THE EFFECTS OF PORT-CENTRIC LOGISTICS ON THE CARBON INTENSITY OF THE MARITIME SUPPLY CHAIN: A PRELIMINARY REVIEW

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ABSTRACT

Port Centric Logistics (PCL) is a concept that applies mainly to deep-sea container logistics and works on the premise that container loading and unloading occurs at or near a port. This can yield operational benefits, including the rationalisation of freight movement within the port hinterland and the opportunity to load of deep-sea containers to a heavier weight than permitted by road restrictions applying in the country of origin or destination. The limited literature so far published on PCL makes limited reference to the environmental impact of PCL, particularly its net effects on carbon emissions. This paper employs an inductive approach to identify five potential ways in which PCL can reduce these emissions. Quantitative modelling is used to illustrate the possible magnitude of these 'decarbonisation effects'. The relationship between PCL and freight modal split are explored though cannot by quantified on the basis of currently available data. Even in the absence of a clear modal shift effect, the CO_2 benefits of using a PCL approach may still be significant, depending on the configuration of import and export supply chains.

Keywords: port, logistics, carbon intensity, maritime supply chain

1. INTRODUCTION

The adoption of the Port Centric Logistics (PCL) concept by large retailers and manufacturers over the past decade has resulted in a significant reconfiguration of some maritime supply chains in the UK. It is a concept that applies mainly, but not exclusively, to deep-sea container traffic. In the case of inbound flows, it involves the unloading (or 'destuffing') of containers and the subsequent storage / handling of the imported goods at distribution centres (DCs) (or 'import centres') on or near the port site (Mangan and Lalwani, 2009). Distributing the goods directly to shops or other customers from the port can eliminate one node and link from the maritime supply chain, cutting costs and saving time. The limited literature on PCL also suggests that it can be beneficial to the environment and, in particular, cut CO_2 emissions. The carbon benefits of PCL are seldom quantified, however, and, where they are, little or no indication is given of the methodology used.

This paper goes back to first principles and examines the ways in which a PCL strategy can help to reduce total CO_2 emissions. Using available data it is possible to quantify several of its carbon-reducing effects, though in the case of others new empirical research will be required to derive realistic estimates. The assessment of the carbon implications of PCL has been conducted within a 'freight transport decarbonisation' framework developed in the course of an earlier research project on 'green logistics' (McKinnon, 2010). It is outlined in the next section. Later sections of the paper discuss each of the possible carbon-reducing impacts of PCL.

2. ANALYTICAL FRAMEWORK

The framework maps the inter-relationship between economic output, measured by weight, and CO_2 emissions from the associated freight transport. This relationship is defined by a series of key parameters. By altering these parameters it is possible for governments and companies to decouple freight-related CO_2 emissions from economic output. The original framework, which was constructed for domestic distribution within a country, has been adapted to a maritime supply chain containing a deep-sea container service (Woolford and McKinnon, 2011) (Figure 1). This revised version contains eight key parameters:

2.1 CHOICE OF TRANSPORT MODE

For the purpose of this PCL analysis, modal split relates to port feeder movements and typically in the UK offers a choice between road, rail, short-sea shipping, inland waterway and various intermodal combinations. As the carbon intensity of these transport options varies widely, modal choice is a critical parameter in the assessment of PCL's CO_2 impact.

2.2 CHOICE OF CARRIER

Available benchmarking data suggests that within a particular mode there can be wide variations in the energy and carbon efficiency of particular carriers (Clean Cargo Working Group, 2008; McKinnon, 2009). If the adoption of PCL affected carrier choice, both for the deep-sea operation and hinterland transport, the total CO_2 emissions from the door-to-door movement could be affected.

2.3 AVERAGE HANDLING FACTOR

In their passage through the supply chain, consignments are loaded on and off vehicles several times. As a consequence, the ratio of the tonnes-lifted statistic to the weight of goods produced (also known as the 'handling factor') can serve as a crude measure of the number of links in the supply chain. As PCL can remove one or more links it can reduce the handling factor and thus cut CO_2 emissions.

2.4 AVERAGE LENGTH OF HAUL

this is the mean length of each link in the supply chain and essentially converts the tonnes-lifted statistic into tonne-kms. By restructuring the supply chain, PCL can alter the lengths of its component links.

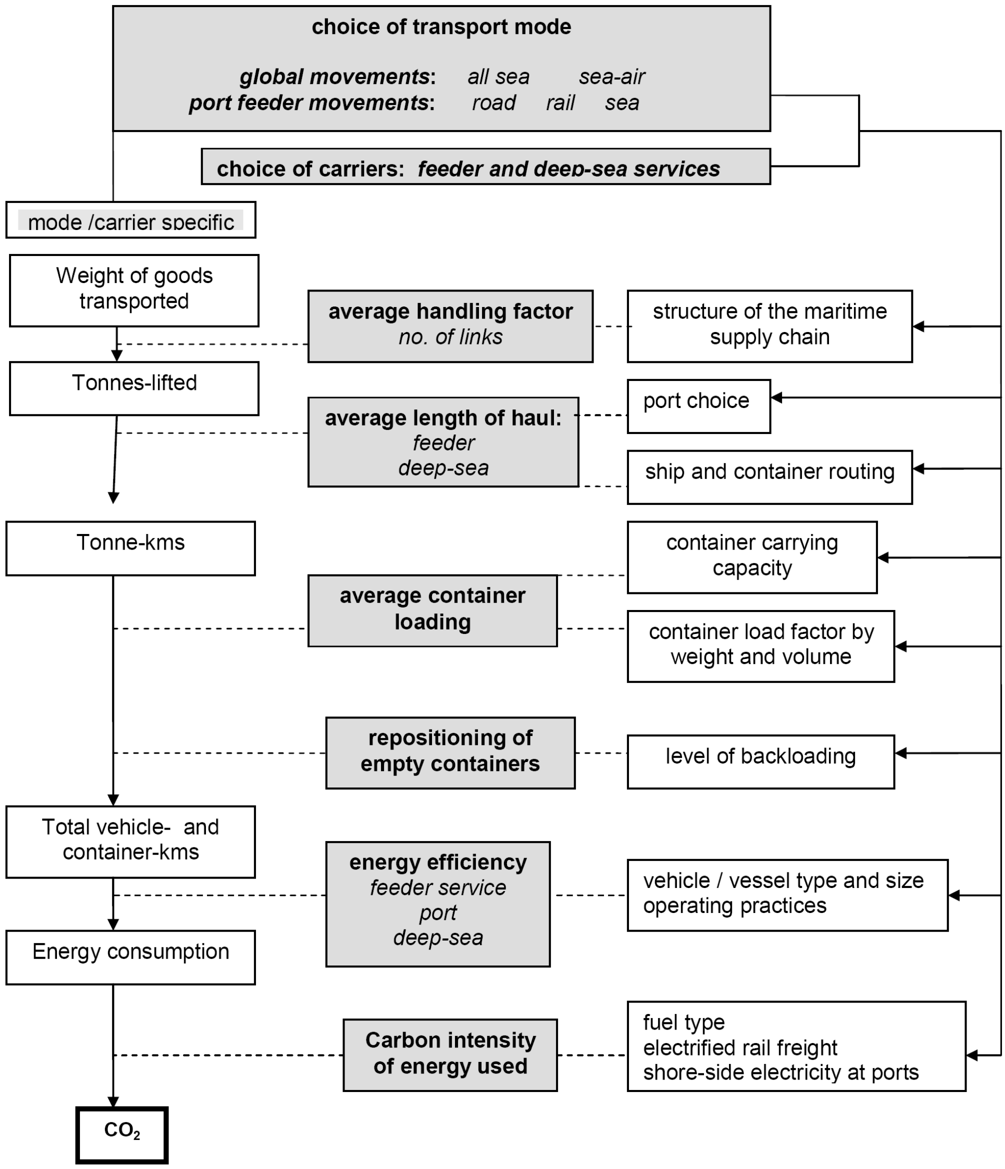

Figure 1: Decarbonisation Framework for the Deep-Sea Container Supply Chain

2.5 AVERAGE CONTAINER / VEHICLE LOADING

This is usually expressed as the average payload weight, though, where possible, account should also be taken of the 'cube fill'. PCL can affect the utilisation of container, ship and vehicle capacity in several ways. For example, by eliminating the need to move containers beyond the port it removes the tare weight of the container from port feeder movements.

2.6 POSITIONING AND REPOSITIONING OF EMPTY CONTAINERS

In the context of PCL, this can be defined as the hinterland movement of empty containers either to the sources of export consignments or, in the case of import flows, back to the port after unloading. This represents significant under-utilisation of road, rail and water-borne capacity on port feeder links, though this is not fully reflected in official freight statistics. Carriers typically regard an empty container as a revenue-earning load and so do not consider a vehicle transporting one to be empty (Woodburn, 2008). By reducing the need to distribute containers beyond the port, PCL can substantially reduce the traffic in empty containers.

2.7 ENERGY EFFICIENCY

The two main activities in the maritime supply chain are transport and handling, each of which can be given an average energy efficiency rating: kWh per tonne- or TEU-km for transport and kWh per container handled for ports or other freight terminals. PCL can affect average energy efficiency both directly, through the concentration at ports of larger-scale, more energy-efficient facilities for stuffing and destuffing containers and indirectly by making it easier for shipping lines cut the carbon footprint of their maritime operations.

2.8 CARBON INTENSITY OF THE ENERGY USED

The main way in which PCL can reduce the carbon content of the energy used in the maritime supply chain is through exploitation of renewable sources of energy in and around the ports. This reduces the net carbon footprint of the port and hence the range of activities based there, either through their use of locally-generated low carbon electricity or the carbon credits gained from feeding this electricity into the grid.

By influencing each of these critical parameters, directly or indirectly, PCL can help to decouple the total mass of goods passing through the maritime supply chain from the total amount of CO_2 emitted in moving, handling and storing it.

The remainder of the paper will examine in more detail the various ways in which this decoupling can be achieved through the application of the PCL principle. Five possible decarbonisation effects are explored, some of which affect more than one of the parameters in the framework.

3. POSSIBLE CARBON-REDUCING IMPACTS OF PORT CENTRIC LOGISTICS

3.1 MORE DIRECT MOVEMENT OF INTERNATIONAL CONTAINER TRADE TO AND FROM PORTS

This is the most widely-quoted environmental benefit of PCL. For example, the non-food director of ASDA claimed that the company's port-centric DC near Teesport would 'enable us to dramatically reduce our impact on the environment. We will save two million road miles a year - equivalent to four trips to the moon and back' (Anon, 2006)

By using expanded storage and handling capabilities at the ports, companies can reduce the need for products, both exports and imports, to be routed through inland terminals and distribution centres. This is reflected in the US expression 'DC bypass' which is sometimes used as a synonym for PCL (Anon, 2008). In some cases, however, this is misleading. 'DC relocation' would be a more accurate description of the situation where, for example, a retailer positions a warehouse in the vicinity of the port and supplies its shops with imported product from there rather than via a more centrally located DC. It is important, therefore, to distinguish more direct routing with and without the removal of a node from the supply chain.

The removal of a node generally occurs where an intervening container 'destuffing' operation takes place between the port at an inland container depot (ICD). The co-location of this destuffing operation with other DC functions at or near the port in a purpose-built 'import centre' effectively streamlines the supply chain, eliminating a node and link. This reduces the total distance the imported goods travel between the port of entry and the shop. It is difficult to generalise about the net distance saving, however, as this depends on the relative locations of the port, the ICD at which the container is emptied and the original DC which the import centre has now replaced. Simulation modelling has been undertaken to illustrate the potential CO_2 savings from the reconfiguration of the inbound supply chain for containerised imports. This has used road distances from the Containerised Cargo Carbon Calculator (CCCC), compiled by Aecom, and the AA Autoroute package, estimates of handling-related CO_2 emissions from CCCC and carbon emissions factors for road transport operations based on fuel consumption data from Coyle and converted to carbon values by McKinnon and Piecyk (2010). The examples chosen use Felixstowe and Teesport as the ports of entry, Birmingham and Wakefield as the locations of ICDs, Manchester as the original DC location and Stoke-on-Trent, Preston and Carlisle as the shop locations (Figure 2). The calculation assumes that:

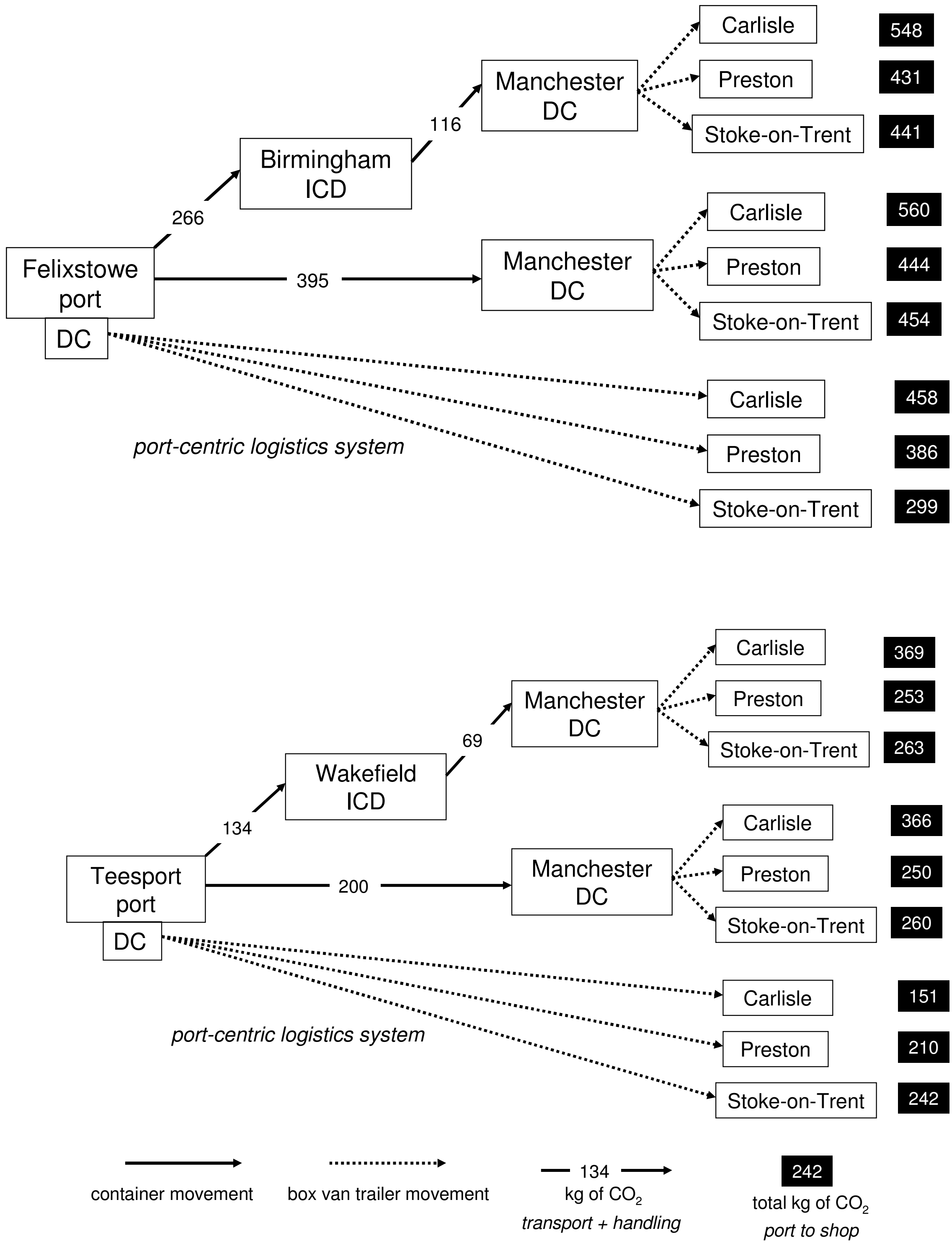

Figure 2: Comparison of the CO_2 Emissions from Conventional and Port-Centric Logistics Supply Chains for Retail Imports

- all freight movements are by road using the fastest routes

- 40ft containers are replaced by articulated box van trailers, in both cases plated with gross weights of 44 tonnes

- containers and trailers are fully-loaded by volume, carrying an average of 12 tonnes of product

- differences in handling-related CO_2 emissions between the PCL and conventional supply chains would be negligible

For the chosen sets of locations, the PCL model yields net reductions in CO_2 varying from 7% to 60%. The actual saving is clearly sensitive to the configuration of the respective chains. The greater the degree of circuity in the conventional chain, the larger will be the potential saving in CO_2 from direct distribution to shops from the port-based DC. This is very pronounced, for instance, in the Teesport – Carlisle route. Where the route involves the backtracking of supplies from a centralised DC in the direction of the port, as for example in the case of the Felixstowe – Stoke-on-Trent route, the % CO_2 reductions are also relatively large. The magnitude of the CO_2 savings is also affected by the relative distances the goods travel in containers and box van trailers.

This calculation requires several qualifications; however, first the assumption of full loading in both the PCL and non-PCL scenarios may be unrealistic. The original DC would centralise supplies from a broader range of suppliers, both foreign and domestic, and therefore be likely to generate bigger consolidated loads for individual shops than a port-based DC handling only imported goods arriving at a single port. It is possible therefore that the trucks delivering directly to shops from the port-based DC would, on average, have lower payloads. This would increase the average carbon intensity (gCO2 per tonne- or cubic metre-km) of radial distribution from the port, offsetting some of the carbon benefit of more direct routing.

Second, simplifying assumptions have been made about the relative weights of the container, the box van trailer and the handling equipment used for the DC-to-shop delivery (generally known as 'secondary distribution'). The average 12 tonne payload delivered at the shop (both from the port-based DC and original DC) comprises the weight of both the goods and the handling equipment (roll cages, pallets etc), whereas within the container products would often be block-stacked or loose-filled to maximise cube fill on the deep-sea movement. On the other hand, allowance must be made for the tare weight of the container (3.7 tonnes for 40ft container). The cubic capacity of the container and box van trailer can also vary, depending on the ISO height of the former (varying between 8'6" and 9'6") and whether the latter is a single or double-deck / high-cube vehicle. The lower the density of the product, the more significant these factors would be. Variations in the nature of the handling equipment, the ratio of container to box van trailer cube and product density can, therefore, substantially distort the calculation.

Table 1: % Savings in CO_2 Emissions from Adopting PCL System

Route	shop location		
	Carlisle	Preston	Stoke-on-Trent
Felixstowe – Birmingham ICD – Manchester DC – shop	16	11	32
Felixstowe – Manchester DC – shop	18	13	34
Teesport –Wakefield ICD – Manchester DC – shop	59	17	8
Teesport (DC) – Manchester DC – shop	59	16	7

In summary, the more direct routing of import flows that PCL permits will influence the number of links in the maritime supply chain and their average length. While the average number of links in the chain may reduce, their average length may increase, though the total distance between port and shop is likely to be decline. As discussed below, the lengthening of ex-port hauls may, under some circumstances, make them more suited to movement by rail, thus affecting the modal split parameter. On the other hand, bypassing a central DC may reduce opportunities for load consolidation and hence compromise the relative utilisation of vehicles in the PCL system.

3.2 REDUCING THE NEED FOR INLAND REPOSITIONING OF EMPTY CONTAINERS

This directly addresses the six critical parameter in the decarbonisation framework. Empty containers need to be moved to the origins of export traffic to collect outbound consignments. Given the UK's large trade imbalance in containerised goods, however, the main traffic in empty containers is from the inland locations where container loads of imports are 'destuffed' back to the ports. In a pure PCL strategy, container loading and unloading is confined to the port, eliminating the need for the hinterland movement of empty containers. Ironically, this undermines the original purpose of containerisation which was to permit the door-to-door, intermodal movement of freight in secure, standardised modules (Levinson, 2008). Full application of the PCL principle would result in containers simply shuttling between ports and spending almost all their time onboard ships or within port complexes.

Minimising the hinterland movement of empty containers can yield two carbon benefits:

First, it accelerates container turnaround times, increasing the annual container trip rate and reducing the total number of containers required to handle a fixed amount of world trade. It is estimated that the average 40ft container has approximately 12 tonnes of 'embedded carbon', calculated on a life-cycle basis assuming that the container is made of plate steel construction and using the figures reported by Hammond and Jones (2008). PCL could contribute to a rationalisation of global container usage, reducing the demand for new containers (below what it would otherwise be) and cut CO_2 emissions in the container manufacturing process. This assumes, of course, that shipping lines take advantage of PCL, returning empty containers on the deep-sea leg more rapidly and not simply allowing larger accumulations of empty containers to build up at the port. Space pressures at ports will help to ensure that the latter situation does not occur.

If it is assumed that hinterland transport in the UK represents a minimum of 4 days in the maritime supply chain, then even for a long haul movement from the Far East, which typically takes 30 days at sea, the requirement for containers could be reduced by around 10% (assuming that port handling times remain unchanged). On shorter trade routes the % reduction in the necessary container capacity would be greater.

The second carbon saving would accrue from reduced freight movement within the port hinterland. In container supply chains there are four types of empty running:

1. *Port to export collection point*: this empty running could be reduced by getting exporters to postpone the containerisation of their products until they arrived the port. The exports would then be channelled through a port-based warehouse / container loading facility. This very rarely occurs at present and would require fundamental re-engineering of the export supply chain. Manufacturers of high value products, such as whisky, are likely to be resistant to this idea, though it could help to alleviate the difficulty that some exporters experience in securing enough empty containers to meet their outbound delivery schedules. The loading of containers with lower value exports, such as waste material, could more easily migrate to the ports, helping to make PCL more symmetrical in its impact on inbound and outbound container flows.

2. *Import destination to port*: this is the dominant flow of empty containers and the one likely to offer the largest carbon savings. In estimating the level of these savings, however, one would have to allow for the movement of empty box van trailers to the ports to collect imports within the PCL system that would otherwise have been distributed in containers. Assuming a one-to-one substitution of empty box van trailer movement for an empty container movement over a similar distance and, a carbon saving of around 4% could be achieved. This substitution would effect a net 3 tonne reduction in the gross tare weight relative to an average payload weight of 12 tonnes. Alternatively, if the container was loaded to its maximum weight, the additional 3 tonnes of weight-carrying capacity released by the switch from container to box van trailer could be used to move extra cargo. For a given volume of freight, this could reduce vehicle-kms by 10% with an equivalent reduction in carbon emissions.

In practice, a proportion of the lorries travelling with box van trailers to the ports to collect import consignments would be carrying a load along some or all of the route, increasing the net carbon saving from the PCL option. The more successful the PCL strategy and the higher the concentration of industrial and distribution development around the port, the greater will be the opportunity of finding a load on the route to port. The probability of a standard box van trailer obtaining a load is generally higher than that of a returning containerised truck movement. Containers are not ideally suited to the movement of palletised goods (Institute of Shipping and Logistics, 2010). A 40' container can accommodate around 25 Euro pallets, whereas a large articulated trailer can handle 38. For certain classes of goods, therefore, three containerised truck movements can be replaced by two non-containerised movements.

3. *Internal movement between import and export location:* Once the imported goods have been unloaded the empty container can go on to pick up an export consignment. This will almost always entail an empty container movement. The length of this journey is likely to be less than that the distance over which an empty container would have to be repositioned from the nearest port. Little data is available, however, on the inland movement of empty containers and so it is not known to what extent the flows are optimised. As discussed under 1 above, confining containers to the ports would eliminate this cross-haul between import and export locations and leave exporters dependent on the

collection of exports by non-containerised transport. Any resulting carbon savings would probably be quite small.

4. *Repositioning between inland container depots:* The cross-haulage of empty containers is often between ICDs rather than directly between import and export locations, adding extra empty legs to the container supply chain. Minimising the movement of containers beyond the port would cut the carbon emissions associated with these intermediate journeys.

Overall, PCL is likely to reduce CO_2 emissions by rationalising the movement of empty containers, though once allowance is made for the repositioning of non-containerised freight capacity to handle the movement of international trade to and from the ports, the net carbon savings may be quite modest.

3.3 OPPORTUNITY TO INCREASE MAXIMUM CONTAINER WEIGHT ABOVE THE MAXIMUM LEGAL WEIGHT OF A TRUCK

The utilisation of trucks on port-feeder movements is constrained by their legal weight limit which, for a six-axle vehicle, is 44 tonnes in the UK. The heavy tare weight of the container (3.7 tonnes for a 40ft container) effectively reduces the available weight-carrying capacity of the vehicle below the maximum weight that could be carried in a conventional box van trailer. For dense products that 'weigh out' before they 'cube out' on hinterland transport, stuffing / unstuffing containers at the ports can allow greater consolidation of loads in fewer trips, yielding significant fuel and carbon savings. The carbon savings in hinterland transport can be supplemented by emission reductions in the deep-sea operation where it is possible to load the containers to heavier weights onboard ship. After all, the maximum weight of containers that can be moved by ship is generally much higher than the maximum road weight. This, however, requires a relaxation of payload weight limits in hinterland transport at both ends of the maritime supply chain. This affects the 'container / vehicle utilisation' parameter in the decarbonisation framework, but is only relevant to denser products such as wines and spirits, paper and electrical appliances.

3.3 HELPING TO ACCOMMODATE CO_2-REDUCING 'SLOW STEAMING' IN LOGISTICS SCHEDULES

It is estimated that between 2008 and 2010, the slow steaming of container ships, involving speed reductions of between 30 and 50%, has cut CO_2 emissions by roughly 11% (Cariou, 2011). This has become one of the most effective means of decarbonising the maritime container supply chain. By compressing transit times on the hinterland links in this chain, PCL should make it easier for companies to accommodate slow-steaming within their logistics schedules. The relationship between PLC and slow-steaming has yet to be explored empirically, but it seems plausible that there will an inter-connection between the two practices. Over the past few years, slow-steaming has been motivated by a desire to cut operating costs in a depressed freight market when oil prices were high and rising. For slow-steaming to remain a common practice in a more buoyant global shipping market, shipping lines may have to do more to minimise its impact on their clients' logistics schedules. PCL has a role to play in the rescheduling of container movements at different stages in the end-to-end supply chain. This may be an indirect, and in some cases rather tenuous, role, but it is still worth including as another possible contribution of PCL to decarbonisation, this time impacting on the energy efficiency parameter.

It is also related to the empty container parameter discussed earlier. Slow-steaming reduces the container trip rate and thus requires a larger stock of containers to handle the same quantity of trade. By accelerating container turnaround at the landward side, PCL partly offsets this effect, moderating the increase in the 'embedded carbon' in containers.

3.4 EXPLOITATION OF RENEWABLE ENERGY SOURCES AT PORTS TO POWER LOGISTICAL ACTIVITIES

Their coastal location and proximity to tides and under-sea currents makes ports good natural locations at which to develop renewable forms of energy. The concentration of logistical activity at port sites may also give port operators greater incentive to invest in the micro-generation of renewable energy, exploiting wind, waves, tides and currents. The electricity generated by these port-based renewable energy schemes can also be fed into the grid, earning carbon credits. Either way, the net carbon footprint of the port is reduced and hence operators of on-site warehousing can effectively reduce their GHG emissions per tonne of product handled. This effect is clearly associated with the carbon intensity parameter.

3.5 FACILITATING MODAL SHIFT TO RAIL AND WATERBORNE SERVICES

As the carbon intensity of railfreight and waterborne services is 2 - 4 times lower than that of maximum size and weight trucks at comparable load factors (DEFRA, 2010), total carbon emissions from hinterland transport are very sensitive to mode choice. PCL can help these lower carbon modes to increase their share of the port feeder market, thereby influencing the modal split parameter. This is well illustrated by the case of ASDA which in

2009 transferred the movement of imported clothing products from road to a coastal feeder service connecting Felixstowe with its port-centric DC in Teesport. It is estimated that use of this initiative reduced CO_2 emission by around 2200 tonnes in its first year (Brett, 2010). There are, however, relatively few examples of such PCL-related modal shifts.

Around a quarter of deep-sea container traffic in the UK is moved by rail to and from ports (Knight et al, 2008). How might PCL increase this proportion? One possibility is that by promoting direct deliveries over longer distances, PCL allows rail to exploit more effectively its comparative advantage in long haul movement. This assumes that the port has a good rail connection and can generate sufficient volumes of freight traffic to build viably-sized trainloads for particular regions. Fundamental to the 'retail import' version of PCL, after all, is the dispersal of imports to individual shops, bypassing a central DC. Shops do not have direct rail connections and therefore must be served by intermodal services built around regional railheads. The railways have a minute share of secondary distribution to shops in the UK, though it has been expanding in recent years. There is a major risk, therefore, that replacing inbound containerised flows of imports to inland terminals and central DCs with the distribution of imported goods directly from ports to the shops in non-containerised loads will erode rather than expand rail's share of the deep-sea market. This reconfiguration of the retail supply chain would also deny rail an advantage that it currently has in the feeder movement of dense product, namely that it can carry heavier containerised loads than are permitted on the road network.

So in the retail sector, where the PCL concept has been most widely applied, it is difficult to see how PCL is likely to promote the use of rail. Other retailers, however, may follow ASDA's example and switch to maritime feeder services. It is possible too that the application of PCL in other sectors may promote a shift to greener modes. There is as yet, however, little evidence of this happening in the UK.

4. CONCLUSION

PCL is the result of a convergence of supply and demand pressures. On the supply side, it allows ports to diversify into a broader range of value-adding activities and evolve from intermodal interchanges into fully-fledged logistics hubs. On the demand side, the huge growth in the proportion of retail supplies sourced from deep-sea locations has created the need for a new generation of 'import centres' located at or near the ports. There have therefore been good commercial reasons for the development of PCL. It is often argued, however, that PCL offers environmental as well as economic benefits, particular in carbon terms. This paper has explored the possible effects of PCL on the carbon footprint of the maritime supply chain for containers. This has been done within a decarbonisation framework constructed around a set of eight key parameters.

An inductive approach has been adopted to identify, on an *a priori* basis, five possible ways in which PCL can reduce carbon emissions. They can do this by influencing one or more of the key parameters. On the basis of simulation modelling, it is possible to demonstrate that the main 'decarbonisation effect', involving the more direct routing of flows and replacement of heavier container movements with lighter box van trailer deliveries, is likely to yield significant carbon savings. Reducing the amount of empty container movement and raising the maximum container weight on the shipping leg above the weight limit on road vehicles offer additional carbon savings. The hypothesis that PCL makes it easier for shippers to accommodate 'slow steaming' in their logistics schedules seems plausible though will require empirical testing. The argument that PCL promotes greater use of lower carbon transport modes also needs to be substantiated, though the case of ASDA provides strong case study evidence that it can. The potential CO_2 savings from some of the effects, however, are not clear-cut and are sensitive to particular configurations of companies' supply chains. This applies particularly to claims about the CO_2 benefits of more direct routing.

More rigorous testing of the various propositions in this paper requires empirical research. This entails the collection and analysis of data from the various stakeholders involved in PCL, including the port operators, shipping lines, shippers and logistics service providers responsible for hinterland transport. This research is currently underway and will be reported in future papers.

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