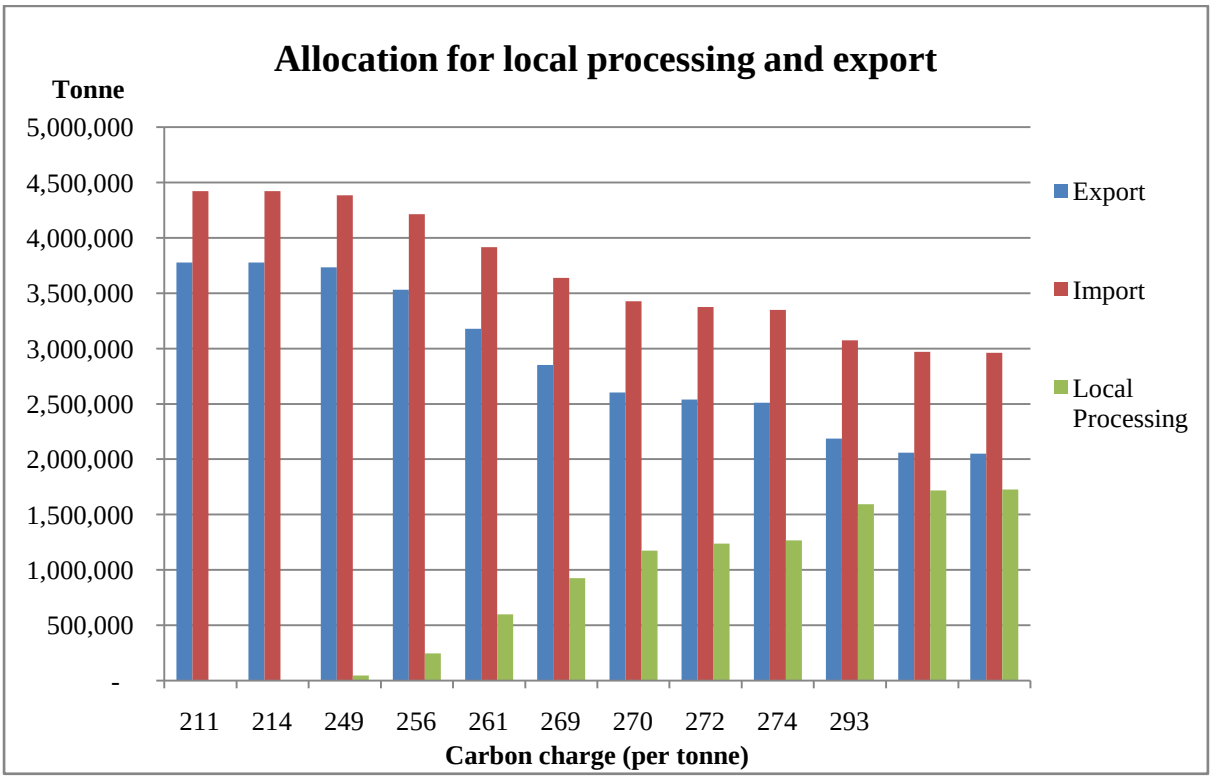

Figure 5.2: Allocation for local processing and export

The impact of carbon charged on reverse logistics supply chain network under both policies gives a reducing pattern of carbon emission, as shown in Figure 5.3. As the carbon charge increases, the total carbon emissions decrease because of the greater allocation to local processing compared to export, and, hence, less carbon emissions formed.

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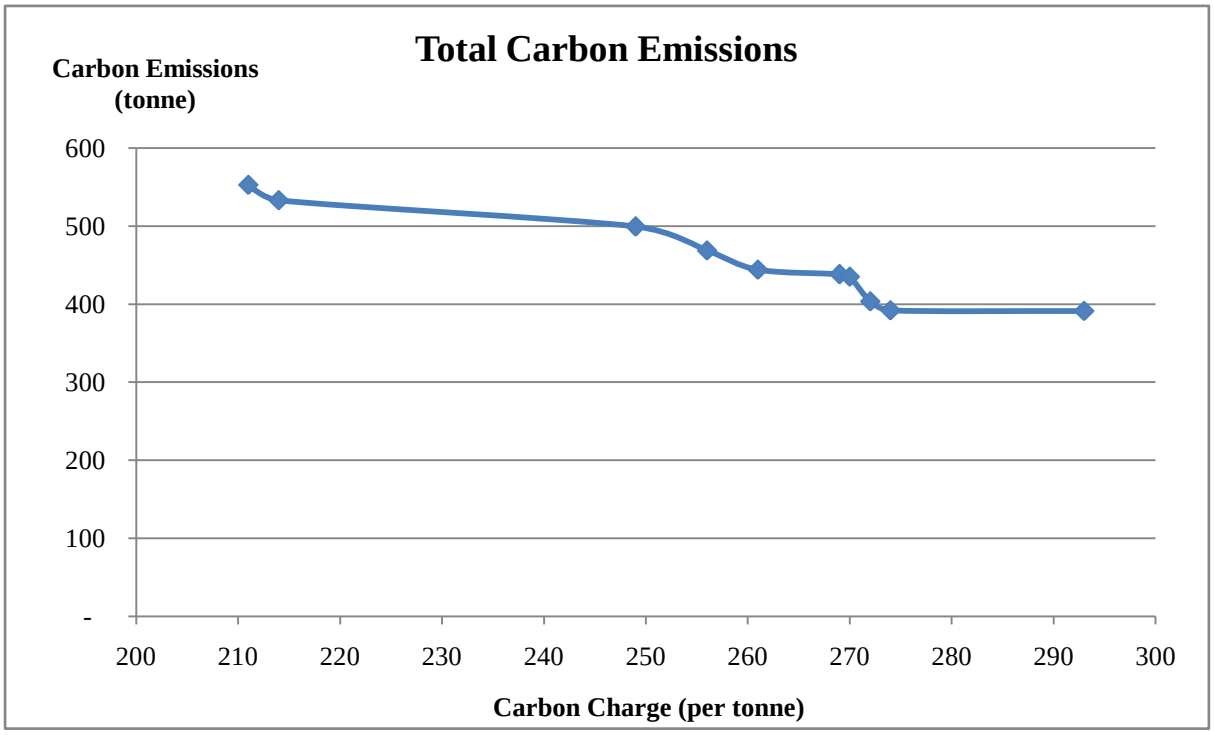

Figure 5.3: Total carbon emissions for reverse logistics supply chain

The shape of the pattern in total carbon emissions fluctuation is again determined by the capacity that has been affected when the model is tested with a different carbon charge. As the carbon charge is increased, the carbon emission decreases. The capacity from the route affects the slope of the decreasing pattern in total carbon emissions.

5.3 FORWARD LOGISTICS SUPPLY CHAIN NETWORK

In this study, logistics in the open supply chain is the case of the fresh produce industry. This case is considered as an open logistics because the network focuses on the distribution of fresh produce from UK ports to local regional distribution centres (RDCs). Fresh produce is imported from overseas to the UK market. An optimisation model of the transportation network in this industry is developed. Since fresh produce is a perishable product, time is an

important factor and is added into the model. Multimodal transportation planning is also included in order to see the behaviour of the open supply chain under carbon emissions policies. For this matter, this case focuses on operational level decision making.

Similar to the closed-loop supply chain in the previous section, the impact of carbon emission trading is tested using the optimisation model. The impact of carbon policy is monitored by minimising the total cost and travel time. First, the model is run without carbon charge, followed by a carbon charge in order to monitor the behaviour of this specific industry under carbon emissions control. When there is no carbon charge, the ideal behaviour is the overall total cost of £415,877 and total travel time of 106 hours, and, because of this, only road transportation is selected as the mode of transportation from the ports to RDCs. When the carbon tax is assessed at £17 per tonne carbon, the model behaviour is still the same but the total cost slightly increases with less than a 1% increment. After that, the carbon charge is increased to £239 per tonne, which only has an impact on the behaviour in the fresh produce import industry, with 8% of the fresh produce that has been brought to the UK (excluding Northern Ireland) being sent to the RDCs using the multimodal option. Because of this, multimodal transportation planning is a way to minimise the total cost at this rate of carbon charge. Multimodal transportation consists of rail transportation for long journeys plus road transportation for the final short journey from the train stations to the RDCs. Although there is no impact on the network behaviour, the overall total cost increased by less than 1%. The next carbon charge that has an impact on the network behaviour is at the rate of £438, which shows a 6% increase in total cost. The allocation to the multimodal option is slightly increased to just over 8% of the allocation of fresh produce in the UK mainland. The cost increases as the carbon charge increases. The pattern is monitored with a carbon tax of £470,

£513 and £751 per tonne, with increases in the total cost of 7%, less than 1% and 2% from the original cost, respectively.

Table 5.5: Fresh produce industry behaviour under carbon tax

Carbon Charge (£)	Total Cost (£)	Total time (hour)	Road Allocation (%)	Multimodal Allocation (%)	Increase in Total Cost
0	415,877	106	100	0	-
17	419,722	106	100	0	1%
239	417,332	141	92	8	0%
438	439,113	170	91.31	8.47	6%
470	445,073	173	91.30	8.48	7%
513	419,482	239	90.25	9.50	1%
751	425,888	352	71	29	2%

The impact of carbon policy on the open supply chain network is then monitored under the carbon emissions trading policy. The summary of the analysis is shown in Table 5.6. When the carbon is charged at £14 per tonne, the total cost slightly increased by less than 1%. At this charge, no multimodal option is considered. At the rate of £239 per tonne, there is some allocation for multimodal, and, hence, the total cost reduced by 5%. Other change in the multimodal selection is when the carbon is charged at £438 per tonne, and the total cost is reduced by 5% from the original total cost. At £470, £513 and £751 carbon charge per tonne, the total cost decreased by 4%, 11% and 16%, respectively. The total cost demonstrates a decreasing pattern. This behaviour appears because carbon emission trading has a carbon limit, where the emissions below the carbon limit are not charged. In this study, the carbon limit is estimated at 100 tonnes. This value is chosen because of the total carbon emissions in the network being more than 200 tonnes. If the carbon limit is set to be too high, there will be

no carbon cost. Sensitivity analysis is done as shown in Figure 5.5 with a different carbon limit. As the carbon charge increases, more allocation is made to the multimodal option, and, hence, the total cost and time are decreased. The decreasing pattern is not linear because the capacity for each cluster is different. If the capacity has a big quantity, a distinct decreasing pattern appears.

Table 5.6: Fresh produce industry behaviour under carbon emission trading

Carbon Charge (£)	Total Cost (£)	Total time (hour)	Road Allocation (%)	Multimodal Allocation (%)	Increase in Total Cost
0	415,880	106	100	0	-
14	417,643	106	100	0	0%
239	393,432	141	92	8	-5%
438	395,313	170	91.31	8.47	-5%
470	398,073	173	91.30	8.48	-4%
513	368,182	239	90.25	9.50	-11%
751	350,788	352	71	29	-16%

If the carbon charge becomes high, different modes of transportation are taken into consideration. In this research, road only and multimodal options are used; the multimodal transportation is rail plus road. The road in the multimodal transportation is used for the short journey from the port to the closest train station and from the closest train station to the final destination. The transportation mode options are illustrated in Figure 5.4. With no carbon emission policies, only road is used as the transportation mode. When the carbon charge is set to be around the current charge, there is still no impact on the selection of the transportation mode albeit the cost is increased. Currently, the transportation industry is paying a carbon charge, but the charge does not have an impact on the selection mode of transportation. This

model behaves as in a real situation, as validated by a paper recycling company. However, the carbon charge is increased in order to see at which rate the carbon policy will have an impact on the transportation mode selection. Figure 5.4 shows that when carbon emission is charged at more than £239, then a network of a fresh produce industry selects 8% of the UK mainland allocation using multimodal transportation, which is rail plus road. If a higher charge for carbon is made, the allocation for multimodal will increase, according to the capacity of the RDCs.

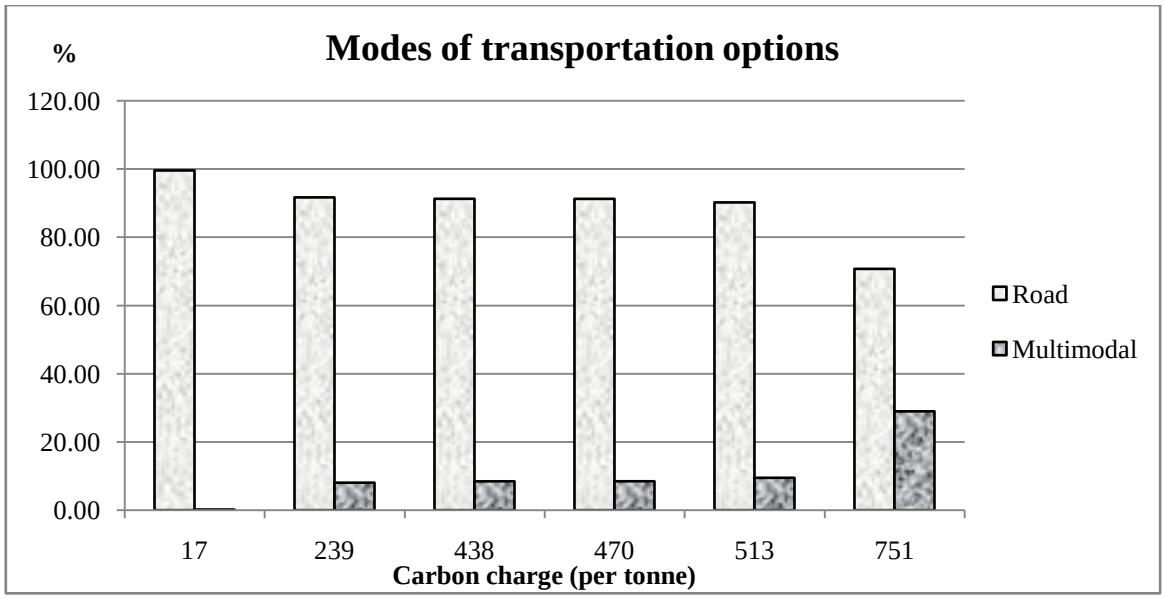

Figure 5.4: Modes of transportation options

The total cost under the carbon tax and carbon emissions is compared and presented in Figure 5.5. Under the carbon tax, the total cost increases as the carbon charge increases although the increment is not as high as in the closed-loop supply chain in section 5.2. For carbon emission trading, however, the total costs decrease with a greater decrease in the higher carbon limit. The carbon limit used in the experiment is 100 tonnes and 200 tonnes. There is a pattern of increasing up to a point, which is at the carbon charge rate of £470 per tonne, and decreasing again for carbon tax and carbon trading at both carbon limits. This trend appears because of the changing from road only to the multimodal option. The capacity of RDCs is

the main factor affecting this trend. The road and multimodal interactions are explained in section 5.2.1.

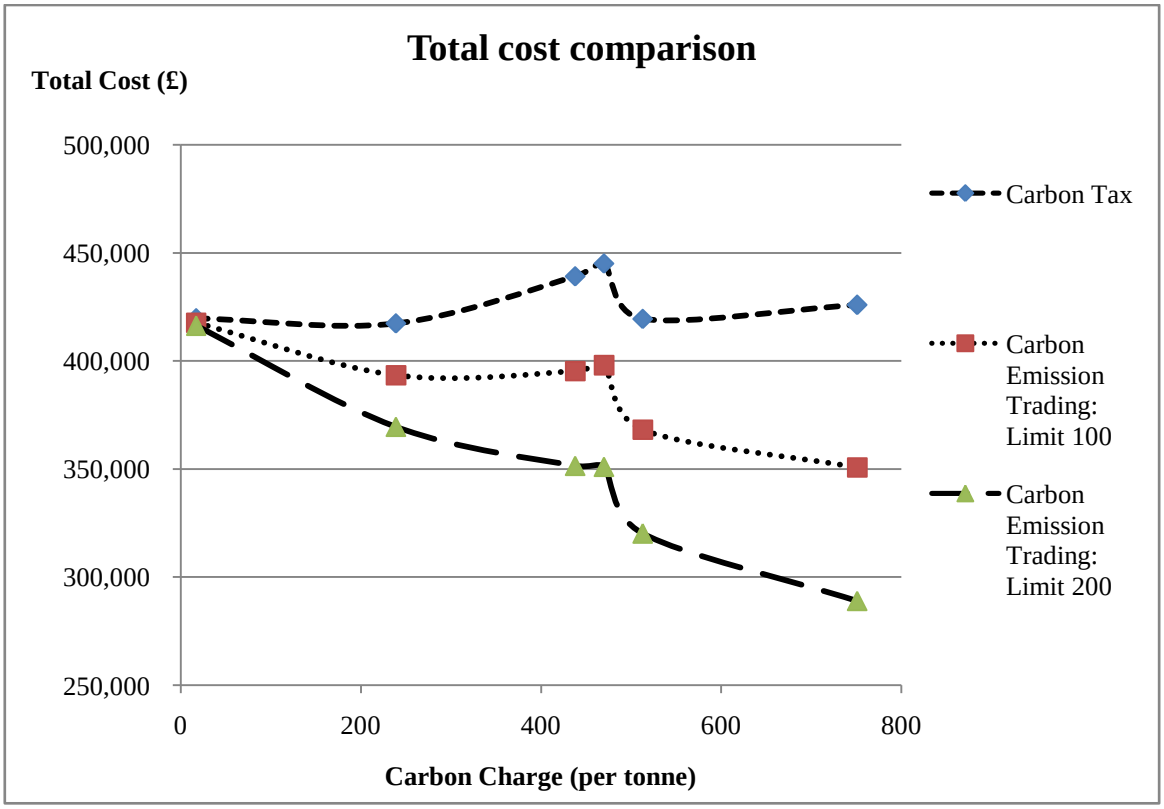

Figure 5.5: Total cost comparison with different carbon policies for open supply chain

Figure 5.6 shows the total travel time in sending 42,644 tonnes of fresh produce from the UK main ports to the RDCs located throughout the country. Overall, the travel time shows an increasing trend due to the changes in the transportation mode from road only to multimodal option. Generally, multimodal transportation incurs more travel time compared to road transportation because multimodal has to change the transportation mode from rail to road to final destination. The long transportation journey in the multimodal, which is rail, can increase the travel time because of the extra time required for handling from rail to road and another road transportation in order to reach the final destination. Therefore, because of the

changes in selection of the transportation mode, as the carbon charge increases, the total travel time also increases.

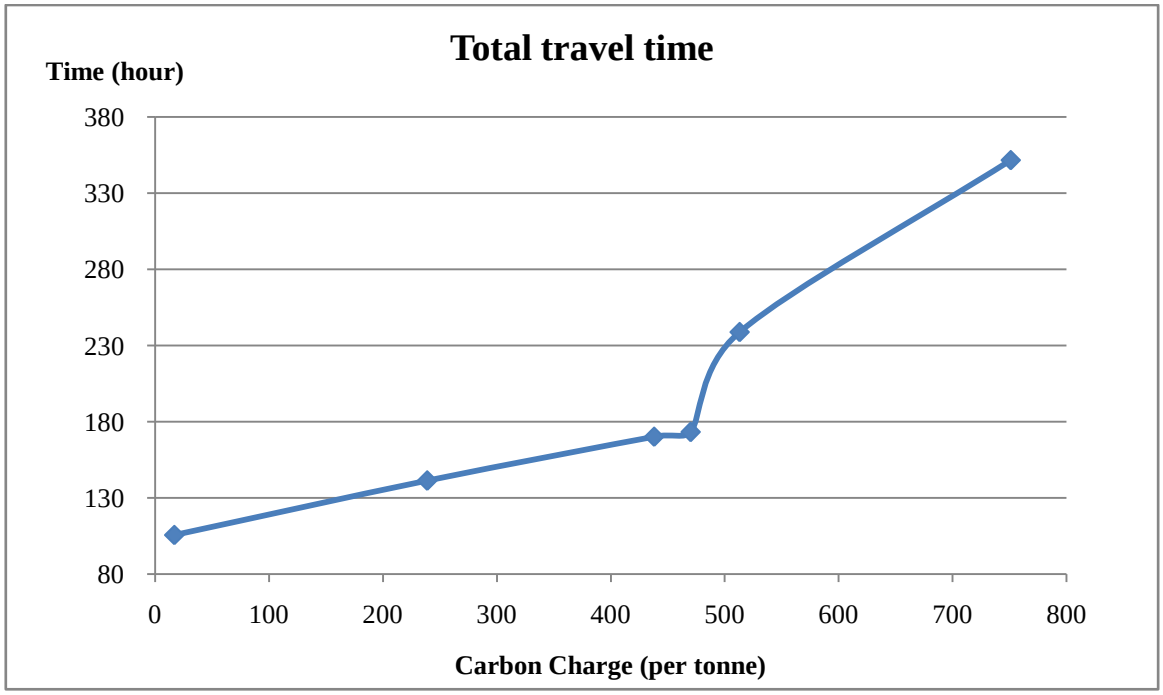

Figure 5.6: Total travel time for open supply chain

Generally, rail transportation emits less carbon emissions than road transportation, as supported by the emissions rate for different types of transportation. Therefore, when the carbon charge is increased, the optimised model is reducing the costs and increasing the travel time by considering multimodal transportation planning. The carbon emissions cost increases as the carbon charged increases in both policies. The carbon tax results in more of an increment in carbon emission cost compared to carbon emissions trading because the tax is charged on all carbon emissions, as demonstrated in Table 5.7. For carbon emissions trading, the increment is smaller compared to the impact from the carbon tax because the carbon cost is only charged on carbon emissions that exceed the allocated carbon limit. The higher the carbon limit, the lower the increase in carbon emissions cost.

Table 5.7: Carbon emissions under carbon tax and carbon emissions trading

Carbon Charge (£)	Total Carbon Emissions (tonne)	Carbon Emissions Cost (Carbon Tax) (£)	Carbon Emissions Cost (Carbon Emissions Trading) (£)
17	226.19	3,845	1,767
239	209.65	50,107	26,207
438	203.95	89,329	45,529
470	203.77	95,772	48,772
513	193.58	99,308	48,008
751	182.20	136,835	61,735

The carbon emissions cost pattern, is illustrated in Figure 5.7. The carbon emissions cost under the carbon tax is higher compared to the carbon emissions trading. When the carbon limit is estimated at 100 tonnes, the pattern is still increasing but by a smaller increment. At 200 tonnes of carbon limit, the carbon cost has a very small increment as the carbon charge is increased. When the carbon is charged at more than £470 per tonne, there is no more carbon charge because the total carbon emissions is less than the carbon limit. The impact of carbon emissions policies on the behaviour of the network is one that minimises the total cost and travel time by selecting a change in transportation mode from road to multimodal transportation planning.

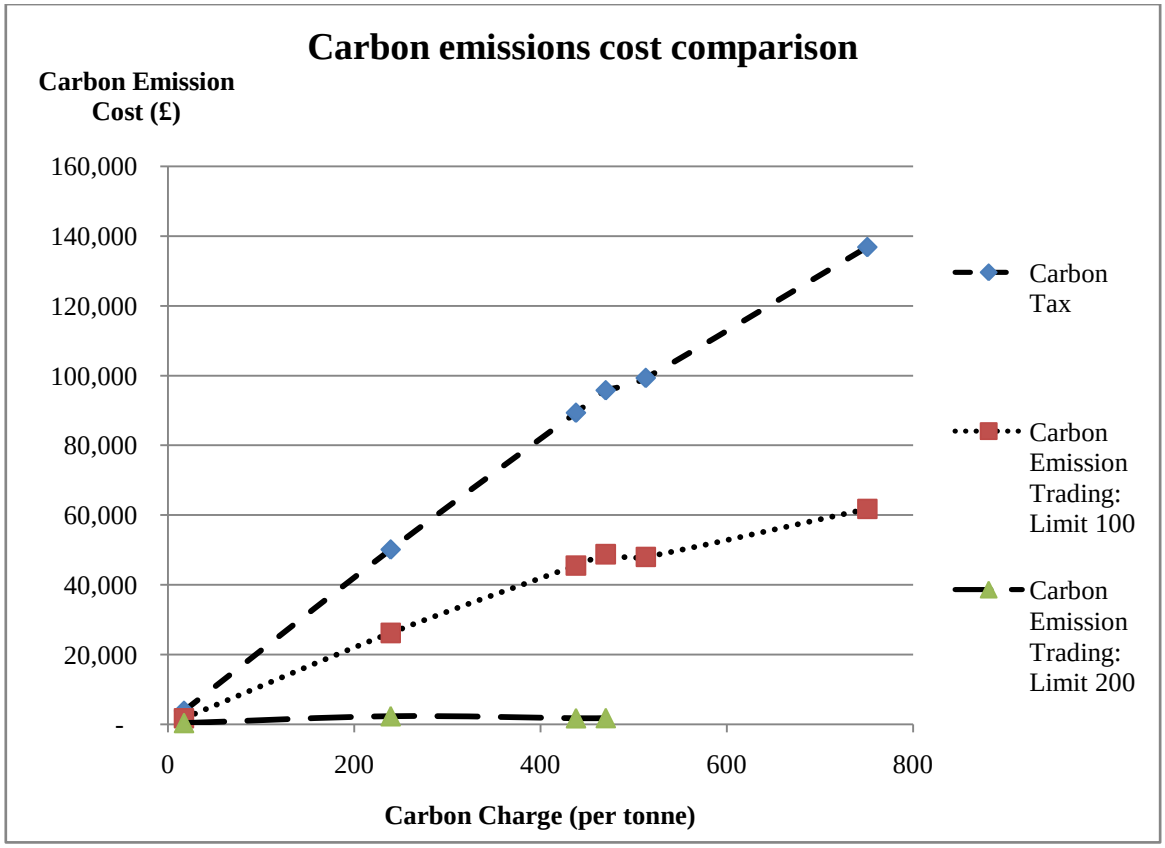

Figure 5.7: Carbon emissions cost comparison with different carbon policies for open supply chain

The total carbon emission decreases with the impact of having both a carbon tax and carbon emissions trading. Figure 5.8 illustrates that total carbon emissions decrease as the carbon charge increases.

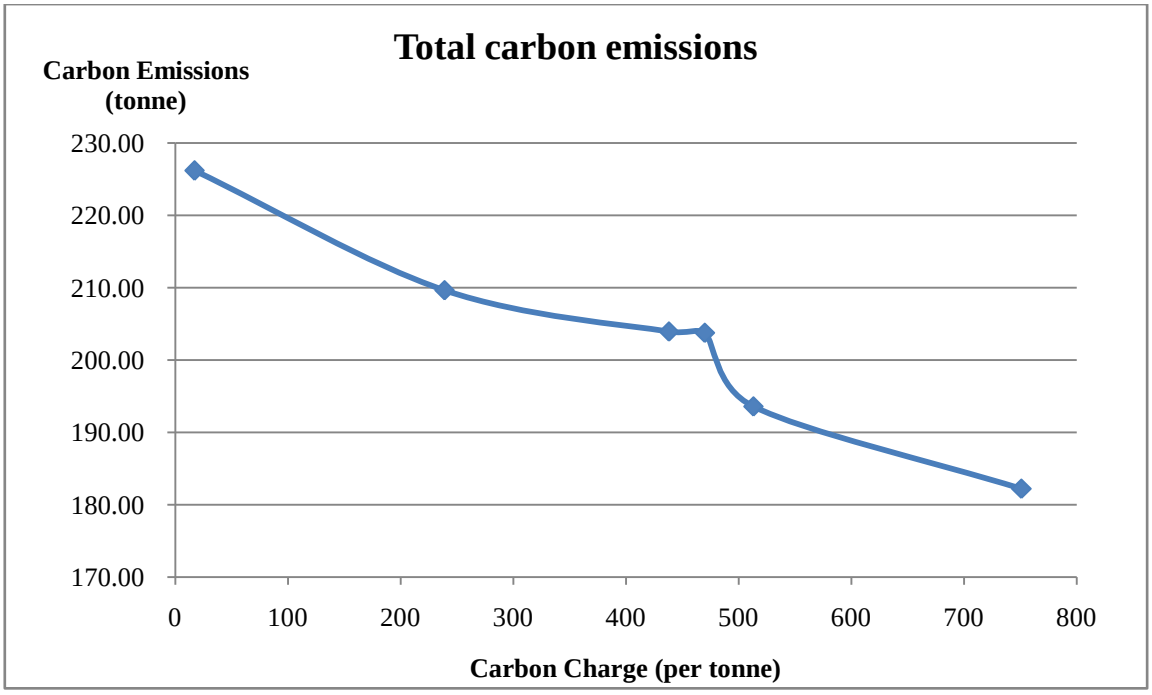

Figure 5.8: Total carbon emissions for open supply chain

The decreasing pattern in the total carbon emission shows the same impact as total cost and total travel time. There is a small increment at the rate of £470 per tonne carbon, because the impact of multimodal option is selected and the small capacity in the designated clusters.

5.3.1 Road – multimodal transportation interactions

The location of regional distribution centres is grouped according to clusters, as explained in Chapter 4. The allocation to each cluster from the responsible ports with no carbon policies is demonstrated in Table 5.8. There is no allocation for the multimodal when there is no charge on carbon. In the UK mainland (without Northern Ireland), the allocation is only using road transportation from the ports to the RDCs. Northern Ireland is not included in the allocation comparison between transportation modes because the location of Northern Ireland cannot be reached by road or rail. From the UK main ports, fresh produce is sent to Belfast Port using

small vessels and distributed to regional distribution centres in Northern Ireland by road. The multimodal option is not considered in Northern Ireland because the location of regional distribution centres is not very far from Belfast Port. The distance of the regional distribution centres is less than 10 km, which is not practical for multimodal consideration and changing of modes. A total of 90 tonnes of fresh produce is sent to Northern Ireland from Liverpool Port and the total travel time is 16 hours per week, considering shipping and road transportation from Belfast Port to the final destination. When the current carbon price is tested in the model, the impact increases the carbon emissions cost. There is no impact on the transportation mode selection.

Table 5.8: Allocations under different transportation modes with no carbon policies and current carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	Scotland	Liverpool	Road	3,383	20	375
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	North East	Immingham	Road	2,031	14	243
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	Birmingham, Coventry, Lutterworth, Alfreton	Bristol	Road	4,353	10	193
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	Tilbury	Road	6,573	8	139

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	Plymouth	Bristol	Road	70	2	195
Cluster 12	Cambridge, Thetford, Peterborough	Felixstowe	Road	510	2	126
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

The average supply chain speed is calculated based on the total time spent for travel and handling time divided by the total distance for sending fresh produce from ports to all RDCs. The average supply chain speed for the allocation without the impact of carbon emissions policies is 0.0483 hour/km. The supply chain speed for each cluster is shown in Table 5.9. Since the allocation with the current carbon charge is the same as the allocation without carbon charge, the average supply chain speed is the same for the no carbon emissions policies and carbon is charged at the rate of £17 per tonne.

Table 5.9: Time/distance for different transportation modes with no carbon policies and current carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	0.028	-
Cluster 3	0.012	-
Cluster 4	0.027	-
Cluster 5	0.016	-
Cluster 6	0.010	-

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 7	0.017	-
Cluster 8	0.047	-
Cluster 9	0.045	-
Cluster 10	0.013	-
Cluster 11	0.009	-
Cluster 12	0.006	-
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	0.483	

At the rate of £239 carbon charge per tonne, 92% of the UK mainland is distributed by road only and another 8% is distributed using multimodal transportation, as shown in Table 5.10. Only the Liverpool – Scotland route, which is Cluster 2, is impacted at this carbon charge rate. The total travel time has increased from 20 hours to 56 hours. Multimodal transportation is selected and a journey for the Liverpool – Scotland route has a capacity of 141 containers. The distance between Liverpool to Scotland is approximately 375 km. Therefore, if the distance is less than 375 km, there is no impact if the carbon charge is lower than £235 per tonne.

Table 5.10: Allocations under different transportation modes with £239 carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	**Scotland**	**Liverpool**	**Rail + Road**	**3,383**	**56**	**375**

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	North East	Immingham	Road	2,031	14	243
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	Birmingham, Coventry, Lutterworth, Alfreton	Bristol	Road	4,353	10	193
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	Tilbury	Road	6,573	8	139
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	Plymouth	Bristol	Road	70	2	195
Cluster 12	Cambridge, Thetford, Peterborough	Felixstowe	Road	510	2	126
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

The average supply chain speed, as the allocation changed when the carbon charge increased to £239 per tonne, is 0.532 km/hour. The impacted cluster is Cluster 2 with the changes in supply chain speed from 0.028 for road supply chain speed to 0.078 hour/km when the transportation mode changed from road to multimodal, as in Table 5.11.

Table 5.11: Time/distance for different transportation modes with £239 carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	-	0.078
Cluster 3	0.012	-
Cluster 4	0.027	-
Cluster 5	0.016	-
Cluster 6	0.010	-
Cluster 7	0.017	-
Cluster 8	0.047	-
Cluster 9	0.045	-
Cluster 10	0.013	-
Cluster 11	0.009	-
Cluster 12	0.006	-
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	0.532	

When the carbon is charged at the rate of £438 per tonne, 8.47% of the allocations are distributed using multimodal, which is rail plus road, as is explained in Table 5.12. The rest, 91.31% remains under road transportation. Besides the Liverpool – Scotland route, Cluster 4, has been impacted from the carbon charge to change from road only to multimodal option. The travel time from Immingham – North East changed from 14 hours to 43 hours. The big increment in travel time is due to the multimodal transportation, which consists of rail in a 85 container using rail and road transportation for the short journey to the final destination.

Table 5.12: Allocations under different transportation mode with £438 carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	**Scotland**	**Liverpool**	**Rail + Road**	**3,383**	**56**	**375**
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	**North East**	**Immingham**	**Rail + Road**	**2,031**	**43**	**243**
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	Birmingham, Coventry, Lutterworth, Alfreton	Bristol	Road	4,353	10	193
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	Tilbury	Road	6,573	8	139
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	Plymouth	Bristol	Road	70	2	195
Cluster 12	Cambridge, Thetford, Peterborough	Felixstowe	Road	510	2	126
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

The transportation mode changed from road to multimodal for the journey for Immingham – North East, with a change in speed from 0.027 to 0.081, which gives a new average supply chain speed of 0.386 hour/km, as shown in Table 5.13.

Table 5.13: Time/distance for different transportation modes with £438 carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	-	0.078
Cluster 3	0.012	-
Cluster 4	-	0.081
Cluster 5	0.016	-
Cluster 6	0.010	-
Cluster 7	0.017	-
Cluster 8	0.047	-
Cluster 9	0.045	-
Cluster 10	0.013	-
Cluster 11	0.009	-
Cluster 12	0.006	-
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	0.586	

Table 5.14 demonstrates the transportation mode option when the carbon is charged at £470 per tonne. Less than 1% of the allocation has an impact at this rate of charge and changed to the multimodal option. On top of the previous clusters, additional cluster that have changed transportation mode to the multimodal is Cluster 11, which covers the Bristol – Plymouth route with a distance of 195 km. The capacity for Plymouth's RDC is 70 tonnes. Because of the isolated location of Plymouth compared to other RDCs, this RDC is not grouped with

other RDCs. This is the reason why all the patterns for total cost and total carbon emissions have a small peak in a decreasing pattern.

Table 5.14: Allocations under different transportation mode with £470 carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	**Scotland**	**Liverpool**	**Rail + Road**	**3,383**	**56**	**375**
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	**North East**	**Immingham**	**Rail + Road**	**2,031**	**43**	**243**
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	Birmingham, Coventry, Lutterworth, Alfreton	Bristol	Road	4,353	10	193
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	Tilbury	Road	6,573	8	139
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	**Plymouth**	**Bristol**	**Rail + Road**	**70**	**5**	**195**
Cluster 12	Cambridge, Thetford, Peterborough	Felixstowe	Road	510	2	126
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

Cluster 5.15 demonstrates the impact at the carbon charge of £470. The new average supply chain speed has changed to 0.598 hour/km as the result of the changes in the transportation mode selection from road to multimodal for Cluster 11 from 0.009 to 0.02 hour/km.

Table 5.15: Time/distance for different transportation modes with £470 carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	-	0.078
Cluster 3	0.012	-
Cluster 4	-	0.081
Cluster 5	0.016	-
Cluster 6	0.010	-
Cluster 7	0.017	-
Cluster 8	0.047	-
Cluster 9	0.045	-
Cluster 10	0.013	-
Cluster 11	-	0.020
Cluster 12	0.006	-
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	0.598	

If the carbon charge is increased up to £513 per tonne, the additional cluster that changed from road only to multimodal options is Cluster 8, which is the Bristol – Birmingham area with an average distance of 193 km. When multimodal transportation is selected, the time increased from 10 hours to 76 hours. The total travel time is different because there is a handling time for rail, which is assumed to be 15 minutes per container. At this rate of carbon

charge, if the distance is more than 193 km, multimodal is a better option compared to road only transportation, as shown in Table 5.16.

Table 5.16: Allocations under different transportation mode with £513 carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	**Scotland**	**Liverpool**	**Rail + Road**	**3,383**	**56**	**375**
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	**North East**	**Immingham**	**Rail + Road**	**2,031**	**43**	**243**
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	**Birmingham, Coventry, Lutterworth, Alfreton**	**Bristol**	**Rail + Road**	**4,353**	**76**	**193**
Cluster 9	Milton Keynes, Bedford, Northampton, Rugby	Tilbury	Road	6,573	8	139
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	**Plymouth**	**Bristol**	**Rail + Road**	**70**	**5**	**195**
Cluster 12	Cambridge, Thetford, Peterborough	Felixstowe	Road	510	2	126
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

With the allocation as the carbon charge of £513 per tonne, the speed for Cluster 8 has changed from 0.047 to 0.336 hour/km, which gives a new supply chain speed of 0.887 hour/km, as shown in Table 5.17.

Table 5.17: Time/distance for different transportation modes with £513 carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	-	0.078
Cluster 3	0.012	-
Cluster 4	-	0.081
Cluster 5	0.016	-
Cluster 6	0.010	-
Cluster 7	0.017	-
Cluster 8	-	0.336
Cluster 9	0.045	-
Cluster 10	0.013	-
Cluster 11	-	0.020
Cluster 12	0.006	-
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	0.887	

Finally, the model is tested with a carbon charge of £751 per tonne in order to monitor the impact of carbon charged at a higher rate. Two clusters were impacted to change from road transportation to multimodal transportation planning, namely, Cluster 9 and 12, which covers the Tilbury to Bedford area and Felixstowe to Cambridge area, as illustrated in Table 5.18. The distances for these clusters are 139 km and 126 km, respectively. Overall, multimodal transportation increased to 29% and another 71% remains under road transportation.

Table 5.18: Allocations under different transportation mode with £751 carbon charge

Cluster	Region	Port	Mode of Transportation	Quantity (tonne)	Time (hour)	Distance (km)
Cluster 1	Northern Ireland	Liverpool	Ship + Road	90	16	252
Cluster 2	**Scotland**	**Liverpool**	**Rail + Road**	**3,383**	**56**	**375**
Cluster 3	Wales, Ross on Wye, Ashchurch	Bristol	Road	3,497	2	23
Cluster 4	**North East**	**Immingham**	**Rail + Road**	**2,031**	**43**	**243**
Cluster 5	Yorkshire and the Humber	Immingham	Road	3,062	6	98
Cluster 6	Liverpool, Manchester	Liverpool	Road	3,604	4	47
Cluster 7	Crewe, Stoke-on-Trent	Liverpool	Road	1,497	5	82
Cluster 8	**Birmingham, Coventry, Lutterworth, Alfreton**	**Bristol**	**Rail + Road**	**4,353**	**76**	**193**
Cluster 9	**Milton Keynes, Bedford, Northampton, Rugby**	**Tilbury**	**Rail + Road**	**6,573**	**112**	**139**
Cluster 10	Bristol, Trowbridge, Wellington	Bristol	Road	1,516	2	27
Cluster 11	**Plymouth**	**Bristol**	**Rail + Road**	**70**	**5**	**195**
Cluster 12	**Cambridge, Thetford, Peterborough**	**Felixstowe**	**Rail + Road**	**510**	**10**	**126**
Cluster 13	Southampton, Portsmouth	Southampton	Road	1,342	2	12
Cluster 14	Andover, Didcot, Bracknell, Farmborough	Southampton	Road	3,868	6	94
Cluster 15	Brent, Harlow	Tilbury	Road	1,872	4	61
Cluster 16	Maidstone, Crawleys,Grays	Tilbury	Road	5,465	2	31

When the carbon charge is increased to £751 per tonne, the Cluster 9 speed changed from 0.045 to 0.6 hour/km and Cluster 12 from 0.006 to 0.038, as shown in Table 5.19. This impact has created a new supply chain speed of 1.475 hour/km.

Table 5.19: Time/distance for different transportation modes with £751 carbon charge

Cluster	Road (Time/Distance)	Multimodal (Time/Distance)
Cluster 1	-	0.018
Cluster 2	-	0.078
Cluster 3	0.012	-
Cluster 4	-	0.081
Cluster 5	0.016	-
Cluster 6	0.010	-
Cluster 7	0.017	-
Cluster 8	-	0.336
Cluster 9	-	0.600
Cluster 10	0.013	-
Cluster 11	-	0.020
Cluster 12	-	0.038
Cluster 13	0.133	-
Cluster 14	0.065	-
Cluster 15	0.025	-
Cluster 16	0.013	-
Average	1.475	

The different modes of transportation and time are not compared as a single allocation because this model minimises the total cost and total travel time, not reducing the travel time for each journey, as travel time for each journey is an input value. The total time is also minimised in comparison from other ports to the same regional distribution centre.

5.3.2 Transportation cost, carbon emissions and time interactions

The main elements in this forward logistics supply chain network consist of transportation cost, carbon emissions and time. The model minimises these elements. With no carbon charge, total transportation cost is £415,877 and the travel time is 106 hours per week. With the current charge of carbon tax being £17 and carbon emissions trading price being £14 per tonne, the carbon emissions under these policies are £3,845 and £1,767, respectively. The carbon charge is increased in order to see the impact of the carbon emissions charge on the selection of transportation modes, as shown in Table 5.20.

Table 5.20: Transportation cost, carbon emissions cost and travel time interactions

Carbon Charge	Transportation Cost (£)	Carbon Emission Cost (Tax) (£)	Carbon Emission Cost (CET) (£)	Time (hour)	Quantity Changed (tonne)	Distance (km)
0	415,877	-	-	106	-	-
17 / 14	415,877	3,845	1,767	106	-	-
239	367,225	50,107	26,207	141	3,383	375
438	349,784	89,329	45,529	170	2,031	243
470	349,300	95,772	48,772	173	70	27
513	320,173	99,308	48,008	239	4,353	217
751	289,053	136,835	61,735	352	9,573	139
					510	126

The relationship between the carbon price and multimodal allocation is illustrated in Table 5.21. As the carbon charge increased, more allocation towards multimodal transportation planning is selected. When there is no carbon charge, less than 1% is allocated to multimodal transportation. With the current carbon charge, there is no impact on the selection of the

transportation mode. However, the model is tested with a different carbon charge and when the carbon charge is £239 per tonne, it is suggested that 8% of the allocation be sent using multimodal transportation. The quantity or capacity at the RDC is 3,383 tonnes of fresh produce. When the carbon charge becomes £438 per tonne, multimodal transportation increases to 8.47% with the change in quantity to 2,031 tonnes. When the price of carbon is £470 per tonne, another 0.01% because of the small capacity in the selected cluster, which is 70 tonnes. When the carbon price is increased to £513 per tonne, an amount of 9.5% of the allocation is designated to multimodal transportation with the capacity of 4,353 tonnes of fresh produce. The last tested carbon charge is £751 per tonne and multimodal dominates almost 29% of the overall allocation with the two clusters changing from road to multimodal.

Table 5.21: Relationship between carbon price and multimodal allocation

Carbon Charge (£)	Multimodal (%)	Quantity changed
0	0.16	-
17	0.16	-
239	8.07	3,383
438	8.47	2,031
470	8.48	70
513	9.50	4,353
751	28.99	10,083

When the carbon emissions charge increased, the mode of transportation changed from road only to multimodal transportation. The trends of change for transportation cost, carbon emissions cost under carbon tax and carbon emissions trading with travel time is illustrated in Figure 5.8. The carbon cost under both policies shows an increasing trend. The carbon tax has

a higher cost compared to the carbon cost under emissions trading because of the carbon limit in carbon emissions trading. On the other hand, transportation cost shows a decreasing trend as time increases. When the transportation mode is changed from road to multimodal, the travel time will increase and the transportation cost will decrease since multimodal has extra time for changing transportation mode, which is not necessary in the road only option.

The quantity for each cluster has an impact on the fluctuations in the cost as the carbon charge is increased. There is one extreme value, which is Cluster 11 for the route from the Port of Bristol to Plymouth. This redistribution was not grouped with the closest regional distribution centre because the location of the Plymouth regional distribution centre is far from other regional distribution centres. Hence, the capacity for Cluster 11 is small compared to the capacity of the regional distribution centres from other clusters. This is why the peak pattern appears on the carbon emissions cost when the changes in transportation planning happens at Cluster 11, as shown in Figure 5.8. Due to this behaviour, the conclusion that can be made is that when the distance is small, road transportation is a better option while if the distance is big, multimodal is a better option. Although Cluster 11 is an outlier from the group of all clusters, this value is still included in the analysis because, by having this outlier, we can see how the close distance with small demand does not have an impact from the changes in carbon charge. At a carbon charge of £239 per tonne, when the distance is over 375 km, the transportation mode changes from road only to the multimodal option. However, if the distance is more than 27 km, the changes in transportation planning from road to multimodal only happens when the carbon is charged at a rate of £470 per tonne.

Figure 5.9 shows the transportation cost and carbon emissions cost versus time. As the time increases, the transportation cost decreases due to the change in the mode of transportation. This increment is due to the increase in carbon charge, and, therefore, the carbon emissions cost increases under both carbon policy selections. The carbon tax, however, incurs more cost compared to the carbon emissions trading policy. The difference in the cost between these two policies is illustrated in the following figure.

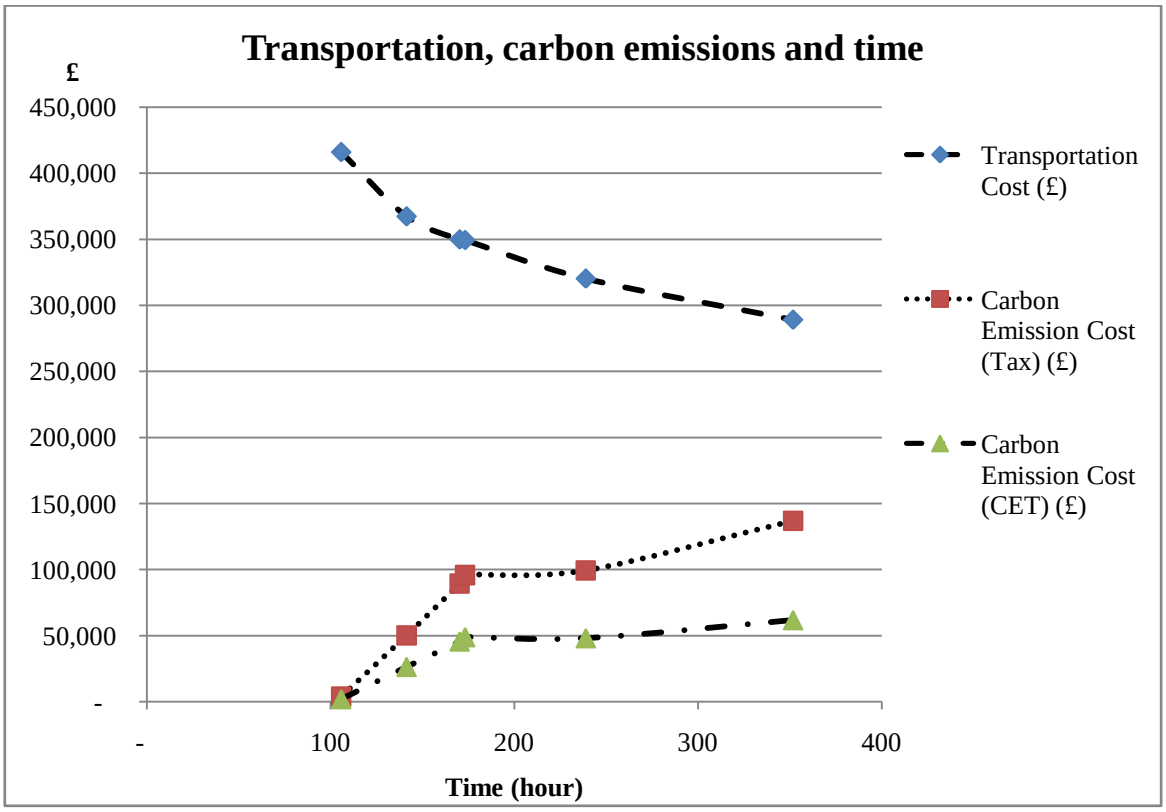

Figure 5.9: Transportation cost, carbon emissions cost and time trends

It illustrates how the supply network performance in time is related to cost performance. Carbon cost under both policies increase as travel time increases. However, the increase slows down significantly after the travel time exceeds a certain value. This can be explained by the result of increased multimodal transportation and reduced carbon emissions as the carbon charge increases. Such environmentally favourable change is likely achieved at the cost of reduced food logistics network speed. This will lead to negative impacts on quality of short-life foods. On the hand, transportation cost decreases as travel time increases. This

would be the result of increase in multimodal transportation for long distance deliveries. As seen in Figure 5.9, carbon tax has a higher cost as compared to emissions trading scheme as carbon emission is not charged under certain level.

The difference of transportation cost and carbon emissions cost with different time is demonstrated in Figure 5.10. At a carbon charge of £17, with 106 hours travel time, most of the overall cost proportion is transportation cost. As the carbon charge increases, and the time increases, the proportion of carbon emissions cost increases, and the proportion of transportation cost decreases. The maximum time is 352 hours with carbon emissions cost amounting to nearly half of the transportation cost under the carbon tax policy.

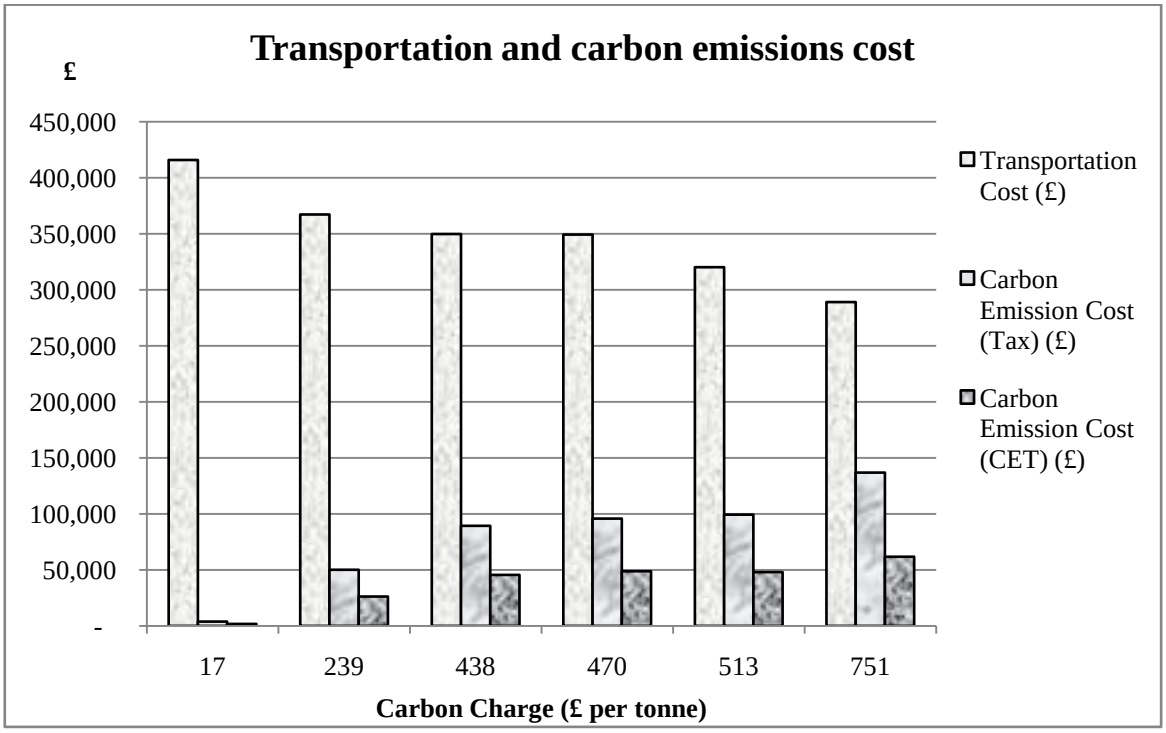

Figure 5.10: Transportation cost, carbon emissions cost and time

Figures 5.11 and 5.12 demonstrate the costs involved in the forward logistics supply chain network under carbon tax and carbon emission trading, respectively. The pattern of the cost changing with different travel time is almost identical. Three costs are monitored on the forward logistics supply chain network. The transportation cost remains the same in if both policies are tested. Since the cost amount under both policies is different, the overall total cost under carbon emissions trading is smaller compared to the impact from the carbon tax policy.

From both figures, it can be noted that there are potential optimal logistics network speed solutions which is associated with minimum overall cost in the logistics network. This implies that, within food shelf-life constraint, the travel time can be optimised to achieve maximum cost efficiency in the food logistics network operations. The optimal logistics network speed in a logistics network varies with different carbon charges applied to service provider. Although all transportation routings as optimal solutions from the model already meet shelf-life constraints, shorter overall delivery time in the network would imply greater value of the perishable foods from the retailers' and consumers' perspectives (Wang and Li, 2012). When carbon charge is low, most of the routes would select road transportation. This leads to fast increase in carbon emission cost in the logistics network as in the early part of the carbon emission cost variations. When multimodal transportation is selected in more routes in the network, the increase of carbon emission cost slows down as the travel time increases. There is an inflection point with emission cost variations as the consequence of a sudden change of proportion of multimodal transportation in the network. The sudden change would be a result that the carbon charge increase has generated a great impact on cost structure of the network, and has driven many routes in the network transferring to multimodal transportation at the same carbon charge level. The inflection point divides the

supply time into two sections which reflect two carbon charge regions, low and high carbon charge regions. In both regions, a minimum cost can be achieved at an optimal supply time or optimal ratio of multimodal to road only transportation under a given carbon charges.

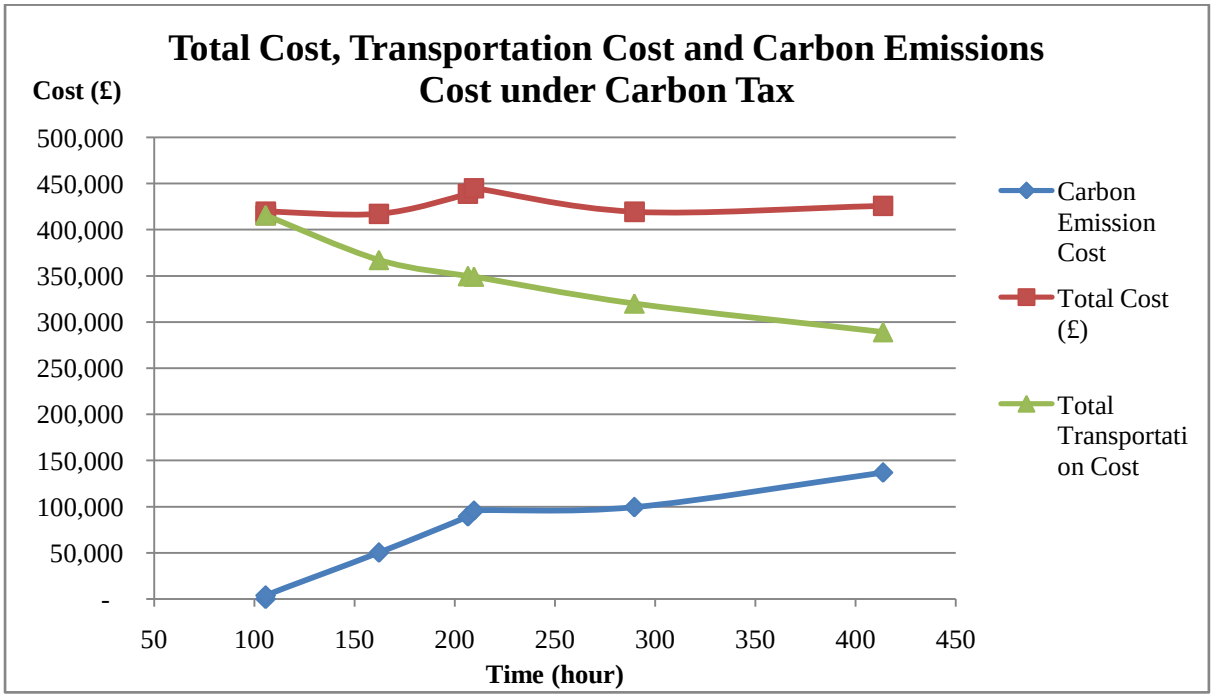

Figure 5.11: Costs under Carbon Tax Policy

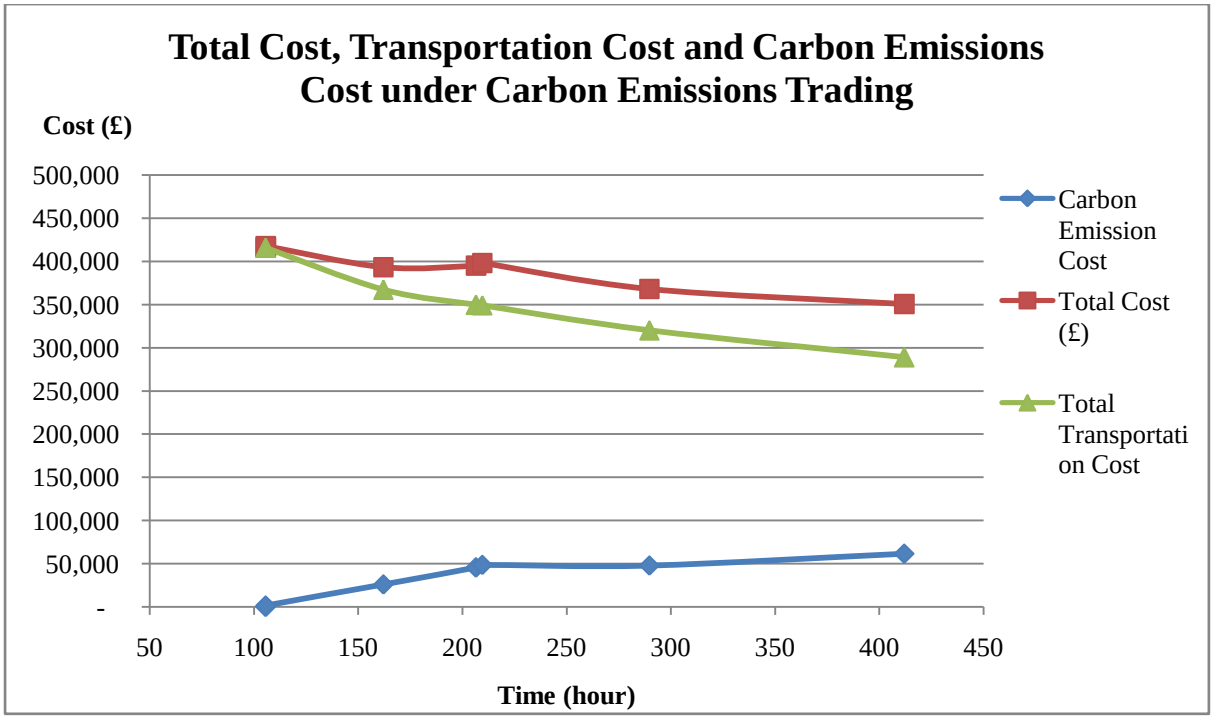

Figure 5.12: Costs under Carbon Emissions Trading Policy

5.4 RESULT VALIDATION

The results were validated by conducting an interview with a paper recycling company. The results were explained to the interviewee. He agreed that the findings are aligning with the company's current practise. This company suggested that with the current carbon charge, the carbon emission policy has no impact on their operations. This interview was used for validation of the results, as currently this recycling company is paying a carbon charge. They are only paying an extra cost on top of the other costs of carbon without having a change in strategic and operational planning. It shows that with the current charge, the operations in paper recycling remain the same.

Currently a carbon tax charge of around £17 per tonne is used and the carbon emissions trading price fluctuation is monitored. The average carbon emission price is used, which is £14. When these charges for both policies are applied in the model, there is no impact on the behaviour of logistics in the closed-loop and open supply chain networks.

5.5 SUMMARY

This chapter explores the probable impact of carbon emission policies on the performance of reverse and forward logistics supply chain networks. Optimisation models were used to assess the impact of carbon emission policies on these networks. Both models were run using the Excel Solver tool. The reverse logistics supply chain network is a strategic level decision making tool showing the impact of carbon emission policies on the paper recycling case with the focus on the allocations of local processing, export and import. Forward logistics, on the

other hand, is an operational level decision making tool for the fresh produce industry showing the impact of carbon emissions policies on the transportation mode selection.

The findings in this study have important implications for both the industries studied – paper recycling and fresh produce. The carbon impact on the network of reverse logistics and forward logistics supply chain were tested using optimisation models with both carbon tax and carbon emissions policies. The carbon emissions cost was changed in order to see the behaviour of the network under different circumstances. The findings from the optimisation model can be summarised as follows. In the reverse logistics supply chain network, with no carbon emissions policies, the optimal decision is to send all the waste paper overseas for recycling. Consideration has been made concerning the transportation cost, carbon emission cost and operations cost in the UK. For exporting the waste paper overseas, strategically, the UK receives a selling profit and in order to import the paper back from overseas to meet the UK's demand on paper, the purchasing cost from the import quantity is considered. When the carbon charge is increased, there is an impact on the network allocations. As the carbon charge increases, more allocation for local processing has to be made in order to remain optimal. The change in allocation is influenced by the distance between the material recycling facilities and both the local paper mills and the closest port. This study focused on waste paper that has been collected and processed from material recycling facilities to paper mills. No consideration has been made of the collection of the waste paper from end customers to the material recycling facilities.

In the case of forward logistics supply chain network, with no carbon emissions policies, all fresh produce that has been imported from overseas is allocated to the closest regional

distribution centre using road transportation. The optimisation model minimises the total costs and time, therefore, road transportation is preferable because road transportation can be used for door to door service. However, as the carbon charge increases, the impact on the transportation mode selection changes because the carbon emission using road transportation is relatively higher than carbon emission using rail transportation. This results in more costs in the whole supply chain network. In this study, multimodal transportation considers rail transportation for long distance journeys plus road transportation for the journey from the final train station to the regional distribution centre. Therefore, the transportation option is either road or multimodal transportation. The main factor affecting the selection of the transportation mode is the distance from the ports to the regional distribution centres and the capacity of the regional distribution centres. The higher the carbon emission charge, the shorter the distance for road transportation because for longer distances the option changes to multimodal transportation.

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 INTRODUCTION

In this chapter, the overall discussion and conclusion of the thesis are presented. The impact of carbon emission policies on both the reverse and forward logistics supply chain networks has been conducted. The transportation cost and carbon emissions cost are the main issue addressed in both the reverse and forward logistics supply chain networks using optimisation models. The impact of carbon emission policy implementation for local processing, export and import of paper is the concern in the reverse logistics supply chain network. However, in the forward logistics supply chain network, the emphasis is on multimodal transportation planning. Since the fresh produce industry is used as a case study in forward logistics, time is an important factor considered in the study. This study contributes significantly to government policy making in respect of carbon emission control.

6.2 CARBON IMPACT DISCUSSIONS

Carbon cost is a small fraction of the overall cost in the reverse and forward logistics supply chain network. This is the reason why the carbon charge has to be very high to have an impact on the network behaviour. The current world carbon policies are not successful because the current charge does not have any impact on the behaviour in current transportation planning. Only when the carbon is too high, is there an impact on the transportation network; however, this will have a direct impact on the whole economy. Currently, the carbon charges result in extra cost to the industries although it is not enough to change the behaviour of the network.

The sensitivity analysis in this study shows that as the carbon charge increases there is an impact on the strategic and operational planning in both industries. The carbon price is increased until there is an impact on the network behaviour and the carbon price change is monitored.

The data that have been used in the study are both primary and secondary. The primary data regarding the reverse logistics case were provided by a paper recycling company in Kent, while the primary data for forward logistics case were from a fresh produce company in Liverpool. A series of interviews were conducted to help understand the operational and strategic planning of these companies. Secondary data were obtained from various resources, such as the companies' annual reports, white papers, journal articles and books.

The validation of the result is given by the paper recycling company as the current charge has no impact on the strategic and operational planning of the company. Through the interviews, the results obtained from the optimisation model are the same as the current practice in the company. Indirectly, the paper recycling company is paying a carbon emission charge, while the fresh produce industry does not, currently pay any carbon charge. However, the implementation of a carbon emissions charge is not far. The network of paper recycling shows that it is affected when the carbon charge is £211 per tonne. The fresh produce network shows a change in operation when the carbon charge is £239 per tonne. These charges show an important impact from the implementation of carbon policies on the reverse logistics and supply chain network. The study conducted by Symons et al. (1994) shows that

the lowest carbon tax to effect a change is £240.50 per tonne. The output from this research also shows an impact when the carbon charge is around that value.

The existing carbon policies can be considered as immature, in as much as there are loopholes in the implementation, as discussed in Chapter 2. However, in the future, carbon policies will be a main factor that can affect global activities, specifically, on the global economy since carbon emission is an issue that will impact on humankind around the world.

6.3 CONTRIBUTION TO KNOWLEDGE

The main purpose of this thesis is to assess the impact of carbon emission policies on reverse and forward logistics supply chain networks, which are paper recycling and the fresh produce industry, respectively. As discussed in Chapter 2, the literature suggests that carbon emissions is an important issue nowadays as it affects all human life. The implementation of carbon emission policies to control carbon emissions has an impact on the strategic and operational decisions in all industries, particularly in the paper recycling industry and fresh produce industry.

Chapter 3 demonstrates the methodology used to carry out the analysis. The formulation of both optimisation models is explained. Both primary data and secondary data are used for analysis. Primary data are given by a paper recycling company in Kent and a fresh produce company in Liverpool. Secondary data are obtained from the literature, such as white papers, journals and publications. The development of the models is then described in Chapter 4. The selection of the locations is shown. In the reverse logistics supply chain network, the

selection of material recycling facilities and paper mills for the paper recycling case are shown. In the forward logistics case, regional distribution centres are grouped into a number of clusters and the average distance is determined.

In Chapter 5 the analysis of the results are presented. The impact of both carbon tax and carbon emissionstrading policies to the reverse and forward logistics supply chain networks are determined. In general, the results in this chapter indicate that: (1) for the reverse logistics supply chain network, with no carbon emissions charge, exporting the waste paper overseas incurs less cost for the overall network. Under the current charge, the situation of an optimal solution is still the same. Therefore, it shows that the reverse logistics network has no impact on strategic planning with the current carbon charge. However, there is an impact on the overall total cost that has been increased due to the extra costs for carbon. (2) For the forward logistics supply chain network, in minimising total costs and travel time, road transportation is the best option with no carbon emissions policies implemented. Currently the company that we are dealing with does not pay for carbon emissions. However their direction is now towards paying for their carbon emissions. Multimodal transportation planning is an option to reduce carbon emissions. Instead of using roads for distributing the fresh produce to the regional distribution centre, multimodal, which is rail, is considered in this study. Although rail has lower carbon emissions than road, the extent to which the rail transportation is beneficial should be determined (Li, 2011). Depending on the carbon charge, the analysis in this study shows the extent to which multimodal using rail is an option to be chosen instead of road transportation.

The findings of the carbon charge rate are expected to be a useful guideline for the government when making decisions on the rate of carbon to be charged, especially for carbon tax, as the government controls the tax rate under this policy. Although the carbon charge in carbon emissions trading policy is determined by the demand supply in the carbon market, the government still has the authority to determine carbon limits for each industry. It is also expected in the future that the carbon limit will be set by the government to a smaller level, for instance, a carbon limit for each company. This will have a better impact on the planning for each company towards reducing carbon emissions. This carbon charge rate is useful for the paper recycling and fresh produce industry as they can see the impact of the carbon charge on their strategic and operations planning. Currently the carbon is charged, and, according to the analysis carried out from the optimisation model, there is no impact on the strategic and operations planning of these industries. The carbon charge might be increased but with this impact of different rates of carbon charge to the paper recycling and fresh produce network will show that if the carbon is charged at more than £211 per tonne for paper recycling industry and £239 per tonne for the fresh produce industry, there will be an impact on the strategic and operations planning in paper recycling and fresh produce industry, respectively.

Paper recycling is not much different from other recycling materials. The network for paper recycling can be generalised for other recycling materials. If it is not recycled, the waste paper as well as other recycling materials like glass, metal and plastic are sent to landfill together with other household waste. The fresh produce industry on the other hand is focusing the impact of carbon emissions policies on the selection of transportation mode with consideration of multimodal transportation planning. This industry can also be generalised to

other industries that have an option for using multimodal transportation planning in their operations.

The study has quantitatively explored potential behavioral changes in a multimodal context, when carbon emission policies are applied to the industry. Logistics service provider would be benefited from the logistics network design approach through developing optimal multimodal transportation strategies with the given carbon policies. The research would also be able to significantly contribute to government policy making for carbon emission control. With understanding of the policy impacts on logistics network configurations, effective carbon control policies could be established to reduce carbon emission, and encourage cost effective and environment friendly transportations.

6.4 LIMITATIONS AND FUTURE RESEARCH

6.4.1 Reverse Logistics

The limitations of the research in the case of the reverse logistics supply chain network is that consideration has only been made for material recycling facilities to the UK paper mills and for export. Prior process is not included in the study. For the imported paper from overseas, the network only considers the imports from the overseas port to the UK ports.

Therefore, further studies are required to cover more entities in the supply chain network, which is covered before and after the chosen process in this research. (1) The process involved before the material recycling facilities, which is the collection of waste paper from

end consumers to material recycling facilities. (2) After the waste paper is ready for the next use, which is the allocation from these paper mills for printing purposes. This could be the paper from UK paper mills or the paper that has been imported from overseas in order to meet the UK paper demand.

6.4.2 Forward Logistics

The operational level of the fresh produce case considers the impact of carbon emissions policies on transportation mode selections. For multimodal transportation planning, only rail transportation is considered, and, hence, the multimodal is rail transportation plus the road for the final journey connecting the last train station to the regional distribution centres.

The future research for this study can include waterways as a transportation mode to be combined with road or rail as another multimodal transportation mode selection. . Besides that a further research can be considered on the impact of carbon emission policy on each individual transport mode, rather than on mode transfer. In addition to other mode of transportation, the number of variables will be increased. The tool used in carried out the analysis is Excel Solver, which has limited number of variables of 200 variables. Therefore, other types of software can be used for a bigger number of variables.

Both cases are focusing at sector viewpoint of the cost. A national level point of view is also covered by the reverse logistics case where the local waste papers are processed locally and exported to be recycled in overseas. In addition to that, some papers are considered to be imported back to the UK in order to meet local demand. A national point of view can be

executed as a future research considering transportation since transportation is the main activity involved in both cases.

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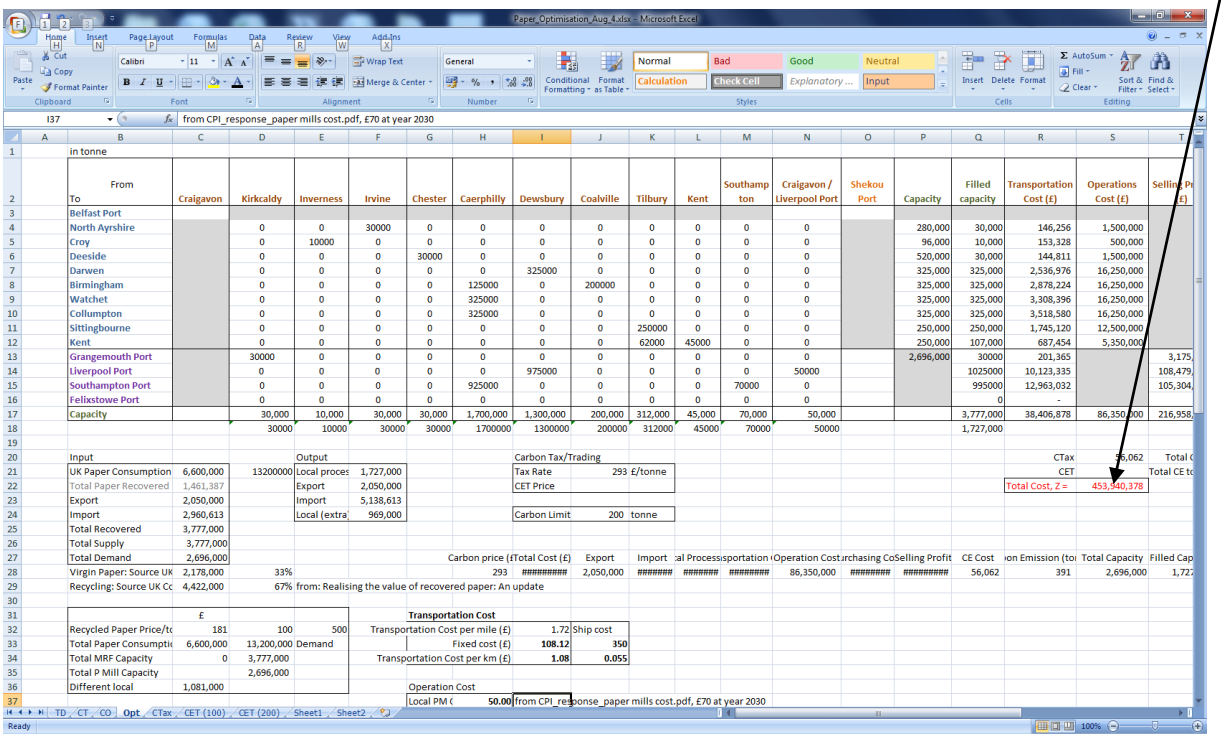
LIST OF ACRONYMS

Acronym	Definition
Annex I	Industrialised Countries under Kyoto Protocol
CDM	Clean Development Mechanism
CERs	Carbon Emission Reductions
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
ERUs	Emission Reduction Units
GHGs	Greenhouse Gases
HGV	Heavy Goods Vehicle
JI	Joint Implementation
KPI	Key Performance Indicator
MILP	Mixed Integer Linear Programming
MRFs	Material Recycling Facilities
Non-Annex I	Developing Countries under Kyoto Protocol
RDCs	Regional Distribution Centres
TEU	Twenty-foot Equivalent Unit

Appendix A: Paper Recycling Optimisation Model in Spreadsheet

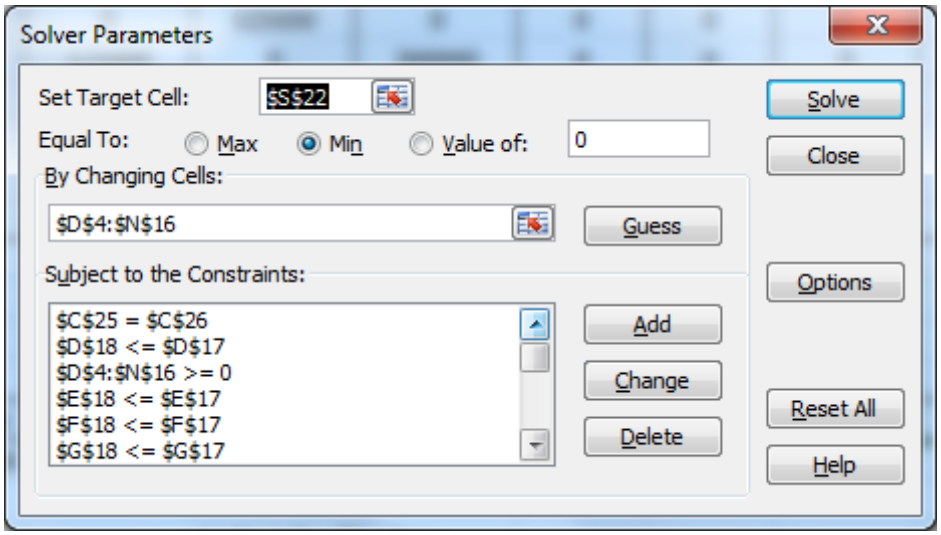
Total Cost = Transportation Cost + Operations Cost – Selling Profit (Export) + Purchasing Cost (Import) + Import Transportation Cost + Carbon Emission Cost

A.1 The Optimisation Model



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		in tonne																		
2		From / To	Craigavon	Kirkcaldy	Inverness	Irvine	Chester	Caerphilly	Dewsbury	Coalville	Tilbury	Kent	Southampton	Craigavon / Liverpool Port	Shekou Port	Capacity	Filled capacity	Transportation Cost (£)	Operations Cost (£)	Selling Pr (£)
3		Belfast Port																		
4		North Ayrshire		0	0	30000	0	0	0	0	0	0	0	0		280,000	30,000	146,256	1,500,000	
5		Croy		0	10000	0	0	0	0	0	0	0	0	0		96,000	10,000	153,328	500,000	
6		Deeside		0	0	0	30000	0	0	0	0	0	0	0		520,000	30,000	144,811	1,500,000	
7		Darwen		0	0	0	0	0	325000	0	0	0	0	0		325,000	325,000	2,536,976	16,250,000	
8		Birmingham		0	0	0	0	125000	0	200000	0	0	0	0		325,000	325,000	2,878,224	16,250,000	
9		Watchet		0	0	0	0	325000	0	0	0	0	0	0		325,000	325,000	3,308,396	16,250,000	
10		Collumpton		0	0	0	0	325000	0	0	0	0	0	0		325,000	325,000	3,518,580	16,250,000	
11		Sittingbourne		0	0	0	0	0	0	0	250000	0	0	0		250,000	250,000	1,745,120	12,500,000	
12		Kent		0	0	0	0	0	0	0	62000	45000	0	0		250,000	107,000	687,454	5,350,000	
13		Grangemouth Port		30000	0	0	0	0	0	0	0	0	0	0		2,696,000	30000	201,365		3,175,
14		Liverpool Port		0	0	0	0	0	975000	0	0	0	0	50000			1025000	10,123,335		108,479,
15		Southampton Port		0	0	0	0	925000	0	0	0	0	70000	0			995000	12,963,032		105,304,
16		Felixstowe Port		0	0	0	0	0	0	0	0	0	0	0			0	-		
17		Capacity		30,000	10,000	30,000	30,000	1,700,000	1,300,000	200,000	312,000	45,000	70,000	50,000			3,777,000	38,406,878	86,350,000	216,958,
18				30000	10000	30000	30000	1700000	1300000	200000	312000	45000	70000	50000			1,727,000			
19																				
20		Input			Output				Carbon Tax/Trading									CTax	56,062	Total C
21		UK Paper Consumption	6,600,000	13200000	Local proces	1,727,000			Tax Rate	293	£/tonne							CET		Total CE to
22		Total Paper Recovered	1,461,387		Export	2,050,000			CET Price									Total Cost, Z =	453,340,378	
23		Export	2,050,000		Import	5,138,613														
24		Import	2,960,613		Local (extra	969,000			Carbon Limit	200	tonne									
25		Total Recovered	3,777,000																	
26		Total Supply	3,777,000																	
27		Total Demand	2,696,000					Carbon price (£	Total Cost (£)	Export	Import	al Process	sportation	Operation Cost	rchasing Co	Selling Profit	CE Cost	on Emission (to	Total Capacity	Filled Cap
28		Virgin Paper: Source UK	2,178,000	33%				293	##########	2,050,000	########	########	########	86,350,000	########	##########	56,062	391	2,696,000	1,72
29		Recycling: Source UK Co	4,422,000	67%	from: Realising the value of recovered paper: An update															
30																				
31			£				Transportation Cost													
32		Recycled Paper Price/to	181	100	500	Transportation Cost per mile (£)			1.72	Ship cost										
33		Total Paper Consumpti	6,600,000	13,200,000	Demand			Fixed cost (£)	108.12	350										
34		Total MRF Capacity	0	3,777,000		Transportation Cost per km (£)			1.08	0.055										
35		Total P Mill Capacity		2,696,000																
36		Different local	1,081,000				Operation Cost													
37							Local PM (	50.00	from CPI_response_paper mills cost.pdf, £70 at year 2030											

A.2. Solver Parameters



A.3 Distance from Material Recycling Facilities to Paper Mills and Ports

Road transportation distance in km

ME20 7PE Postcode

1 mile = 1.61 km

From / To	Craigavon	Kirkcaldy	Inverness	Irvine	Chester	Caerphilly	Dewsbury	Coalville	Tilbury	Kent	Southampton	Craigavon / Liverpool Port	Shekou Port	Capacity
Belfast Port	49											298	17853	
North Ayrshire		137	314	13	422	675	427	536	726	754	723	384		280,000
Croy		80	256	71	384	637	389	498	688	714	685	347		96,000
Deeside		453	640	405	12	328	125	190	379	406	378	44		520,000
Darwen		378	565	330	97	349	81	211	400	427	398	61		325,000
Birmingham		530	717	480	154	187	179	54	229	256	227	168		325,000
Watchet		738	925	688	362	136	400	275	355	341	171	376		325,000
Collumpton		754	939	704	378	151	414	290	371	314	163	392		325,000
Sittingbourne		790	976	741	414	325	381	256	62	28	192	429		250,000
ME6 5AX Kent		810	995	760	434	334	400	274	81	5	200	448		250,000
Grangemouth Port		56	251	94	406	659	411	520	710	736	709	380	10022	
Liverpool Port		413	598	363	49	339	116	200	390	416	387	0	18458	
Southampton Port		752	938	702	376	218	376	256	186	171	2	300	10587	
Felixstowe Port		738	923	688	411	398	347	251	122	157	288	420	17795	
Capacity	50,000	30,000	10,000	30,000	30,000	1,700,000	1,300,000	200,000	312,000	45,000	70,000			

A.4 Carbon Emissions from Transportation from Material Recycling Facilities to Paper Mills and Ports

Carbon emissions for Transportation in kg/km/tonne of paper, for the given distance

From / To	Craigavon	Kirkcaldy	Inverness	Irvine	Chester	Caerphilly	Dewsbury	Coalville	Tilbury	Kent	Southampton	Craigavon / Liverpool Port	Shekou Port	Capacity
Belfast Port	5.8													
North Ayrshire		5.8	13.2	0.5	17.7	28.4	17.9	22.5	30.5	31.7	30.4	16.1		280,000
Croy		3.4	10.8	3.0	16.1	26.7	16.3	20.9	28.9	30.0	28.8	14.6		96,000
Deeside		19.0	26.9	17.0	0.5	13.8	5.2	8.0	15.9	17.1	15.9	1.8		520,000
Darwen		15.9	23.7	13.8	4.1	14.6	3.4	8.9	16.8	17.9	16.7	2.6		325,000
Birmingham		22.2	30.1	20.2	6.5	7.9	7.5	2.3	9.6	10.8	9.5	7.1		325,000
Watchet		31.0	38.8	28.9	15.2	5.7	16.8	11.6	14.9	14.3	7.2	15.8		325,000
Collumpton		31.7	39.4	29.6	15.9	6.4	17.4	12.2	15.6	13.2	6.9	16.5		325,000
Sittingbourne		33.2	41.0	31.1	17.4	13.6	16.0	10.8	2.6	1.2	8.1	18.0		250,000
Kent		34.0	41.8	31.9	18.2	14.0	16.8	11.5	3.4	0.2	8.4	18.8		250,000
Grangemouth Port		2.3	10.6	4.0	17.1	27.7	17.3	21.8	29.8	30.9	29.8	16.0	76.2	
Liverpool Port		17.3	25.1	15.3	2.1	14.2	4.9	8.4	16.4	17.5	16.3	0.0	140.3	
Southampton Port		31.6	39.4	29.5	15.8	9.1	15.8	10.8	7.8	7.2	0.1	12.6	80.5	
Felixstowe Port		31.0	38.8	28.9	17.3	16.7	14.6	10.6	5.1	6.6	12.1	17.6	135.2	
Capacity	50,000	30,000	10,000	30,000	30,000	1,700,000	1,300,000	200,000	312,000	45,000	70,000			

Road Transportation

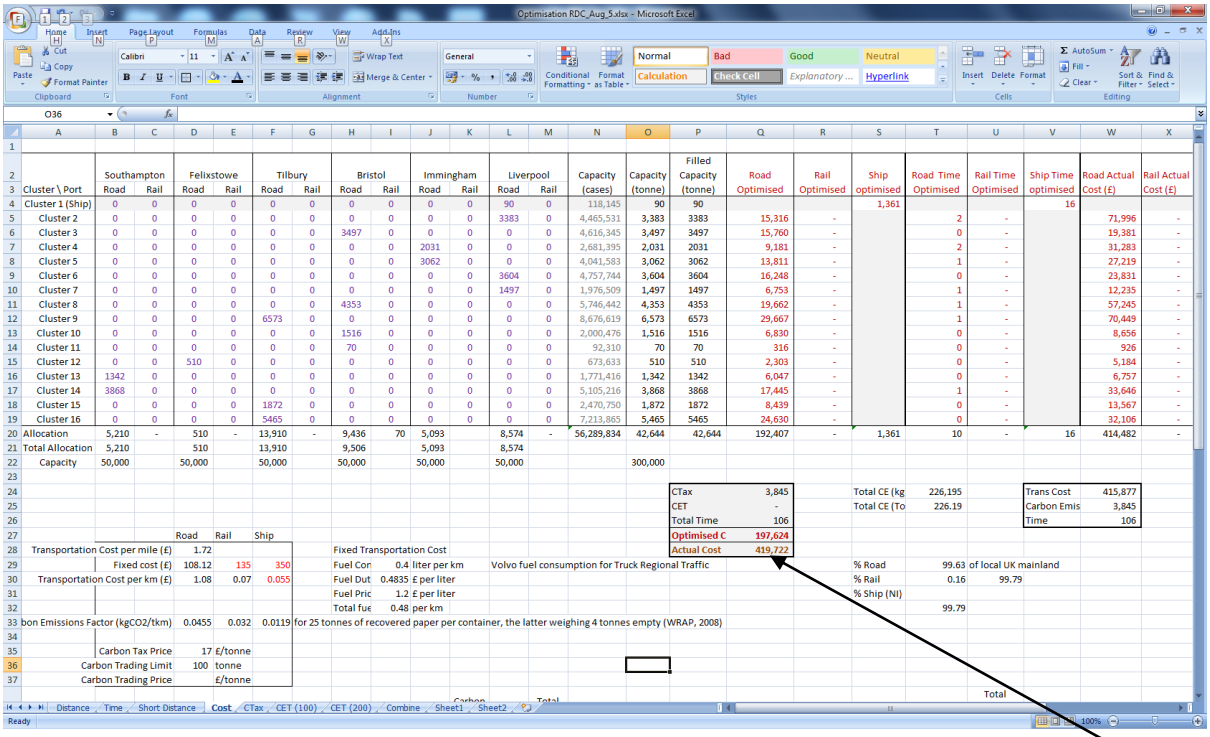
Emission factor (kgC 0.042

Ship

Emission f 0.0076

Appendix B: Fresh Produce Optimisation Model in Spreadsheet

B.1 The Optimisation Model



Cluster \ Port	Southampton Road	Southampton Rail	Felixstowe Road	Felixstowe Rail	Tilbury Road	Tilbury Rail	Bristol Road	Bristol Rail	Immingham Road	Immingham Rail	Liverpool Road	Liverpool Rail	Capacity (cases)	Capacity (tonne)	Filled Capacity (tonne)	Road Optimised	Rail Optimised	Ship optimised	Road Time Optimised	Rail Time Optimised	Ship Time optimised	Road Actual Cost (£)	Rail Actual Cost (£)
Cluster 1 (Ship)	0	0	0	0	0	0	0	0	0	0	90	0	118,145	90	90			1,361			16		
Cluster 2	0	0	0	0	0	0	0	0	0	0	3383	0	4,465,531	3,383	3383	15,316	-		2	-		71,996	-
Cluster 3	0	0	0	0	0	0	3497	0	0	0	0	0	4,616,345	3,497	3497	15,760	-		0	-		19,381	-
Cluster 4	0	0	0	0	0	0	0	0	2031	0	0	0	2,681,395	2,031	2031	9,181	-		2	-		31,283	-
Cluster 5	0	0	0	0	0	0	0	0	3062	0	0	0	4,041,583	3,062	3062	13,811	-		1	-		27,219	-
Cluster 6	0	0	0	0	0	0	0	0	0	0	3604	0	4,757,744	3,604	3604	16,248	-		0	-		23,831	-
Cluster 7	0	0	0	0	0	0	0	0	0	0	1497	0	1,976,509	1,497	1497	6,753	-		1	-		12,235	-
Cluster 8	0	0	0	0	0	0	4353	0	0	0	0	0	5,746,442	4,353	4353	19,662	-		1	-		57,245	-
Cluster 9	0	0	0	0	6573	0	0	0	0	0	0	0	8,676,619	6,573	6573	29,667	-		1	-		70,449	-
Cluster 10	0	0	0	0	0	0	1516	0	0	0	0	0	2,000,476	1,516	1516	6,830	-		0	-		8,656	-
Cluster 11	0	0	0	0	0	0	70	0	0	0	0	0	92,310	70	70	316	-		0	-		926	-
Cluster 12	0	0	510	0	0	0	0	0	0	0	0	0	673,633	510	510	2,303	-		0	-		5,184	-
Cluster 13	1342	0	0	0	0	0	0	0	0	0	0	0	1,771,416	1,342	1342	6,047	-		0	-		6,757	-
Cluster 14	3868	0	0	0	0	0	0	0	0	0	0	0	5,105,216	3,868	3868	17,445	-		1	-		33,646	-
Cluster 15	0	0	0	0	1872	0	0	0	0	0	0	0	2,470,750	1,872	1872	8,439	-		0	-		13,567	-
Cluster 16	0	0	0	0	5465	0	0	0	0	0	0	0	7,213,865	5,465	5465	24,630	-		0	-		32,106	-
Allocation	5,210	-	510	-	13,910	-	9,436	70	5,093		8,574	-	56,289,834	42,644	42,644	192,407	-	1,361	10	-	16	414,482	-
Total Allocation	5,210		510		13,910		9,506		5,093		8,574												
Capacity	50,000		50,000		50,000		50,000		50,000		50,000			300,000									

CTax	3,845
CET	-
Total Time	106
Optimised C	197,624
Actual Cost	419,722

Trans Cost	415,877
Carbon Emis	3,845
Time	106

	Road	Rail	Ship
Transportation Cost per mile (£)	1.72		
Fixed cost (£)	108.12	135	350
Transportation Cost per km (£)	1.08	0.07	0.055
bon Emissions Factor (kgCO2/tkm)	0.0455	0.032	0.0119

Fixed Transportation Cost

Fuel Cor 0.4 liter per km Volvo fuel consumption for Truck Regional Traffic

Fuel Dut 0.4835 £ per liter

Fuel Pric 1.2 £ per liter

Total fue 0.48 per km

for 25 tonnes of recovered paper per container, the latter weighing 4 tonnes empty (WRAP, 2008)

Carbon Tax Price 17 £/tonne

Carbon Trading Limit 100 tonne

Carbon Trading Price £/tonne

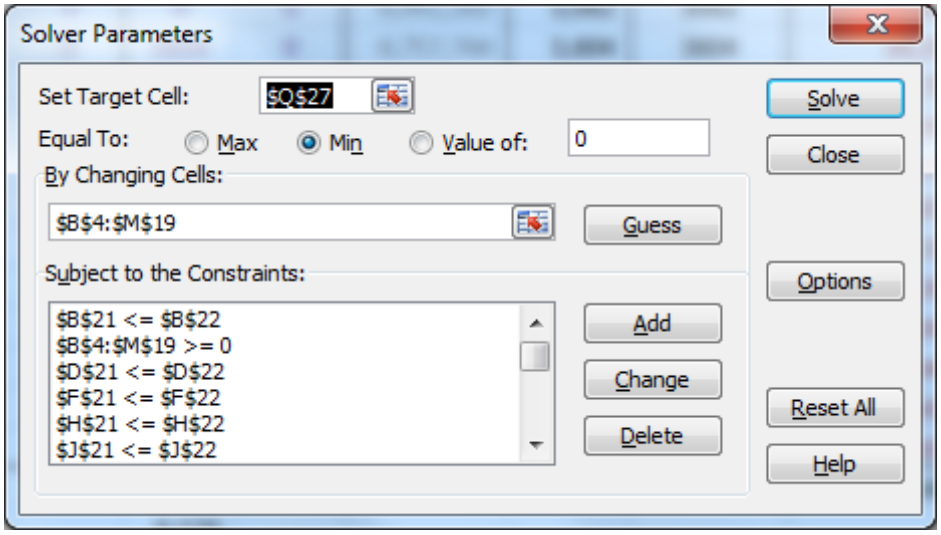
Total CE (kg	226,195
Total CE (To	226.19

% Road	99.63	of local UK mainland
% Rail	0.16	99.79
% Ship (NI)		
	99.79	

Total

Total Cost = Road Cost + Rail Cost + Ship Cost + Carbon Emission Cost

B.2. Solver Parameters



B.3 Distance from ports to clusters

Distance in km

Cluster \ Port	Southampton Road	Southampton Rail	Felixstowe Road	Felixstowe Rail	Tilbury Road	Tilbury Rail	Bristol Road	Bristol Rail	Immingham Road	Immingham Rail	Liverpool Road	Liverpool Rail
Cluster 1	889		1191		1204		574		1272		252	
Cluster 2	716	716	749	749	717	717	625	625	480	480	375	375
Cluster 3	181	181	362	362	282	282	23	23	369	369	303	303
Cluster 4	517	517	467	467	456	456	462	462	243	243	278	278
Cluster 5	365	365	317	317	316	316	310	310	98	98	196	196
Cluster 6	375	375	396	396	376	376	284	284	192	192	47	47
Cluster 7	315	315	350	350	315	315	191	191	226	226	82	82
Cluster 8	221	221	240	240	203	203	193	193	202	202	201	201
Cluster 9	181	181	190	190	139	139	217	217	248	248	261	261
Cluster 10	171	171	373	373	293	293	27	27	382	382	318	318
Cluster 11	248	248	546	546	406	406	195	195	554	554	486	486
Cluster 12	263	263	126	126	148	148	310	310	180	180	335	335
Cluster 13	12	12	291	291	187	187	179	179	421	421	393	393
Cluster 14	94	94	229	229	134	134	149	149	356	356	333	333
Cluster 15	169	169	144	144	61	61	238	238	275	275	349	349
Cluster 16	172	172	137	137	31	31	264	264	324	324	398	398

Area
Northern Ireland
Scotland
Wales, Ross on Wye, Ashchurch
North East
Yorkshire and the Humber
Liverpool & Manchester
Crewe and Stoke
Birmingham, Coventry, Lutterworth, Alfreton
Milton Keynes, Bedford, Northampton, up to Rugby
Bristol, Trowbridge, Wellington
Plymouth
Cambridge, Thetford, Peterborough
Southampton, Portsmouth
Andover, Didcot, Bracknell, Farmborough
Brent, Harlow
Maidstone, Crawleys,Grays

Normalised Distance

Cluster \ Port	Southampton Road	Southampton Rail	Felixstowe Road	Felixstowe Rail	Tilbury Road	Tilbury Rail	Bristol Road	Bristol Rail	Immingham Road	Immingham Rail	Liverpool Road	Liverpool Rail
Cluster 1	0.70		0.94		0.95		0.45		1.00		0.20	
Cluster 2	0.56	0.56	0.59	0.59	0.56	0.56	0.49	0.49	0.38	0.38	0.29	0.29
Cluster 3	0.14	0.14	0.28	0.28	0.22	0.22	0.02	0.02	0.29	0.29	0.24	0.24
Cluster 4	0.41	0.41	0.37	0.37	0.36	0.36	0.36	0.36	0.19	0.19	0.22	0.22
Cluster 5	0.29	0.29	0.25	0.25	0.25	0.25	0.24	0.24	0.08	0.08	0.15	0.15
Cluster 6	0.29	0.29	0.31	0.31	0.30	0.30	0.22	0.22	0.15	0.15	0.04	0.04
Cluster 7	0.25	0.25	0.28	0.28	0.25	0.25	0.15	0.15	0.18	0.18	0.06	0.06
Cluster 8	0.17	0.17	0.19	0.19	0.16	0.16	0.15	0.15	0.16	0.16	0.16	0.16
Cluster 9	0.14	0.14	0.15	0.15	0.11	0.11	0.17	0.17	0.20	0.20	0.20	0.20
Cluster 10	0.13	0.13	0.29	0.29	0.23	0.23	0.02	0.02	0.30	0.30	0.25	0.25
Cluster 11	0.19	0.19	0.43	0.43	0.32	0.32	0.15	0.15	0.44	0.44	0.38	0.38
Cluster 12	0.21	0.21	0.10	0.10	0.12	0.12	0.24	0.24	0.14	0.14	0.26	0.26
Cluster 13	0.01	0.01	0.23	0.23	0.15	0.15	0.14	0.14	0.33	0.33	0.31	0.31
Cluster 14	0.07	0.07	0.18	0.18	0.11	0.11	0.12	0.12	0.28	0.28	0.26	0.26
Cluster 15	0.13	0.13	0.11	0.11	0.05	0.05	0.19	0.19	0.22	0.22	0.27	0.27

B.4 Travel time from ports to clusters

Time in hour

Cluster \ Port	Southampton Road	Southampton Rail	Felixstowe Road	Felixstowe Rail	Tilbury Road	Tilbury Rail	Bristol Road	Bristol Rail	Immingham Road	Immingham Rail	Liverpool Road	Liverpool Rail
Cluster 1	48.00		64.80		64.80		31.20		69.60		14.40	
Cluster 2	7.52	8.73	7.83	7.83	7.38	7.23	6.47	8.32	5.41	5.89	4.07	5.21
Cluster 3	2.08	3.46	3.83	6.45	2.96	4.19	0.42	1.89	3.91	4.91	3.25	4.13
Cluster 4	5.67	6.72	5.16	5.60	5.24	5.15	4.94	6.92	2.78	3.89	3.14	4.49
Cluster 5	4.01	5.21	3.54	4.15	3.41	4.08	3.28	5.35	1.18	1.76	1.75	3.22
Cluster 6	4.05	5.94	4.23	5.76	3.93	4.62	2.98	5.08	2.14	4.05	0.73	1.51
Cluster 7	3.45	4.73	3.79	5.50	3.33	3.64	2.13	4.13	2.55	3.42	1.05	1.49
Cluster 8	2.65	3.87	2.71	4.02	2.23	3.08	2.09	3.61	2.22	3.44	2.30	3.17
Cluster 9	2.24	3.80	2.31	3.69	1.62	2.80	2.46	4.28	2.77	4.25	2.88	3.54
Cluster 10	2.10	2.80	3.96	5.35	3.25	4.13	0.43	0.49	3.91	5.59	3.40	5.03
Cluster 11	3.28	4.62	5.72	7.15	4.72	5.45	2.12	4.02	5.78	7.32	5.13	6.72
Cluster 12	3.00	4.10	1.56	2.69	1.71	2.85	3.39	4.95	2.74	2.97	3.74	4.98
Cluster 13	0.31	0.29	3.12	5.38	2.03	3.39	1.97	3.31	4.52	6.15	4.21	6.14
Cluster 14	1.23	2.07	2.62	3.70	1.65	2.42	1.67	2.75	3.82	4.64	3.52	4.65
Cluster 15	1.96	3.90	1.70	2.90	0.83	1.75	2.57	3.25	3.37	3.71	3.78	4.12
Cluster 16	1.96	3.67	1.60	3.27	0.46	1.84	2.79	4.95	3.81	4.47	4.22	4.64

Area
Northern Ireland
Scotland
Wales, Ross on Wye, Ashchurch
North East
Yorkshire and the Humber
Liverpool & Manchester
Crewe and Stoke
Birmingham, Coventry, Lutterworth, Alfreton
Milton Keynes, Bedford, Northampton, up to Rugby
Bristol, Trowbridge, Wellington
Plymouth
Cambridge, Thetford, Peterborough
Southampton, Portsmouth
Andover, Didcot, Bracknell, Farmborough
Brent, Harlow
Maidstone, Crawleys,Grays

Normalised Time

Cluster \ Port	Southampton Road	Southampton Rail	Felixstowe Road	Felixstowe Rail	Tilbury Road	Tilbury Rail	Bristol Road	Bristol Rail	Immingham Road	Immingham Rail	Liverpool Road	Liverpool Rail
Cluster 1	0.69		0.93		0.93		0.45		1.00		0.21	
Cluster 2	0.11	0.13	0.11	0.11	0.11	0.10	0.09	0.12	0.08	0.08	0.06	0.07
Cluster 3	0.03	0.05	0.06	0.09	0.04	0.06	0.01	0.03	0.06	0.07	0.05	0.06
Cluster 4	0.08	0.10	0.07	0.08	0.08	0.07	0.07	0.10	0.04	0.06	0.05	0.06
Cluster 5	0.06	0.07	0.05	0.06	0.05	0.06	0.05	0.08	0.02	0.03	0.03	0.05
Cluster 6	0.06	0.09	0.06	0.08	0.06	0.07	0.04	0.07	0.03	0.06	0.01	0.02
Cluster 7	0.05	0.07	0.05	0.08	0.05	0.05	0.03	0.06	0.04	0.05	0.02	0.02
Cluster 8	0.04	0.06	0.04	0.06	0.03	0.04	0.03	0.05	0.03	0.05	0.03	0.05
Cluster 9	0.03	0.05	0.03	0.05	0.02	0.04	0.04	0.06	0.04	0.06	0.04	0.05
Cluster 10	0.03	0.04	0.06	0.08	0.05	0.06	0.01	0.01	0.06	0.08	0.05	0.07
Cluster 11	0.05	0.07	0.08	0.10	0.07	0.08	0.03	0.06	0.08	0.11	0.07	0.10
Cluster 12	0.04	0.06	0.02	0.04	0.02	0.04	0.05	0.07	0.04	0.04	0.05	0.07
Cluster 13	0.00	0.00	0.04	0.08	0.03	0.05	0.03	0.05	0.06	0.09	0.06	0.09
Cluster 14	0.02	0.03	0.04	0.05	0.02	0.03	0.02	0.04	0.05	0.07	0.05	0.07
Cluster 15	0.03	0.06	0.02	0.04	0.01	0.03	0.04	0.05	0.05	0.05	0.05	0.06

B.4 Distance and travel time from train stations to RDCs

Cluster \ Port	Distance km	Time Hour	Normalised Distance	Normalised Time	Area
Cluster 1	9.39	0.16	0.90	0.76	Northern Ireland
Cluster 2	3.66	0.11	0.35	0.52	Scotland
Cluster 3	5.77	0.16	0.55	0.76	Wales, Ross on Wye, Ashchurch
Cluster 4	10.44	0.21	1.00	1.00	North East
Cluster 5	4.45	0.16	0.43	0.76	Yorkshire and the Humber
Cluster 6	8.23	0.17	0.79	0.81	Liverpool & Manchester
Cluster 7	4.87	0.13	0.47	0.62	Crewe and Stoke
Cluster 8	5.83	0.15	0.56	0.71	Birmingham, Coventry, Lutterworth, Alfreton
Cluster 9	5.79	0.15	0.55	0.71	Milton Keynes, Bedford, Northampton, up to Rugby
Cluster 10	8.63	0.21	0.83	1.00	Bristol, Trowbridge, Wellington
Cluster 11	2.72	0.12	0.26	0.57	Plymouth
Cluster 12	2.84	0.10	0.27	0.48	Cambridge, Thetford, Peterborough
Cluster 13	5.37	0.16	0.51	0.76	Southampton, Portsmouth
Cluster 14	2.57	0.10	0.25	0.48	Andover, Didcot, Bracknell, Farmborough
Cluster 15	2.82	0.09	0.27	0.43	Brent, Harlow
Cluster 16	1.84	0.06	0.18	0.29	Maidstone, Crawleys,Grays

Appendix C: Carbon Price Monitored Daily from http://www.pointcarbon.com

Date	Increase	Decrease	Carbon Price (€)
16-Dec-09		0.03	14.40
17-Dec-09		0.74	13.66
18-Dec-09			13.02
21-Dec-09			12.37
22-Dec-09	0.36		12.73
23-Dec-09			12.99
24-Dec-09		0.22	12.77
28-Dec-09			12.77
29-Dec-09		0.20	12.57
30-Dec-09			12.68
31-Dec-09		0.15	12.53
04-Jan-10	0.56		13.09
05-Jan-10		0.34	12.75
06-Jan-10		0.30	12.45
07-Jan-10	0.15		12.60
08-Jan-10	0.39		12.99
11-Jan-10	0.21		13.20
12-Jan-10		0.27	12.93
13-Jan-10	0.01		12.94
14-Jan-10	0.61		13.55
15-Jan-10		0.23	13.32
18-Jan-10	0.33		13.65
19-Jan-10	0.06		13.71
20-Jan-10		0.31	13.40
21-Jan-10		0.09	13.31
22-Jan-10			13.20
25-Jan-10	0.19		13.39
26-Jan-10	0.18		13.57
27-Jan-10		0.04	13.53
28-Jan-10		0.41	13.12
29-Jan-10			12.96
01-Feb-10		0.22	12.74
02-Feb-10		0.10	12.64
03-Feb-10	0.11		12.75
04-Feb-10			13.08
05-Feb-10			13.40
08-Feb-10	0.25		13.65

Date	Increase	Decrease	Carbon Price (€)
09-Feb-10		0.17	13.48
10-Feb-10		0.21	13.27
11-Feb-10		0.04	13.23
12-Feb-10		0.28	12.95
15-Feb-10			13.02
16-Feb-10	0.30		13.32
17-Feb-10		0.29	13.03
18-Feb-10			12.90
19-Feb-10		0.32	12.58
22-Feb-10	0.11		12.69
23-Feb-10	0.09		12.78
24-Feb-10	0.21		12.99
25-Feb-10		0.10	12.89
26-Feb-10	0.08		12.97
01-Mar-10			13.26
02-Mar-10	0.05		13.31
03-Mar-10	0.24		13.55
04-Mar-10		0.30	13.25
05-Mar-10	0.09		13.34
08-Mar-10		0.16	13.18
09-Mar-10		0.07	13.11
10-Mar-10	0.13		13.24
11-Mar-10		0.25	12.99
12-Mar-10			12.84
15-Mar-10	0.18		13.02
16-Mar-10		0.05	12.97
17-Mar-10	0.06		13.03
18-Mar-10	0.07		13.10
19-Mar-10			13.08
22-Mar-10	0.09		13.17
23-Mar-10		0.24	12.93
24-Mar-10		0.19	12.74
25-Mar-10			12.68
26-Mar-10	0.21		12.89
29-Mar-10		0.05	12.84
30-Mar-10		0.06	12.78
31-Mar-10	0.08		12.86
01-Apr-10	0.17		13.03
06-Apr-10	0.43		13.46
07-Apr-10	0.03		13.49
08-Apr-10			13.63

Date	Increase	Decrease	Carbon Price (€)
09-Apr-10	0.05		13.68
12-Apr-10	0.01		13.69
13-Apr-10	0.03		13.72
14-Apr-10			13.93
15-Apr-10			14.13
16-Apr-10	0.31		14.44
19-Apr-10	0.09		14.53
20-Apr-10	0.20		14.73
21-Apr-10		0.07	14.66
22-Apr-10	0.04		14.70
23-Apr-10	0.22		14.92
26-Apr-10	0.65		15.57
27-Apr-10		0.13	15.44
28-Apr-10		0.41	15.03
29-Apr-10	0.36		15.39
30-Apr-10	0.48		15.87
03-May-10	0.63		16.50
04-May-10		0.53	15.97
05-May-10		0.11	15.86
06-May-10	0.40		16.26
07-May-10		0.70	15.56
10-May-10		0.27	15.29
11-May-10			15.63
12-May-10	0.01		15.64
13-May-10	0.18		15.82
14-May-10		0.08	15.74
17-May-10		0.62	15.12
18-May-10	0.15		15.27
19-May-10		0.54	14.73
20-May-10		0.12	14.61
21-May-10	0.21		14.82
24-May-10	0.53		15.35
25-May-10		0.18	15.17
26-May-10	0.49		15.66
27-May-10		0.09	15.57
28-May-10			15.41
31-May-10			15.32
01-Jun-10			15.28
02-Jun-10			15.24
03-Jun-10	0.02		15.26
04-Jun-10	0.07		15.33

Date	Increase	Decrease	Carbon Price (€)
07-Jun-10		0.15	15.18
08-Jun-10	0.53		15.71
09-Jun-10	0.05		15.76
10-Jun-10		0.27	15.49
11-Jun-10	0.07		15.56
14-Jun-10	0.35		15.91
15-Jun-10		0.10	15.81
16-Jun-10		0.21	15.60
17-Jun-10	0.02		15.62
18-Jun-10	0.08		15.70
21-Jun-10	0.14		15.84
22-Jun-10			15.34
23-Jun-10	0.02		15.36
24-Jun-10		0.14	15.22
25-Jun-10	0.13		15.35
28-Jun-10	0.08		15.43
29-Jun-10		0.23	15.20
30-Jun-10	0.04		15.24
01-Jul-10		0.03	15.21
02-Jul-10	0.11		15.32
05-Jul-10	0.01		15.33
06-Jul-10		0.09	15.24
07-Jul-10		0.35	14.89
08-Jul-10		0.41	14.48
09-Jul-10	0.19		14.67
12-Jul-10		0.51	14.16
13-Jul-10		0.32	13.84
14-Jul-10			13.89
15-Jul-10		0.01	13.88
16-Jul-10	0.48		14.36
19-Jul-10	0.16		14.52
20-Jul-10		0.27	14.25
21-Jul-10		0.37	13.88
22-Jul-10	0.38		14.26
23-Jul-10			14.07
26-Jul-10		0.38	13.69
27-Jul-10		0.13	13.54
28-Jul-10	0.21		13.75
29-Jul-10	0.28		14.03
30-Jul-10			14.12
02-Aug-10	0.29		14.41

Date	Increase	Decrease	Carbon Price (€)
03-Aug-10	0.02		14.43
04-Aug-10		0.07	14.36
05-Aug-10		0.02	14.34
06-Aug-10		0.13	14.21
09-Aug-10	0.25		14.46
10-Aug-10	0.04		14.50
11-Aug-10		0.09	14.41
12-Aug-10		0.01	14.40
13-Aug-10	0.08		14.48
16-Aug-10		0.09	14.39
17-Aug-10	0.10		14.49
18-Aug-10		0.11	14.38
19-Aug-10	0.52		14.90
20-Aug-10			15.04
23-Aug-10		0.27	14.77
24-Aug-10	0.19		14.96
25-Aug-10	0.35		15.31
26-Aug-10	0.02		15.33
27-Aug-10			15.32
30-Aug-10			15.45
31-Aug-10		0.16	15.29
01-Sep-10	0.11		15.40
02-Sep-10	0.41		15.81
03-Sep-10		0.06	15.75
06-Sep-10			15.78
07-Sep-10			15.77
08-Sep-10			15.77
09-Sep-10			15.54
10-Sep-10		0.28	15.26
13-Sep-10	0.11		15.37
14-Sep-10		0.11	15.26
15-Sep-10	0.15		15.41
16-Sep-10			15.24
17-Sep-10	0.04		15.28
20-Sep-10		0.22	15.06
21-Sep-10		0.19	14.87
22-Sep-10			14.97
23-Sep-10			14.87
24-Sep-10	0.45		15.32
27-Sep-10	0.07		15.39
28-Sep-10	0.29		15.68

Date	Increase	Decrease	Carbon Price (€)
29-Sep-10		0.08	15.60
30-Sep-10			15.48
01-Oct-10		0.12	15.36
04-Oct-10		0.10	15.26
05-Oct-10	0.24		15.50
06-Oct-10	0.07		15.57
07-Oct-10		0.14	15.43
08-Oct-10			15.56
11-Oct-10	0.27		15.83
12-Oct-10		0.11	15.72
13-Oct-10		0.03	15.69
14-Oct-10		0.10	15.59
15-Oct-10		0.10	15.49
18-Oct-10		0.16	15.33
19-Oct-10		0.26	15.07
20-Oct-10	0.02		15.09
21-Oct-10		0.21	14.88
22-Oct-10	0.08		14.96
25-Oct-10			15.17
26-Oct-10		0.18	14.99
27-Oct-10	0.08		15.07
28-Oct-10		0.16	14.91
29-Oct-10		0.25	14.66
01-Nov-10	0.01		14.67
02-Nov-10	0.08		14.75
03-Nov-10		0.01	14.74
04-Nov-10		0.36	14.38
05-Nov-10	0.08		14.46
08-Nov-10		0.27	14.19
09-Nov-10	0.10		14.29
10-Nov-10	0.21		14.50
11-Nov-10	0.30		14.80
12-Nov-10	0.11		14.91
15-Nov-10			15.10
16-Nov-10		0.46	14.64
17-Nov-10	0.25		14.89
19-Nov-10			14.85
20-Nov-10	0.10		14.95
22-Nov-10	0.13		15.08
23-Nov-10		0.08	15.00
24-Nov-10	0.15		15.15

Date	Increase	Decrease	Carbon Price (€)
25-Nov-10		0.06	15.09
26-Nov-10		0.03	15.06
29-Nov-10		0.09	14.97
30-Nov-10		0.27	14.70
01-Dec-10	0.14		14.84
02-Dec-10		0.16	14.68
03-Dec-10	0.08		14.76
06-Dec-10	0.09		14.85
07-Dec-10		0.07	14.78
08-Dec-10		0.11	14.67
09-Dec-10		0.14	14.53
10-Dec-10	0.01		14.54
13-Dec-10		0.10	14.53
14-Dec-10		0.07	14.46
15-Dec-10		0.13	14.33
16-Dec-10		0.05	14.28
17-Dec-10			14.12
21-Dec-10	0.05		14.17
22-Dec-10	0.17		14.34
23-Dec-10		0.21	14.14
24-Dec-10		0.08	14.05
31-Dec-10			14.24
03-Jan-11	0.00		14.24
04-Jan-11	0.17		14.41
05-Jan-11	0.07		14.48
06-Jan-11	0.24		14.72
07-Jan-11		0.10	14.62
10-Jan-11		0.29	14.33
11-Jan-11		0.02	14.31
12-Jan-11		0.09	14.22
13-Jan-11	0.06		14.28
14-Jan-11	0.16		14.44
17-Jan-11	0.12		14.56
18-Jan-11	0.00		14.56
19-Jan-11			14.48
20-Jan-11			14.40
21-Jan-11	0.07		14.47
24-Jan-11	0.11		14.58
25-Jan-11	0.28		14.86
26-Jan-11	0.11		14.97
27-Jan-11		0.20	14.77

Date	Increase	Decrease	Carbon Price (€)
28-Jan-11		0.09	14.68
31-Jan-11	0.24		14.92
01-Feb-11		0.04	14.88
02-Feb-11	0.09		14.97
03-Feb-11		0.27	14.70
04-Feb-11	0.00		14.70
07-Feb-11			14.62
08-Feb-11	0.11		14.73
09-Feb-11		0.07	14.66
10-Feb-11	0.03		14.69
11-Feb-11	0.18		14.87
14-Feb-11	0.02		14.89
15-Feb-11		0.09	14.80
16-Feb-11	0.00		14.80
17-Feb-11			14.92
18-Feb-11	0.07		14.99
21-Feb-11	0.24		15.23
22-Feb-11	0.15		15.38
23-Feb-11		0.08	15.30
24-Feb-11	0.06		15.36
25-Feb-11	0.03		15.39
28-Feb-11	0.12		15.51
01-Mar-11			15.49
02-Mar-11	0.13		15.62
03-Mar-11		0.13	15.49
04-Mar-11	0.34		15.83
07-Mar-11	0.09		15.92
08-Mar-11		0.08	15.84
09-Mar-11	0.03		15.87
10-Mar-11			15.82
11-Mar-11			15.76
14-Mar-11	0.85		16.61
15-Mar-11	0.71		17.32
16-Mar-11		0.01	17.31
17-Mar-11			16.90
18-Mar-11	0.22		17.12
21-Mar-11		0.23	16.89
22-Mar-11	0.08		16.97
23-Mar-11	0.00		16.97
24-Mar-11		0.38	16.59
25-Mar-11	0.21		16.80

Date	Increase	Decrease	Carbon Price (€)
28-Mar-11	0.44		17.24
29-Mar-11		0.13	17.11
30-Mar-11		0.09	17.02
31-Mar-11	0.26		17.28
01-Apr-11		0.08	17.20
04-Apr-11	0.16		17.36
05-Apr-11		0.22	17.14
06-Apr-11			17.10
07-Apr-11			17.05
08-Apr-11		0.06	16.99
11-Apr-11		0.24	16.75
12-Apr-11		0.14	16.61
13-Apr-11	0.02		16.63
14-Apr-11	0.15		16.78
15-Apr-11	0.35		17.13
18-Apr-11		0.38	16.75
19-Apr-11	0.02		16.77
20-Apr-11	0.20		16.97
21-Apr-11			16.92
25-Apr-11			16.86
26-Apr-11	0.04		16.90
27-Apr-11	0.12		17.02
28-Apr-11			17.09
29-Apr-11			17.15
02-May-11	0.19		17.34
03-May-11			17.21
04-May-11		0.11	17.10
05-May-11		0.18	16.92
06-May-11	0.11		17.03
09-May-11	0.01		17.04
10-May-11		0.07	16.97
11-May-11		0.13	16.84
12-May-11	0.00		16.84
13-May-11			16.78
16-May-11	0.10		16.88
17-May-11			16.68
18-May-11		0.10	16.58
19-May-11		0.07	16.51
20-May-11		0.13	16.38
23-May-11		0.23	16.15
24-May-11		0.01	16.14

Date	Increase	Decrease	Carbon Price (€)
25-May-11			**16.34**
26-May-11	**0.05**		**16.39**
27-May-11			**16.85**
30-May-11	**0.20**		**17.05**
31-May-11			
01-Jun-11			
02-Jun-11			**16.64**
03-Jun-11	**0.18**		**16.82**
06-Jun-11		**0.14**	**16.68**
07-Jun-11	**0.01**		**16.69**
08-Jun-11		**0.16**	**16.53**
09-Jun-11	**0.06**		**16.59**
10-Jun-11			**16.57**
13-Jun-11	**0.10**		**16.67**
14-Jun-11		**0.14**	**16.53**
15-Jun-11		**0.22**	**16.31**
16-Jun-11		**0.18**	**16.13**
17-Jun-11		**0.46**	**15.67**
20-Jun-11		**0.40**	**15.27**
21-Jun-11		**0.34**	**14.93**
22-Jun-11		**0.05**	**14.88**
23-Jun-11		**1.44**	**13.44**
24-Jun-11		**1.24**	**12.20**
27-Jun-11	**0.91**		**13.11**
28-Jun-11	**0.36**		**13.47**
29-Jun-11			**12.93**
30-Jun-11	**0.54**		**13.47**
01-Jul-11		**0.21**	**13.26**
04-Jul-11	**0.06**		**13.32**
05-Jul-11	**0.20**		**13.52**
06-Jul-11		**0.24**	**13.28**
07-Jul-11		**0.28**	**13.00**
08-Jul-11		**0.34**	**12.66**
11-Jul-11		**0.62**	**12.04**
12-Jul-11	**0.39**		**12.43**
13-Jul-11		**0.41**	**12.02**
14-Jul-11	**0.27**		**12.29**
15-Jul-11	**0.19**		**12.48**
18-Jul-11		**0.26**	**12.02**
19-Jul-11			**12.45**
20-Jul-11	**0.32**		**12.77**

Date	Increase	Decrease	Carbon Price (€)
21-Jul-11	0.35		13.12
22-Jul-11			13.01
25-Jul-11			12.90
26-Jul-11	0.02		12.92
27-Jul-11		0.54	12.38
28-Jul-11	0.20		12.58
29-Jul-11		0.36	12.22
01-Aug-11		0.30	11.82
02-Aug-11		0.45	11.37
03-Aug-11	0.00		11.37
04-Aug-11		0.59	10.78
05-Aug-11			10.76
08-Aug-11			10.73
09-Aug-11	0.60		11.33
10-Aug-11	0.22		11.55
11-Aug-11	0.70		12.25
12-Aug-11			12.45
15-Aug-11		0.07	12.38
16-Aug-11	0.01		12.39
17-Aug-11	0.41		12.80
18-Aug-11		0.41	12.39
19-Aug-11	0.11		12.50
22-Aug-11	0.07		12.57
23-Aug-11			12.82
24-Aug-11	0.35		13.17
25-Aug-11		0.20	12.97
26-Aug-11			13.11
29-Aug-11			13.25
30-Aug-11	0.22		13.47
31-Aug-11		0.42	13.05
01-Sep-11			12.86
02-Sep-11		0.22	12.64
05-Sep-11			12.44
06-Sep-11			12.23
07-Sep-11	0.22		12.45
08-Sep-11			12.28
09-Sep-11		0.36	11.92
12-Sep-11	0.02		11.94
13-Sep-11	0.07		12.01
14-Sep-11	0.17		12.18
15-Sep-11	0.21		12.39

Date	Increase	Decrease	Carbon Price (€)
16-Sep-11		0.23	12.16
19-Sep-11		0.32	11.84
20-Sep-11		0.01	11.83
21-Sep-11		0.04	11.79
22-Sep-11		0.41	11.38
23-Sep-11		0.06	11.32
26-Sep-11		0.44	10.88
27-Sep-11		0.15	10.73
28-Sep-11		0.24	10.49
29-Sep-11			10.87
30-Sep-11		0.14	10.73
03-Oct-11		0.56	10.17
04-Oct-11			10.08
05-Oct-11	0.19		10.27
06-Oct-11	0.15		10.42
07-Oct-11		0.02	10.40
10-Oct-11	0.31		10.71
11-Oct-11			10.63
12-Oct-11	0.10		10.73
13-Oct-11		0.39	10.34
14-Oct-11	0.11		10.45
17-Oct-11		0.07	10.38
18-Oct-11		0.15	10.23
19-Oct-11		0.18	10.05
20-Oct-11	0.09		10.14
21-Oct-11	0.24		10.38
24-Oct-11	0.09		10.47
25-Oct-11		0.08	10.39
26-Oct-11		0.23	10.16
27-Oct-11			10.41
28-Oct-11		0.03	10.38
31-Oct-11		0.21	10.17
01-Nov-11		0.30	9.87
02-Nov-11			9.69
03-Nov-11		0.02	9.67
04-Nov-11		0.19	9.48
07-Nov-11	0.38		9.86
08-Nov-11	0.25		10.11
09-Nov-11		0.22	9.89
10-Nov-11		0.15	9.74
11-Nov-11	0.45		10.19

Date	Increase	Decrease	Carbon Price (€)
14-Nov-11		0.14	10.05
15-Nov-11		0.03	10.02
16-Nov-11		0.15	9.87
17-Nov-11		0.19	9.68
18-Nov-11		0.37	9.31
21-Nov-11		0.38	8.93
22-Nov-11	0.13		9.06
23-Nov-11		0.69	8.37
24-Nov-11		0.49	7.88
25-Nov-11		0.28	7.60
28-Nov-11	0.31		7.92
29-Nov-11			7.85
30-Nov-11	0.52		8.37
01-Dec-11		0.44	7.93
02-Dec-11		0.13	7.80
05-Dec-11		0.41	7.39
06-Dec-11		0.20	7.19
07-Dec-11		0.01	7.18
08-Dec-11	0.29		7.47
09-Dec-11	0.48		7.95
12-Dec-11		0.37	7.58
13-Dec-11		0.49	7.09
14-Dec-11		0.67	6.42
15-Dec-11	0.38		6.80
16-Dec-11	0.08		6.88
19-Dec-11	0.12		7.00
20-Dec-11			8.81
21-Dec-11		0.46	8.35
22-Dec-11		0.19	8.16
23-Dec-11			7.74
02-Jan-12	0.03		7.32
03-Jan-12		0.54	6.78
04-Jan-12		0.29	6.49
05-Jan-12	0.21		6.70
06-Jan-12		0.11	6.59
09-Jan-12	0.14		6.73
10-Jan-12	0.40		7.13
11-Jan-12			7.08
12-Jan-12	0.14		7.22
13-Jan-12		0.15	7.07
16-Jan-12		0.33	6.74

Date	Increase	Decrease	Carbon Price (€)
17-Jan-12	0.11		6.85
18-Jan-12	0.00		6.85
19-Jan-12	0.27		7.12
20-Jan-12	0.07		7.19
23-Jan-12		0.14	7.05
24-Jan-12	0.51		7.56
25-Jan-12	0.01		7.57
26-Jan-12	0.04		7.61
27-Jan-12	0.59		8.20
30-Jan-12		0.33	7.87
31-Jan-12	0.11		7.98
01-Feb-12	0.51		8.49
02-Feb-12	0.28		8.77
03-Feb-12		0.21	8.56
06-Feb-12	0.15		8.71
07-Feb-12	0.01		8.72
08-Feb-12		0.36	8.36
09-Feb-12		0.19	8.17
10-Feb-12			7.96
13-Feb-12		0.29	7.67
14-Feb-12			8.02
15-Feb-12			8.36
16-Feb-12	0.61		8.97
17-Feb-12	0.28		9.25
20-Feb-12		0.36	8.89
21-Feb-12	0.30		9.19
22-Feb-12	0.04		9.23
23-Feb-12		0.31	8.92
24-Feb-12	0.40		9.32
27-Feb-12	0.16		9.48
28-Feb-12		0.44	9.04
29-Feb-12		0.31	8.73
01-Mar-12	0.16		8.89
02-Mar-12	0.20		9.09
05-Mar-12		0.19	8.90
06-Mar-12		0.43	8.47
07-Mar-12	0.15		8.62
08-Mar-12		0.03	8.59
09-Mar-12			8.04
12-Mar-12		0.22	7.82
13-Mar-12		0.06	7.76

Date	Increase	Decrease	Carbon Price (€)
14-Mar-12	0.30		8.06
15-Mar-12	0.01		8.07
16-Mar-12		0.26	7.81
19-Mar-12		0.08	7.73
20-Mar-12		0.39	7.34
21-Mar-12			7.91
22-Mar-12		0.61	7.30
23-Mar-12	0.13		7.43
26-Mar-12		0.05	7.38
27-Mar-12			7.17
28-Mar-12	0.00		7.17
29-Mar-12		0.24	6.93
30-Mar-12			7.06
23-Apr-12			7.18
24-Apr-12		0.03	7.15
25-Apr-12		0.04	7.11
26-Apr-12	0.21		7.32
27-Apr-12			7.36
30-Apr-12	0.15		7.51
01-May-12	0.07		7.58
02-May-12		0.32	7.26
03-May-12		0.11	7.15
04-May-12			6.95
08-May-12		0.02	6.75
09-May-12	0.02		6.77
10-May-12		0.03	6.74
11-May-12			6.83
14-May-12		0.16	6.67
15-May-12		0.12	6.55
16-May-12	0.11		6.66
17-May-12			6.61
18-May-12		0.12	6.49
21-May-12	0.14		6.63
22-May-12	0.30		6.93
23-May-12		0.13	6.80
24-May-12	0.05		6.85
25-May-12	0.07		6.92
28-May-12		0.12	6.80
29-May-12		0.05	6.75
30-May-12		0.28	6.47
31-May-12			6.56

Date	Increase	Decrease	Carbon Price (€)
08-Jun-12	0.14		6.65
11-Jun-12	0.02		6.67
12-Jun-12		0.02	6.65
13-Jun-12	0.10		6.75
14-Jun-12			6.94
15-Jun-12	0.35		7.29
18-Jun-12	0.15		7.44
19-Jun-12			7.56
20-Jun-12		0.06	7.50
21-Jun-12		0.03	7.47
22-Jun-12	0.65		8.12
25-Jun-12		0.07	8.05
26-Jun-12	0.07		8.12
27-Jun-12		0.16	7.96
28-Jun-12			7.93
29-Jun-12	0.38		8.31
02-Jul-12		0.19	8.12
03-Jul-12	0.16		8.28
04-Jul-12	0.02		8.30
05-Jul-12	0.05		8.35
06-Jul-12		0.22	8.13
09-Jul-12		0.12	8.01
10-Jul-12		0.11	7.90
11-Jul-12	0.03		7.93
12-Jul-12			7.76
13-Jul-12		0.18	7.58
16-Jul-12			7.53
17-Jul-12	0.14		7.67
18-Jul-12		0.47	7.20
19-Jul-12			6.88
20-Jul-12	0.27		7.15
23-Jul-12	0.01		7.16
24-Jul-12	0.06		7.22
25-Jul-12		0.37	6.85
26-Jul-12			6.92
27-Jul-12		0.04	6.88
30-Jul-12		0.29	6.59
31-Jul-12	0.29		6.88
01-Aug-12	0.04		6.92
02-Aug-12	0.16		7.08
03-Aug-12			7.13

Date	Increase	Decrease	Carbon Price (€)
06-Aug-12	0.04		7.17
07-Aug-12	0.16		7.33
08-Aug-12		0.10	7.23
09-Aug-12			7.17
10-Aug-12		0.02	7.15
13-Aug-12	0.22		7.37
14-Aug-12			7.66
15-Aug-12		0.16	7.50
16-Aug-12	0.13		7.63
17-Aug-12			7.69
20-Aug-12		0.09	7.60
21-Aug-12	0.28		7.88
22-Aug-12	0.11		7.99
23-Aug-12			8.09
24-Aug-12			8.19
27-Aug-12		0.04	8.15
28-Aug-12		0.17	7.98
29-Aug-12		0.27	7.71
30-Aug-12		0.11	7.60
31-Aug-12			

Appendix D: The Conference Paper Presented at International Conference on Operations and Supply Chain Management (ICOSCM 2011)

AN OPTIMISATION MODEL FOR PAPER RECYCLING LOGISTICS NETWORK

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Abstract

Product recycling in industries aims to reduce environment impact and increase resource reuse. The logistics and recycling networks to reprocess waste products have been widely established in industries. Reverse logistics to recycle end-of-life products is playing more important roles in supply chains as a key business process in the whole product supply chain cycle. While the reverse logistics and recycling activities helps to reduce negative impact on environment, they also generate carbon emission and other pollutions, and consume resources. This study therefore focuses on development of optimal strategies for waste paper recycling in reverse logistics networks under various carbon emission control policies in the UK. The optimisation model is formulated and run with different context in order to identify the impact of carbon emissions trading and carbon tax on the logistics network performance and environment.

Keywords: Recycling, carbon emission policy, optimisation.

I. Introduction

Logistics activities in relation to recycling and returned products from customers are known as reverse logistics. This research focuses on logistics activities dealing with waste paper products. Although the recycling activities facilitate reduction of waste and its impact on environment, the activities also consume resources and generate carbon emission. Therefore, a major challenge is to minimize the environmental impact of the reverse logistics activities while efficiently recycle the waste products. Various carbon control policies have been set up to encourage innovation in businesses to reduce carbon emission. It is expected that different policies will have different impact on businesses.

This research is conducted with a case of waste paper recycling which is crucial in the UK due to lack of processing capacity and large demand of paper products. Recycling of paper products result in a great amount of carbon emission [1]. To overcome this challenge, the reverse logistics operations for recycling the waste paper need to be optimised with constraints of recycling locations, processing capacities, transportation modes, demand, and export quantity and routes to achieve the objectives in low costs and minimum environment impacts [2]. The focus of this research is to identify the impact of the carbon control policies on the logistics service performance. Consequently the best policy options to control carbon emission and encourage sustainable recycling strategies can be identified. To achieve these objectives, an optimisation analytical model is proposed to analyse the performance of the reverse logistics service and recycling operations in the waste paper recycling case in the UK. The research outcome provides valuable guidance for recycling logistics businesses and the Government in effectiveness of carbon control policies and costs of logistics operations under such policies.

II. Literatures Review

Back in 1970's, reverse logistics was known as activities dealing with recovery of waste after consumptions [3]. In 1992 Pohlen and Farris II [4] identified different reverse logistics channel structures and described the details of functions of the channels with discussion of the issues affecting the structure of reverse logistics channels used in recycling. There are three classes of product recovery namely reusable, remanufacturing and recycling [5]. Reverse logistics can be defined as a type of business processes that involve planning, managing, and controlling the flow of wastes for either reuse or final disposal of wastes [6]. Transportation has a close relationship with reverse logistics. Numerous studies on transportation operations management have been reported in the literature. Transportation models associated with carbon emissions has been studied by Kim and Van Wee [7] and Janic [8]. As transportation systems expand and become more integrated, their impacts on the physical environment will become more complex [9]. Environment impact is a one of the main issues relating to the transportation management and has significant impact on traditional supply chain strategies.

Since Kyoto Protocol introduced in 1997, industrialised countries have to reduce the emission of green house gases at an average of 5% against 1990 level over five-year period [10]. Carbon policies such as carbon tax, cap-and-trade, baseline-and-credit, clean development mechanism and joint implementation have been introduced. Among these policies, cap-and-trade mechanism is a major policy in the world. Theoretically cap-and-trade schemes should provide assurance of meeting an overall emissions target at least cost [11]. In cap-and-trade mechanism, all participants are allocated with a cap or fixed number of annual allowances [12]. These participants can emit their carbon as long as their emissions are within the allocated cap. However, if they need to emit more, they need to buy from other's allowance. The transaction price is based on the price of carbon emission permit at the trade market [13]. Carbon tax on the other hand is another type of policy instruments imposed on every amount of carbon emissions. The calculations of tax rate are varying. Some calculation based on specific tax, fossil fuels and carbon content, and for end users in energy production [14][15]. While many researches focus only on one carbon policies at one time, some researchers use hybrid policy which is the combination of carbon emissions trading and carbon tax [16][17].

With the carbon emissions charge and the impact on environment, carbon policies become more and more important as it has significant impact on the performance of the business performance and cost structure in the reverse logistics supply chain network. Research in this policy impact on strategic planning of the reverse logistics is rarely found in the literature, and is critical to build sustainable recycling industry.

III. Model Description

In the waste paper recycling case, the recycling network include manufacturing mills to reprocess used paper products to recover the value of the products, materials recycling facilities to sort the used paper products, the export shipping lines to deliver the products to overseas and the logistics service facilities to distribute the products in the UK. To achieve the overall efficiency and minimise carbon emission, this research proposed an optimisation model which considers both carbon emission by different recycling operations (allocation of the used paper products to different processing facilities and with different quantities) and the operation costs.

The analysis is mainly focused on the strategic decisions on logistics network configuration and overall recycling arrangement between local processing and export. The detailed operational cost components, such as fixed costs, differences of processing costs and handling costs between different centres, etc. are not considered in the analysis. Figure 1 illustrates the problem scope that this research is focused on.

The commonly used mixed integer linear programming (MILP) method is used in the optimisation model. The objective of the model is to minimise total costs of recycling operations and carbon emission. The carbon emission costs are environmental costs which include tax and carbon credit purchase in the carbon trading scheme. The recycling operational costs include production costs, and transportation costs.

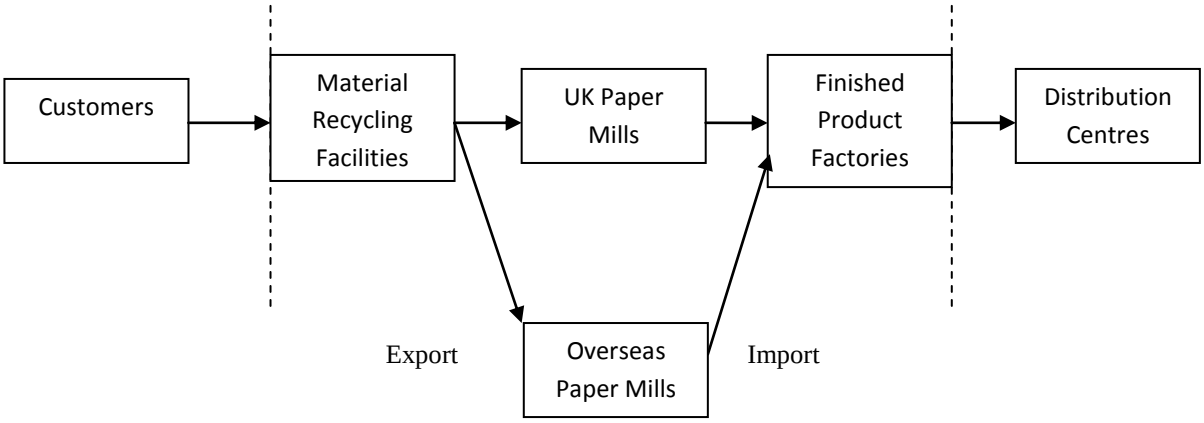

Figure 1: Reverse logistics network for paper recycling in the UK [2]

The optimisation model is described as following:

Objective function:

Total cost = Local transportation cost + Local production cost +Transportation cost for export + + Purchase cost for imported remanufactured materials – Sales revenue from export

+ Carbon emission cost of local transportation from material recycling facilities (MRF) to local paper mills (PM) + Carbon emission cost at local paper mills + Carbon emission cost for export transportation + Carbon emission surcharge or credit purchase if over the local total limit (1).

The constraints formulated in order to find the optimised solution contains of carbon emissions are in the capped limit (2), paper for local processing, exported and imported are the same as paper demand (3), waste paper for local processing and export are equal to waste paper supplied by material recycling facilities (4) and waste paper for each paper mill should not exceed capacity of the given paper mill (5). All the variables must be in positive values. Binary variable is used for selecting the paper mills.

$$\sum_{j}^{n}\sum_{i}^{m}[\![(TC]\!]_{i,j} * DT_{i,j} + PC_i * YF_i) * X_{i,j} + \sum_{g}^{p}\sum_{i}^{m}(TC_{i,g} * DT_{i,g}) * X_{i,g} + \sum_{h} PUR_h * PP_h + \sum_{g}^{p}\sum_{i}^{m} X_{i,g} * SP_i + \sum_{l}(CP * L\delta_l^+) \quad (1)$$

$$\sum_{j}^{n}\sum_{i}^{m}[\![(TC_{i,j}]\!] * DT_{i,j} + FUE_j) * X_{i,j} + \sum_{g}^{p}\sum_{i}^{m}[\![(TC_{i,g}]\!] * DT_{i,g}) * X_{i,g} - L\delta^+ = CL \quad (2)$$

$$\sum_{j}^{n}\sum_{i}^{m} X_{i,j} + \sum_{g}^{p}\sum_{i}^{m} X_{i,g} + \sum_{h} PUR_h = DRP \quad (3)$$

$$\sum_{j}^{n}\sum_{i}^{m} X_{i,j} + \sum_{g}^{p}\sum_{i}^{m} X_{i,g} = TSP \tag{4}$$

$$\sum_{j}^{n}\sum_{i}^{m} X_{i,j} \leq Z_i \tag{5}$$

$$X_{i,j}, X_{i,g} \geq 0,\ YF_j \in \{0,1\}$$

Notations:

i : Material recycling facilities (MRF) index

j : Paper mills (PM) index

g : Port index

m : Number of MRF

n : Number of PM

p : Number of Port

Z : Capacity of PM

X_{ij} : Quantity from MRF i to PM j

X_{ig} : Quantity from MRF i to Port g

DT_{ij} : Distance from MRF i to PM j

DT_{ig} : Distance from MRF i to Port g

TC_{ij} : Unit transportation cost from MRF i to PM j

TC_{ig} : Unit transportation cost from MRF i to Port g

YF_j : if PM j is employed, 0 otherwise

FUE_j : Unit carbon emission cost at PM j

PUR : Imported recovered paper

PP : Paper price

SP : Selling price

DRP : Demand for recovered paper

TSP : Total supply of waste paper

CP : Carbon price per unit/carbon emission surcharge

CL : Local carbon limit

$L\delta^+$: Local carbon emission excess

Assumptions in this model:

vi. The demand for recovered paper in this model is about 50% of the overall paper demand in the UK, which is 14 million tonnes [18].
vii. The carbon limit for this model is arbitrarily use at 10,000 tonnes.
viii. Carbon tax is estimated at £17 per tonne.
ix. The transportation cost and carbon emission cost for export is at seller's expense.
x. The amount of carbon emissions over the given limit can be either charged by penalty (carbon emission tax) or covered by purchasing credit from the market at the current price by the cap-and-trade scheme [19].

The data about paper recycling in the UK such as demand, total paper consumption, paper price, and types of paper are obtained from white paper published by WRAP [18][20]. The local material recycling facilities, paper mills, locations and capacity for each paper mill are obtained from the companies' information on line. There are many material recycling facilities and paper mills in the UK. Some core regional material recycling facilities and paper mills are chosen in the study, which covers Northern Ireland, Scotland, Wales, North England, Midlands and South England.

IV. Analysis Results

The optimisation analysis with the MIP model is performed with the Excel Solver tool. The objective of the model is to minimise the total cost in paper recycling network. Waste papers are sent from local material recycling to local paper

mills as well as for export. The model is run with different local capacity. The original local capacity is 2,696,000 tonnes. The sensitivity analysis for changes in local capacity is performed.

The result shows that the optimal solution allocates waste paper from material recycling facilities to the closest paper mills, according to supply and demand amount from material recycling facilities and paper mill. If the demand of the closest paper mill is already fulfilled, then the model allocates the waste paper to the next closest paper mill. Figure 2 shows total cost vs. local capacity with carbon emissions trading and carbon tax policies respectively. Carbon tax is relatively high in cost compared with carbon trading. However, with more local capacity the difference of these two policies becomes smaller. At about three million tonnes or 40% of local capacity, the total cost is almost the same for both carbon trading and carbon tax.

Figure 3 shows that there is no export with 40% increase in capacity as local capacity is fully filled. This explains same total cost for carbon trading and carbon tax policies after 40% capacity increase. Most of the cost in this model comes from exporting the waste paper to overseas. Therefore export contributes a large part of carbon emissions, and hence increase total cost for the paper recycling network. Figure 4 shows total cost vs. carbon emissions in tonne. The pattern shows positive relationship. As carbon emissions increases, total cost increases as well. Even though the difference exists in both policies, but it does not showed so much because in this model, transportation cost plays an important role. There is a huge difference between transportation cost and carbon emissions cost. However, if we compare between these two policies, carbon trading is better than carbon tax because carbon trading acquire less cost although there is a uncertainty in carbon trading which always depends on carbon limit and carbon price. In this analysis, the carbon limit is quite low, and still the total cost is still less than carbon tax. If the carbon limit is higher, the difference between these policies will be bigger.

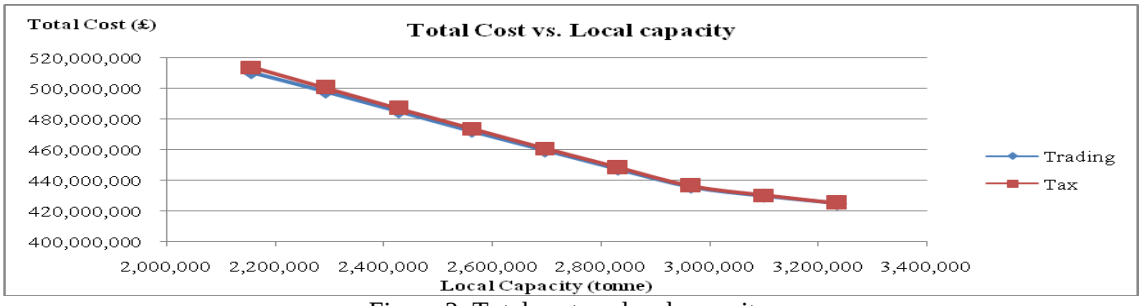

Figure 2: Total cost vs. local capacity

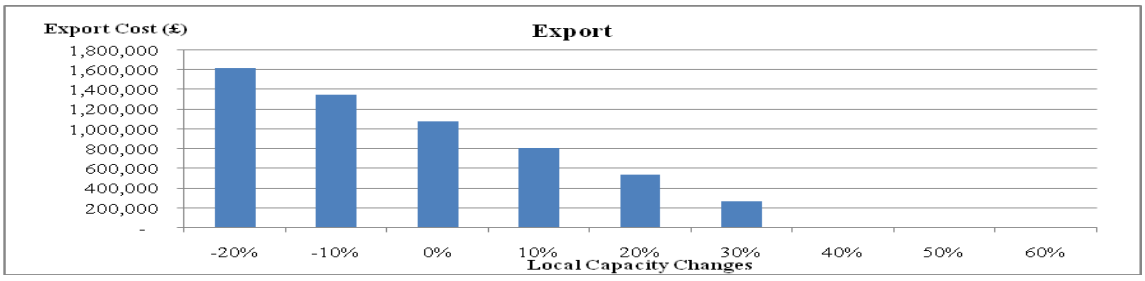

Figure 3: Export cost

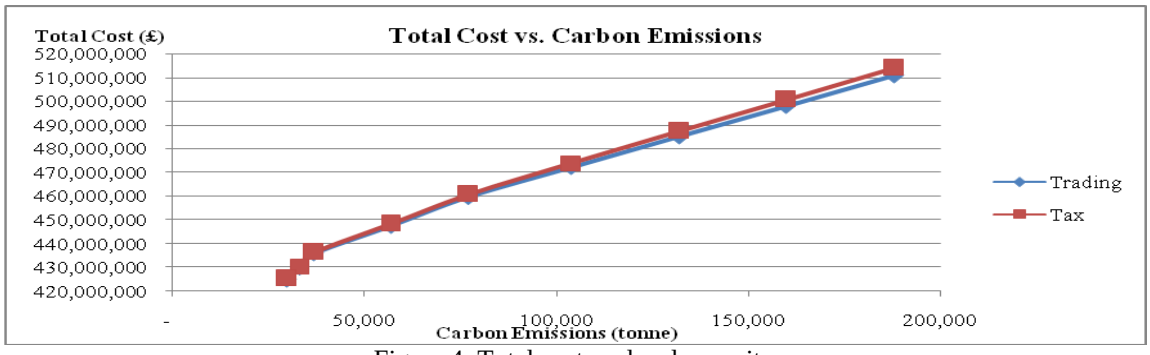

Figure 4: Total cost vs. local capacity

Scenario 1: Without import cost and demand

The import cost and local demand on paper constraint are removed from the original model in order to see the impact on export of waste paper. The graph of total cost vs. local capacity is shown in Figure 5. Carbon tax has a higher cost than carbon trading policy. At five million tonnes capacity or 100% increase in local capacity, the impacts of cost for carbon trading and carbon tax policies become almost the same. Similar to the original case, the impact of carbon trading and carbon tax policies on cost is almost the same because at this point, the export becomes the same with both policies. When we remove import cost and local demand the optimal solution always allocate some waste paper for export. With 100% increase in local capacity, the export cost will remains at the same level. Local capacity is always not fully filled because the allocations have been made to the closest paper mills. The remaining amount of waste paper that has not been allocated needs to be sent to very far processing facilities which may not have cost advantage (transport cost and processing cost) over export to overseas. The optimal solution implies that export will incur less cost than distribute them locally at the situation that the reprocessing mills are not distributed geographically within economic distance to waste paper recycling centres.

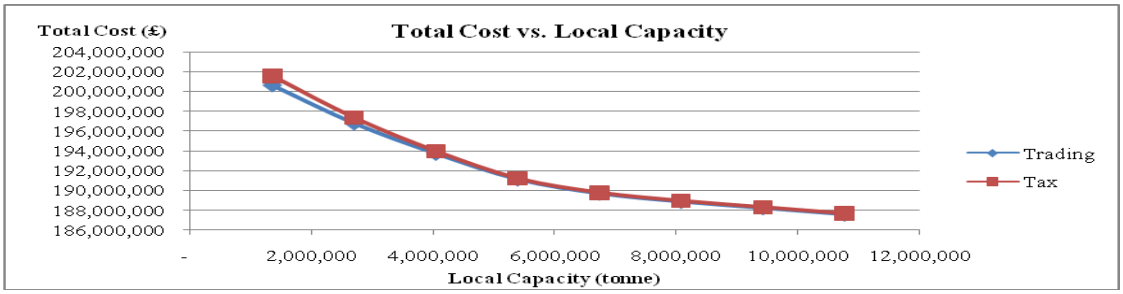

Figure 5: Total cost vs. local capacity without considering import cost and demand

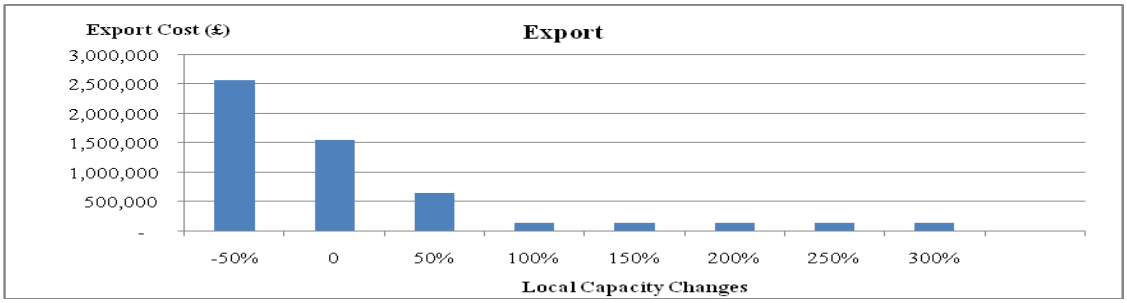

Figure 6: Export cost without considering import cost and demand

Scenario 2: Without import cost, demand and selling profit

In this scenario with figure 7, import cost, local paper demand and selling profit are removed from the original model. This scenario behaves almost the same as in previous scenario. Only small difference between total cost using carbon trading and carbon tax exists. Total cost is reduced as local capacity increases. The reduction becomes smaller and remains almost the same at around five million tonnes or 100% increase in local capacity.

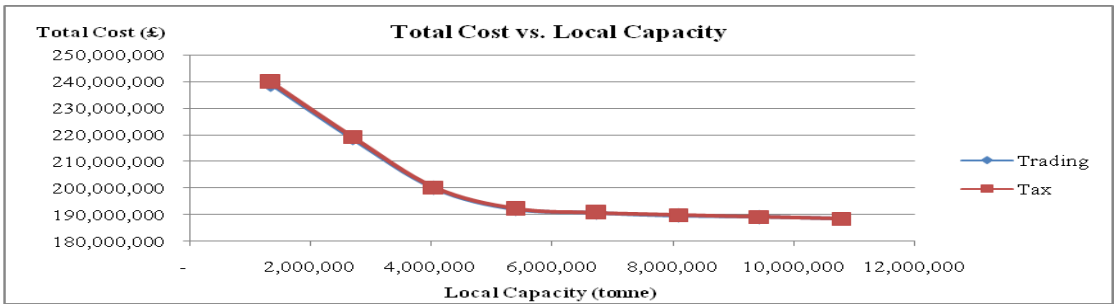

Figure 7: Total cost vs. local capacity without considering import cost, demand and selling profit

In figure 8, at 100% increase in local capacity, the optimal solution does not allocate waste paper for export. Compare to Scenario 1, there is always export selling profit which can reduce the total cost. In this scenario, the remaining amount mentioned in Scenario 1 is distributed locally and will involve less cost than export without considering selling profit.

Figure 9 compares total cost vs. carbon emissions for scenario 1 and scenario 2. There is a gap and this gap becomes wider as local capacity increases. Scenario 2 shows more cost associates with carbon emissions as compared to scenario 1. This is due to selling profit that can bring positive value in the calculation of total cost. The finding implies that the price of waste paper in the market has greater impact than the carbon policy on the recycling network performance.

V. Conclusions

In this paper, we investigate the impact of the carbon emission policies on reverse logistics strategies and operations and propose optimisation model for the recycling paper in the UK. Optimisation model is used to allocate the waste paper to different local paper mills and overseas market. Sensitivity analysis is done by comparing the case when carbon policies are used. Generally, local processing is better than export waste paper from the UK, provided the waste paper are sent from material recycling facilities to the closest paper mills. If sending locally to a far paper mills, then export to overseas will reduce the cost. Since transportation cost is the main contribution to the total cost, carbon emissions cost do not give a big impact to total network cost. This paper contributes to both the policy perspective and eco-logistics management approach of recycling logistics. It also has the generality in a view of interactions between strategic management of logistics network and carbon control policies for other recycling materials. The limitation of the research is on the operational details of the logistics operations. The research did not consider the impacts of transportation modes and differences in processing costs in different geographical regions.

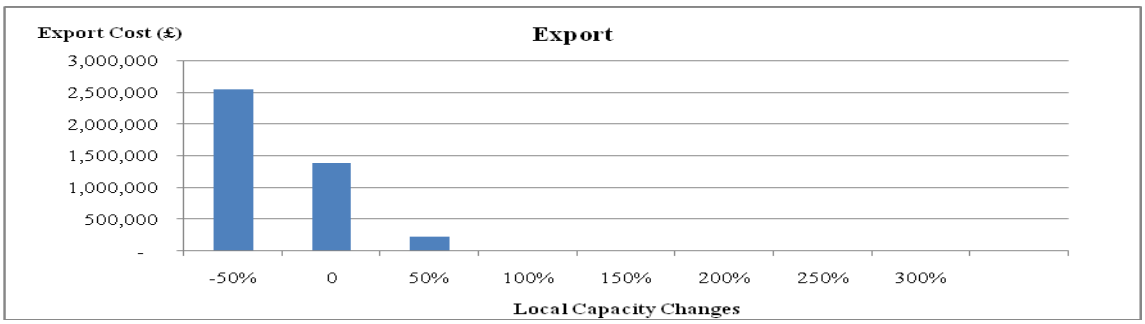

Figure 8: Export cost without considering import cost, demand and selling profit

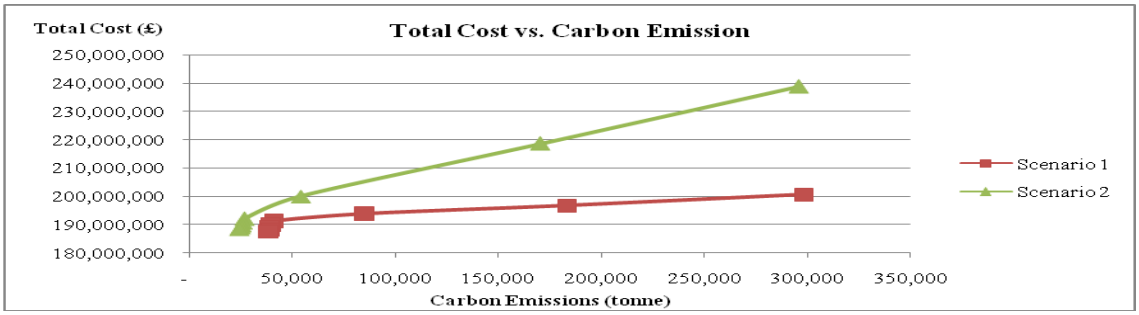

Figure 9: Total cost vs. local capacity for scenario 1 and scenario 2

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Appendix E: The Conference Paper Presented at International Conference on Logistics, Informatics and Service Science (LISS 2012)

A study of Eco-performance 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 and sustainability 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 policies. Carbon emissions policy is a driving factor for multimodal transportation planning in eco-logistics management. With differences in the level of carbon emissions control, the different characteristics of the cost structure and carbon emission in different logistics processes will lead to different business performance. The research investigates and identifies impact of the policies on logistics performance.*
Keywords*:* Multimodal transportation planning, carbon emission control policy, fresh produce, optimisation.

Introduction

Since last decade, over 50% of the fresh produce supplies in the UK market are imported [1]. The large volume of import has significant impact on transportation costs and carbon footprint in such global fresh produce supply chains which cross several sectors from farms, logistics to manufacturing and retailing. How to manage the supply chain sustainably to achieve both economic and ecological objectives in such a complex multi-sector, multimodal transportation and international context has been a great challenge. With the negative impacts from the prevalent road-based freight transport in congestion, energy consumption and carbon emission and with a trend of speeding up application of carbon emissions policies (carbon tax and carbon trading scheme, etc) to the industry, multimodal transportation has been attracted increasing attention due to its potential contribution to reduce the impact on environment [2]. Research on transportation planning has been extensively reported in the literature [3][4] [5][6]. Some research has been reported on logistics planning considering environmental impact [7][8][9][10].

However, research is still rare on interactions among the economic and ecological performance of the supply chains and the carbon control policies so that logistics services through multimodal transportation services can be optimised with various potential carbon control policies [11].

This study is focused on a fresh fruit supply chain case in the UK and investigates the impact of different carbon emission control policies on operations of food service industry. The research aims to

identify optimal strategies of multimodal transportation operations of the supply network under changing carbon policies, and provide a policy making reference that 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.

Sustainable Logistics Model

An optimisation model as seen in equation 1 is proposed to generate the 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][13]. In this paper, a mixed-integer programming is developed with four main elements: cost, time, distance, and mode of transportation as proposed by Banomyang and Beresford [14]. To analyse the economic and ecological performance of the logistics network, particularly the carbon emission policy impact on strategic options of the supply chain design. The objective function of the model is to minimise the total cost, with consideration of policies of carbon emissions trading and carbon tax [15]. The different modes of transportation used in this study are road, rail, ship and their combinations.

Objective function:

Min total cost = transportation cost + carbon emissions cost.

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

Subject to: (1)

$$\sum_{k=1}^{p}\sum_{j=1}^{n}\sum_{i=1}^{m} CC_{i,j,k} * YT_{i,j,k} * YP_{i,j,k} * X_{i,j,k} = CL; \sum_{j=1}^{n} X_{i,j,k} = D_i;$$

$$\sum_{j=1}^{n} TT_{i,j} * YT_{i,j,k} \leq RT_i; X_{i,j,k} \geq 0; YT_{i,j,k} \in \{0,1\}; \quad YP_{i,j,k} \in \{0,1\}.$$

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

CL = carbon limit; $TC_{i,j}$ - transportation cost to centre (maritime port, rail freight terminal or a regional distribution centre) i with transportation mode j;

RT_i – Required time for trip to a port or regional distribution centre i; $TT_{i,j}$ – time taken to centre i by transport mode j; $CC_{i,j,k}$ - carbon emissions cost to a centre i with transport mode j and carbon policy k; $YT_{i,j,k}$ - 1 if transportation mode j is used, 0 otherwise; $YP_{i,j,k}$ - 1 if policy k is chosen, 0 otherwise; D_i - demand at centre i.

Some interviews have been conducted with the operational team of a fresh produce logistics company which provides service of consolidation, warehousing, re-packaging and delivery. Primary data are obtained from the company such as locations of regional distribution centres (RDC), demands and capacity for each RDC, costs, etc. in the network. The distance and time between each port and RDC were obtained from public media such as Google maps and National Rail website. Six ports are

used as distribution point s in the UK. The carbon emission factor for transportation is from WRAP [16]. Carbon emission price and carbon tax are obtained from the public media.

At present, the logistics companies in this case 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-foot refrigerated containers are normally used with heavy goods vehicles (HGVs) for this service. HGVs consumes enormous amount of fuels and creates environmental issues. Through the optimization analysis, solutions of the logistics service network with different carbon policies can be identified and compared to provide insight into the policy impact and best strategies of the business to take.

Analysis and Finding

Firstly the model is optimised without considering carbon emission and associated costs. The model suggests distribution of fresh produce from all ports to all RDCs using road transportation. The minimum cost can be obtained by the road only option. All the allocations in the solution are actually sent by trucks from main UK ports to closest RDCs in the country. 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 allocation for the UK mainland being 87% and 13% respectively.

Carbon tax has a greater impact due to higher direct cost to be added to the operations at a given carbon price level. In the following sections, further details of the policy impacts on economic and ecological performance are analysed.

Carbon Tax vs. Carbon Emission Trading

Two major carbon control policies are involved in this research, Cap-and-trade approach in carbon emission trading scheme and carbon tax scheme. Cap-and-trade approach has a fixed number of annual allowances allocated to the participants as a cap. Participants who face high abatement costs can continue emission by buying additional allowances, while participants who face low abatement costs can take abatement action and sell their surplus allowances for a profit [15]. The trade is based on the price of carbon emission price at the trade market. Carbon tax is based on consumption of fossil fuels and according to their carbon content. The two policies are commonly employed by governments.

To identify potential business reactions or behaviour with government carbon control policies, the analysis is performed with different carbon charge rates as sensitivity analysis through the optimisation model. For carbon emission trading policy, different carbon limits from 50k to 150k ton are used in the analysis. As the limit or carbon emission cap increases, the optimal carbon price associated with the minimum total cost is also increasing.

The optimum 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 therefore plays a significant role in managing carbon emissions. The analysis with the optimisation model uses different rate of carbon charges so that the sensitivity of the logistics performance to the carbon policy can be reserved. The total cost includes transportation cost and carbon cost with consideration of time. The analysis of total cost demonstrated optimum carbon charges with different carbon emission limit (CET in the Fig1) and carbon tax.

With different carbon limit, the graph pattern of the total cost is almost the same, but with different minimum point. As the 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.

Time Performance

For fresh produce supply chains, time is an important factor. Therefore the performance in overall delivery time is analysed in this research. The time spent in the transportation processes with different carbon charging rates is shown in Fig 2. In the optimization model, time is a constraint for a trip to ensure food product 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.

Transportation Mode Selection with Carbon Costs

To investigate the impact of carbon control policy on transportation network configuration, the percentage of deliveries in the supply network with different carbon charges is analysed in Fig 3. Result shows that the higher the carbon price, the higher the percentage of multimodal transportation is chosen in the network.

The optimum carbon charge is observed when carbon tax is chosen at the rate of £7 per ton of carbon emission, with the overall travel time of 64,245 hours per week. Multimodal transportation accounted at 8% with the remaining 92% is suggested for road only option.

If carbon emission trading is chosen, with 50,000 ton of carbon limit, the optimum cost is at the price of £15 per ton of carbon emission. This option produces total travel time of 74,316 hours per week.

When the carbon limit is setting at 100,000 ton and above, total cost is decreasing until at the point of carbon price at £30, which is the optimum price with these limits. After this point, total cost starts to increase as carbon price increases. Total travel time at this optimum point is 89,626 hours per week. At this price multimodal transportation becomes important than road only transportation.

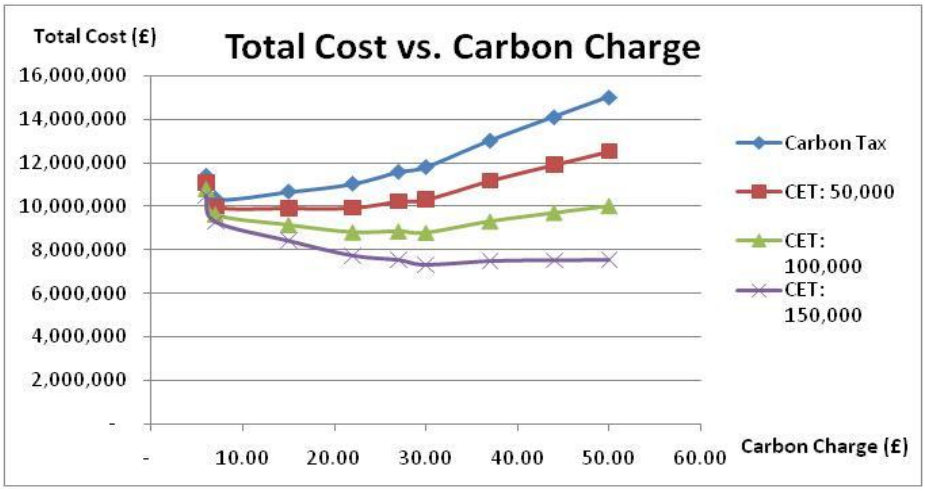

Fig.1. Total cost fluctuations with different carbon charge

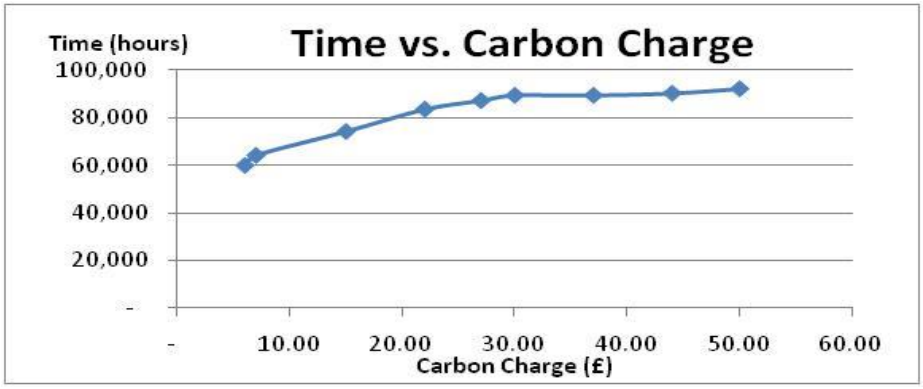

Fig. 2. Travel time with different carbon charge

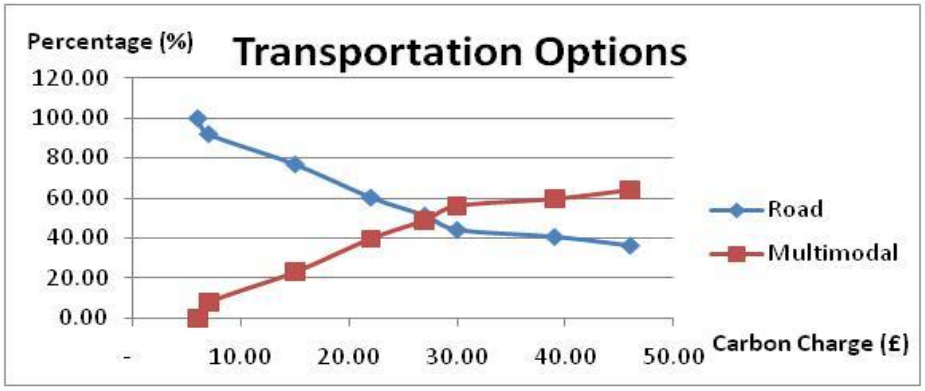

Fig. 3. Transportation options between road only and multimodal.

Conclusion

This research has investigated impacts of the carbon emission policies on transportation operations for fresh produce industry. Through the research, an optimal network design approach for the fresh produce logistics services under carbon emission control is established. If carbon policy is introduced, the optimal decision on transportation planning in fresh produce logistics will be affected by types of policies applied, carbon emission limits and the carbon price involved. The higher the charge on carbon emission, the more the allocation should be made to multimodal transportation in deliveries. 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 applied by governments can play an effective role to shape the logistics network and affect economic and ecologic performance of business. This research outcome can be generalised to other industries developing strategies with given carbon control policies, and for government to set up policies to encourage best business practice.

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