The Impact of Alternative Routeing and Packaging Scenarios on Carbon and Sulphate Emissions in International Wine Distribution

Irina Harris[a], Vasco Sanchez Rodrigues[a], Stephen Pettit[a], Anthony Beresford[a], Rodion Liashko[b]

[a] Logistics and Operations Management Section, Cardiff Business School, Cardiff University, United Kingdom
[b] Yusen Logistics, United Kingdom

Abstract

There is a large body of research related to carbon footprint reduction in supply chains and logistics from a wide range of sectors; however the decarbonisation of freight transport is mostly explored from a single mode perspective and at a domestic/regional level. This paper takes into account a range of alternative transport modes, routes and methods with particular reference to UK wine imports from two regions: northern Italy and Southeast Australia. The research examines supply chain structures, costs and the environmental impact of international wine distribution to the UK. A number of options are evaluated to calculate the carbon footprint and sulphate emissions of alternative route, mode, method of carriage, and packaging combinations. The estimation of CO_2e emissions incorporates three main elements - cargo mass, distance and method of carriage; sulphate emissions are derived from actual ship routes, engine power and operational speeds. The bottling of wine either at source or close to destination is also taken into consideration. The key findings are: there are major differences between the environmental footprint of different routeing and packaging scenarios; the international shipping leg almost always has a much larger footprint than inland transport within the UK except in the hypothetical case of the rail shipments from Italy using flexitanks. With reference to sulphate, the lowest cost scenario among the sea maximising options is also the sulphate minimising solution.

Keywords: international freight transport, wine port/node/route selection, CO_2e reduction, sulphate emissions

1. Introduction

Choice of mode, route and method of carriage are important decisions that the supply chain players face. Literature regarding the variables and determinants of mode choice is varied in terms of methodology, type of carrier, geography and type of industry. The traditional work of Murphy et al. (1991); for example, suggested that freight transport decisions no longer reside with one party but may be taken or influenced at a number of points along the supply chain. They include marketing, production, shipping, consignees, buyers and also intermediaries in the transport chain. Thus, continuing research into the mode choice decision-making process is needed. As Bontekoning et al. (2004) highlight, decision-making process related to mode selection is more complicated than presented in the literature. Underlying factors that influence the choice of mode, route and form of carriage also affect the overall commercial and carbon efficiency of supply chains, therefore understanding mode choice determinants is required (Bontekoning et al., 2004).

As Christopher (2011) states, logistics over long distances can be very carbon-intensive. This notion can be applied in the context of the global nature of wine sourcing, since the absolute greenhouse effect of wine consumption is roughly estimated at around 0.4% of all UK CO_2e emissions and about 0.3% of annual global CO_2e emissions (Garnett, 2007). It has been estimated that each bottle of wine produced is responsible for 1.6kg of CO_2e, where significant contributions are related to agricultural machines (9.3%) and products transportation (8.2%) (Ardente et al., 2006). Further, post-production logistics within wine supply chains are carbon intensive and can be the source of up to 50% of the total GHG emissions from the industry (Cholette and Venkat, 2009; Point et al., 2012). Therefore, improving the understanding of the environmental impact of the wine trade in general, and of its carbon footprint in particular, is important for achieving a better understanding of the wine industry with particular reference to its production, distribution and consumption.

Recent research on carbon mitigation in freight transport has focused on the reduction of CO_2e emissions in separate modes of transport. For example, Qi and Song (2012) and Chen et al. (2014) investigated carbon mitigation of maritime legs of freight transport. However, the literature on port selection in international

supply networks does not seem to incorporate other logistics operations in the estimation of CO_2e emissions of supply chains. One key aspect is how changes in packaging operations can bring efficiency improvements to freight transport movements by decreasing the freight weight and distance of inland road distribution (Murphy and Poist, 2003).
This paper is concerned with the post-production distribution aspect of the wine industry, from the 'vineyard gate' to the final point of consumer purchase. The paper addresses the impact of the bottling and international distribution decisions involving imports from two countries: Italy and Australia. The impact of alternative bottling locations is also brought into the analysis since the decision as to whether to bottle close to source or close to point of distribution could have a significant impact on the overall CO_2e emissions on a per bottle basis. A range of other factors are also considered in the discussion, including length of haul, modal combination, where bottling takes place and the decentralisation of the port of entry in order to minimise costs from road transport once the wine is offloaded at the UK port. The paper compares the outcomes from the case routes to identify where further reductions in the levels of CO_2e and sulphate emitted during the distribution process may be achieved.

The study presents a series of scenarios for various routes and combinations of modes and nodes. Two geographically distinct areas, southern Europe and Australia, are taken as source regions for wine imports into the UK. For Europe, the country used, as an exemplar case is Italy as it is produces significant quantities of wine for export. Australian and Italian wine imports represent respectively 24.3% and 17.2% of the total volume of wine imported to the UK (WSTA, 2014). Furthermore, in the case of Italy-UK distribution, there are a wide range of options available for freight transport movement including road, rail or sea, or multimodal combinations. Account is also taken of the type of unitisation which, in the case of wine, takes three main forms: (i) wine in bulk using conventional ISO containers with flexitank facility and moved by truck; (ii) multiple cases of bottled wine, palletised and transported using curtain-sider trucks, and (iii) multiple cases of bottled wine, palletised within ISO containers and moved predominantly by sea. It should also be noted that wine can be transported in container-tank units but these are less common on the case study routes used in this research and therefore not considered here.

The unitised wine (in curtain-sider trailers or containers) almost invariably moves within the UK by road, which accounts for 89% of the inland freight transport market at a macro level (Eurostat, 2012). This bias towards road transport justifies the main purpose of the paper, which is to explore the possibility that there may be more carbon-efficient transport solutions (derived from fresh modal combinations and revised routeings) for the transport of wine imports into the UK. Specific data for volumes moved along the respective channels are not known and are commercially confidential, so this paper uses aggregated data and applies a cost minimisation model to produce best estimates of flows along the respective routes.

The objectives of this study, therefore, are: (1) to model the carbon footprint and sulphate emissions of the respective wine supply chains; (2) to present a series of new scenarios with alternative combinations of modes and nodes from the Australia and Italy; and (3) to identify areas where carbon reduction opportunities may exist.

The underlying reasons for selecting these two source regions are that one is a traditional wine production region, whereas the other is new world thus enabling a comparison of 'traditional' and 'new world' sourcing to be carried out. In addition, wine sourced from continental Europe is moved over relatively short distances, whereas Australian wine, as an exemplar of new world sourcing, involves much longer supply chains. Furthermore, the structure of the respective chains is different, with European wine often being bottled close to source, while Australian wine is commonly transported in bulk and bottled close to market.

In summary, the paper contrasts the decision-making for a number of routes from each of the two countries in terms of length of haul including varying land and sea legs, form of carriage including traditional and more contemporary forms of packaging, modal combinations and the impact of the decision as to where to most effectively bottle imported wine. The paper contributes to the literature in several ways: firstly different combinations of modes, nodes, routes and locations are evaluated in detail. Secondly, the analysis is specific to the wine industry and thus offers insights into wine distribution that have not previously been provided.

Thirdly, the relocation of the wine bottling process closer to market based on population density is an approach that has not been previously used in the context of wine distribution.

2. Carbon Efficiency in Supply Chains and Logistics

Research on the physical flow of goods in international freight transport corridors has traditionally focused on the commercial side of distribution, i.e. costs, schedules, and factors such as inventory carrying. The performance of distribution operations therefore has a tendency to be measured using freight transport as the main supply chain element, without including other relevant stages of distribution, such as packaging and handling. A substantial body of research on supply chain structures largely relates to the coordination of the chains and the distribution of economic value among supply chain partners (see, for example, Leslie and Riemer, 1999; Oro and Pritchard, 2011; Alvarez-San Jaime et al., 2013). Recent studies, however, such as those developed by Sanchez Rodrigues et al. (2014) and The European Chemical Industry Council (2011) have embraced both commercial and environmental parameters. Such studies have examined, in particular, the relationship between cost/ CO_2e efficiency and supply chain structures within international container flows. These mainly focused on the question of port selection as focal point for carbon efficiency improvements. Other nodes, such as inland distribution facilities are similarly recognised as key focal points of logistics activity and they can also potentially significantly affect the efficiency of supply chain structures and, in turn, overall freight transport performance.

In order to better understand the environmental footprint created by the wine distribution from Europe and Australia, reference is made to the body of literature on node, mode and route selection in international freight transport which has grown substantially in recent years (see, for example, Jonkeren at al., 2007; Beresford et al., 2009; Nieuwenhuis, 2012). In addition, there is now a large and growing literature on carbon efficiency and carbon footprinting; here, the papers most applicable to long-distance shipping, transport and distribution are reviewed. Much of the research on supply chain structures relates to the coordination of the supply chain and the distribution of economic value among supply chain partners (see, for example, Leslie and Riemer, 1999; Oro and Pritchard, 2011; Alvarez-San Jaime et al., 2013). Ports are important nodes in international freight transport networks, but other decisions (e.g. form of packaging, method of cargo handling) can be vital to enhancement of the supply chain performance. International freight transport literature mainly focus on port choice where a significant body of research focuses on economic aspects (Suykens and Van de Voorde, 1998; Tongzon, 2001; Malchow and Kanafani, 2004; Gonzalez and Trujillo, 2008; Tongzon, 2009; Steven and Corsi, 2012). Leachman (2008) and Tongzon (2009) concentrate on inland freight transport management as a port choice factor whereas Steven and Corsi (2012) examine port selection in the context of US logistics.

A more contemporary aspect of improving the performance of global maritime-based supply chains is carbon efficiency improvement. CO_2e emissions reduction can be achieved by decarbonising each of the supply chain elements, which include supply chain processes such as production, inventory handling, freight transport and packaging. Early studies on transport mode selection and route choice (McKinnon, 1989) have been updated and refined by, for example, Beresford (1999), Jonkeren et al. (2011), Sanchez Rodrigues et al. (2014) and Sanchez Rodrigues et al. (2015). These papers, respectively, examine European transport costs taking a multimodal approach, model the modal split effects of climate change with particular emphasis on the competitive position of waterway transport, and superimpose a carbon footprint algorithm on international supply chains, again in a European context. Sanchez Rodrigues et al. (2014; 2015) examined the relationship between cost/ CO_2e efficiency and supply chain structures in relation to international container flows, with the focus on port selection as an enabler of carbon efficiency improvements. This theme was further developed by Nieuwenhuis et al. (2012), where emphasis was placed on both multimodal transport costs and on the carbon footprint of alternative automotive production locations. The locations considered were Korea, and the United States, where Korea has a lower production cost alternative and the United States is a close-to-market option.

In all cases it is clearly demonstrated that for long supply chains, transport solutions are invariably multimodal and complex and they operate within a range of physical, organisational and geo-political constraints. It is widely acknowledged that the further cargo is transported the more likely it is to be shipped by a mode other than truck. This principle is clearly demonstrated by, for example, Jonkeren et al. (2011) who show that, at least in theory, short inland freight movements should be performed by road, medium hauls should be by rail, and longer inland transport movements performed most cheaply by inlands waterway, provided that all three modes are available. Importantly, although the longer haul distances would appear to be most attractive for road – rail or road – rail – waterway solutions, freight volumes sharing a common origin and common destination reduce as transport distances increase, thus mitigating against modes other than road haulage for long distance deliveries (Beresford, 1999). Furthermore, the longer the transport distance within Europe, for example, the more likely it is that interoperability barriers are encountered (European Commission, 2014).

Among their business strategies, wine companies make improvements related to the quality of their product and customer service to gain competitive advantage. However their perspectives on increasing sustainability remain unclear, diminishing potential business improvements (Soosay et al., 2012). Indeed, occasional controversies in emissions calculations and consumer surveys can be observed which is detrimental to developing a low pollution, sustainable industry (Fearne et al., 2009; Amienyo et al., 2014). Rugani et al. (2013) indicate the necessity for a holistic and integrated approach towards environmental performance in the wine industry avoiding an over-reliance on carbon footprint calculations. However, it should be noted that the distribution phase of wine is largely independent from grape farming and wine vinification (Cholette and Venkat, 2009).

Moreover, logistics within the wine supply chain include multiple phases of storage and transportation by several modes of transport prior to reaching the final consumer. This means that carbon emissions from wine distribution need to be evaluated in their own right. Only a few Life-Cycle Analysis (LCA) studies within the wine industry focus on logistics provision within the supply chain even though improved performance can lead to substantial carbon reductions irrespective of the wine production phase (Cholette and Venkat, 2009). Indeed, it can be argued that logistics services within the wine industry should be a primary focus. Even though recent wine LCA highlights a wide selection of environmental issues, it is the carbon footprint that makes the largest impact derived from logistics provision and can therefore be used for mitigation strategies (Colman and Päster, 2009; Daniel and Susan, 2009; Barry, 2011).

3. Carbon efficiency research in wine supply chains

In the wider literature on carbon efficiency improvement, there is a large body of research on GHG emissions reduction in supply chains and logistics in general and for wine distribution in particular. Thus, McKinnon et al. (2010) proposed a framework, which include strategic, tactical and operational perspectives of green logistics and a range of incremental and radical changes to freight transport networks that can lead to improvements in carbon efficiency. The decarbonisation of freight transport operations is arguably the mostly commonly explored aspect of logistics. The mode-based focal points of green logistics research are: air transport (Jardine 2009), road transport (Piecyk and McKinnon 2010; Nieuwenhuis 2012; Nieuwenhuis et al., 2012; Vázquez-Rowe et al. 2013), shipping (Wiesmann 2010; Maersk 2013) and port choice (Sanchez-Rodrigues et al. 2014, Sanchez-Rodrigues et al., 2015). The selection of the least polluting modes of transport is rarely, if ever, the logistics manager's priorities, as corporate objectives are almost invariably commercial in the first instance. Nevertheless, in the case of more complex supply chains with longer lead times, modal shift can become an effective mechanism for reducing CO_2e emissions in supply chains, although the primary reason for modal shift will be cost reduction or commercial performance enhancement. Modal shift is particular relevant to the case of fairly heavy commodities such as bottled wine or bulk wine transport.

Most of research undertaken on carbon efficiency of wine supply chains concentrates on estimating the carbon footprint of wine bottles by including all operation elements of wine supply chains. However, research on wine supply chains seems to ignore the alternative solutions that can be adopted to reduce the carbon footprint of wine supply chains, such as using alternative ports and bottling facilities. LCA is most commonly used to calculate the carbon footprint of wine bottles, since it is believed to be an effective tool for the evaluation of environmental impacts in any food and beverage sector in general and wine industry in particular (Christ and Burritt 2013). However, as Table 1 shows, research on the carbon efficiency of wine supply chains has concentrated mainly on estimating the carbon footprint of wine bottling in specific countries. Furthermore, in recent research, the scope of the carbon footprint calculation of wine bottling varies greatly. Several authors include a wide range of carbon footprint elements such as production, packaging and local distribution (e.g. Soosay et al., 2012; Villanueva-Rey et al., 2014; Fusi et al., 2014) whereas some others only wine production and bottling for the estimation of CO_2e emissions (e.g. Vazquez-Rowe et al., 2013; Benedetto, 2013). However, only two Australian wine studies consider the international freight transport element of wine distribution (Fearne et al., 2009; Soosay et al., 2012).

In addition, Rugani et al. (2013) argue that there is a need for more holistic and integrated approaches towards assessing the carbon efficiency of the wine industry. Most recent studies do not include the international element of wine distribution, nor do they model alternative distribution solutions available to wine distiburors. The need for modelling alternative solutions in wine distribution is highlighted by Amienyo et al. (2014) who argue that further reduction in CO_2e emissions generated from the wine production process would be marginal, since viticulture practices have been continually improved over time, and more radical carbon reduction solutions can be found in the distribution elements of wine supply chains.

Within recent research on the carbon efficiency of wine supply chains, there are few modelling-based studies which evaluate measures that could improve the CO_2e/cost/sulphate efficiency of such chains. Several wine supply chain research studies have focused primarily on CO_2e emissions as the main factor and they have not included distribution as an explicit element of their models. For example, Sundarakania et al. (2010) estimated the carbon footprint across a range of supply chains, including a wine supply chain, by adopting an analytical model using the long-range Lagrangian and Eulerian transport methods. Hua et al. (2010) went further than this by investigating how wine supply chains manage carbon footprints in inventory management environments under the carbon emission trading mechanism, the authors did not include freight transport as one of the model elements. Neto et al. (2013) used SimaPro and the Ecoinvent database to perform an environmental assessment of a Portuguese wine supply chain. However, modelling-based studies have not attempted to evaluate the impact of the location of bottling or choice of port of entry on the overall distribution cost, carbon footprint and sulphate emissions of wine supply chains.

Table 1. Examples of research undertaken on carbon efficiency for wine supply chains.

Author	Source country	Production	Bottling	Warehousing	Local distribution	Storage	International distribution	Carbon Footprint Calculation	Modelling
Ardente et al. (2006)	Italy	✓	✓		✓			✓	
Pizzigallo et al. (2008)	Italy	✓	✓					✓	
Cholette and Venkat (2009)	USA				✓			✓	
Ferne et al. (2009)	Australia	✓	✓		✓	✓	✓	✓	
Hua et al. (2010)	China			✓	✓				✓
Sundarakania et al (2010)	Several	✓	✓			✓			✓
Barry (2011)	New Zealand	✓	✓		✓	✓		✓	
Point et al. (2012)	Canada	✓	✓		✓	✓		✓	
Soosay et al. (2012)	Australia	✓	✓		✓	✓	✓	✓	
Vazquez-Rowe et al. (2013)	Spain	✓	✓					✓	
Benedetto (2013)	Italy	✓	✓					✓	
Pattara et al. (2012)	Italy	✓	✓		✓		✓	✓	
Fusi et al. (2014)	Italy	✓	✓		✓	✓		✓	
Villanueva-Rey et al. (2014)	Spain	✓	✓		✓	✓		✓	

Recent studies in green logistics mainly focus on reducing the carbon footprint of freight transport and do not integrate other distribution elements in their analysis. A valid strategy to reduce the CO_2e emissions generated from distribution networks is postponing the final packaging of products to locations closer to the market. As Twede et al. (2000) argue, packaging postponement can improve the efficiency of distribution movements by increasing the weight of the freight carried in transport movements. In the particular case of the wine supply chain literature, WRAP (2008), Point et al. (2012) and Atkinson (2013) discuss strategies related to the postponement of the bottling process from the sourcing country to the market country, such as optimised shipping in bulk, introduction of light-weight bottles and substitution of glass with cartons or PET plastic bottles. The model developed in this study includes bottling and freight transport as the main supply chain elements, which can bring CO_2e/cost efficiency improvements to distribution operations.

4. Sulphate Emissions

An additional important pollutant derived from sea transport is that of sulphates derived from the burning of the sulphur within the marine diesel fuel. Following burning, sulphate particulates accumulate in the middle atmosphere, acting as a barrier to incoming long-wave solar radiation, and thus as a 'damper' on the warming derived from the accumulation of greenhouse gases such as CO_2 which forms the focal point of research in this paper. Further, sulphur dioxide emissions contribute to acid rain, and generate fine particulates, which impact on human health causing respiratory and cardiovascular diseases (European Commission, 2016). Both the damping effect of atmospheric sulphates derived from burning marine diesel fuel and the broader environmental and health impacts are therefore important considerations, but it is a complex issue and not fully understood. It is the intention of this paper, therefore, to highlight only the macro picture of sulphate emissions; from this the sulphates, which can be confidently attributed to the long-distance sea transport of wine, are quantified.

An important issue surrounding the sea transport leg of an international transport operation into Europe, in this case wine, relates to the implementation of sulphur emission control areas (SECAs) which restrict the amount of atmospheric pollutants that ships are allowed to emit. In 2005, the International Maritime Organization, through amendments to Annex VI of the Marine Pollution Convention, MARPOL 73/78, lowered the maximum permissible sulphur content of marine fuels both inside and outside of SECAs. Also in 2005, the European Commission suggested that without action on sulphate emissions from shipping would exceed those from all land-based sources in the EU by 2020 (European Commission. 2005). Subsequently, legislation[1] specifically designated the Baltic Sea, the North Sea and the English Channel as SECAs and limited the maximum sulphur content of the fuels used by ships operating in these sea areas to 1.5%. This was further reduced to 0.1% from 2015. In the cases considered in this paper, SECAs are relevant within in a relatively limited area including the English Channel and North Sea (HMSO, 2012). Thus any ship entering this area will be required to control the volume of sulphates emitted. This requirement can be addressed in several ways, the most obvious being to use ships with modern engines that use fuels with a lower sulphur content. In terms of the supply chains being considered here, there is therefore little or no impact on sulphate emissions due to the sea distance being covered within the SECA being a very small proportion of the overall sea leg from Australia and a relatively small proportion of the shipping route from Italy.

There have been various estimates of the volume of sulphates produced through the combustion of heavy fuel oil used in ocean transport. Agrawal et al. (2010), for example, estimate that the emission factor for sulphur dioxide is 11.53g per kilowatt hour. Similarly, the United States Environmental Protection Agency (EPA, 2007) suggests that sulphate emissions are 11.29g per kilowatt hour for the gas phase and 0.35 g per kilowatt hour for the particulate phase of fuel burning. Thus, for the purposes of modelling sulphate emissions for this paper, the two examples given are broadly similar so, for pragmatic reasons, the higher estimates of the EPA have therefore been used.

5. Wine Production

5.1. Wine Production in Italy

According to statistics presented by Italian Wine Central (2015), Italy produces a wide variety of wines and is the world's largest wine producer by volume with production totaling around 40 to 45 million hecto-litres per annum. Grapes are grown in almost every region of the country with more than one million vineyards under

[1] Regulation of sulphate emissions from ships came under Directive 1999/32/EC which was later amended by Directive 2005/33/EC. European legislation was further revised in 2012 under Directive 2012/33/EU with compliance required by 18th June 2014.

cultivation. Italy has twenty wine regions corresponding to the twenty administrative regions. Wines produced within regions carry specific designations. Vini IGP (Protected Geographical Indication) is traditionally implemented in Italy as IGT - Typical Geographical Indication) and follows a series of regulations regarding authorised varieties, viticultural and vinification practices. In 2014 there were 118 IGPs/IGTs. A higher level of designation is Vini DOP (Protected Designation of Origin) which includes two sub-categories; Vini DOC (Controlled Designation of Origin) and Vini DOCG (Controlled and Guaranteed Designation of Origin) which generally come from smaller regions, within a certain IGP territory. In 2014 there were a total of 405 DOPs comprised of 332 DOCs and 73 DOCGs. All wines with these designations are bottled at source, boxed and palletised for distribution. Wines designated as Vino da Tavola can be transported in bulk and bottled close to market.

Of the twenty regions, the northern regions of Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piedmont, Tuscany, Trentino-Alto Adige, Valle d'Aosta and Veneto, account for around 56% of production. Key cities in these regions are Modena (Emilia-Romagna), Udine (Friuli-Venezia Giulia), Genoa (Liguria), Milan (Lombardy), Turin (Piedmont), Florence (Tuscany), Bolzano (Trentino-Alto Adige), Aosta (Valle d'Aosta), Treviso (Veneto) and which are used as the exemplar cities for production. All of these are substantial road distances from the UK, varying from 1060 km to Calais from Turin to 1430 km to Calais from Florence; onward haulage to the market within the UK will typically add another 100 – 700 km, depending on the location of the local distributor.

5.2. Wine Production in Australia

According to an Australian Bureau of Statistics (2012) report on Australian wine production, Australia is the world's fourth largest exporter of wine, producing around 750 million litres a year for the international export market. For wine distribution from Australia, it is first necessary to understand where the principal wine production areas are. Although wine is produced in every state, Australia's wine regions are mainly in the southern, cooler parts of the country. Since the 1960s, Australia has used an appellation system known as the Australian Geographical Indication (AGI or geographical indication), which distinguishes the geographic origins of the grape. It is a requirement being that 85% of the grapes must be from the region designated on the label. In the late 1990s, more definitive boundaries were established; these divided Australia up into Geographic Indications known as zones, regions and sub regions. A significant proportion of wine is produced in New South Wales which has eight large GI zones, which also includes grapes grown in Victoria, Tasmania and parts of Queensland and South Australia.

An Australian Bureau of Statistics (2012) report identifies the key regions which account for around 60% of Australian wine production are the 'Lower Murray', 'Big Rivers' and 'Murray Darling Swan Hill' regions. The Big Rivers region includes the sub-regions of Perricoota, Riverina plus Murray Darling and Swan Hill which are shared with the state of Victoria. The Big Rivers Zone is the largest wine producing area in New South Wales and Australia's second most prolific wine producing region. The major wine producing centre is located around the Riverina area and the city of Griffith where the major crush facilities are located. Griffith is thus used as the indicator city for the source of production for the Big Rivers region. The Murray Darling Swan Hill regions account for approximately 24% of Australian grape production and are centered on Swan Hill, which is used as the indicator city for the source of production. In South Australia, a fourth geographical indication known as a super zone is used which consists of a group of adjoining zones. The Adelaide Super Zone consists of the Barossa, Fleurieu and Mount Lofty Ranges zones. Other zones are the Far North zone, Limestone Coast zone, Peninsulas zone and Lower Murray zone. The Lower Murray zone is located to the east of the Adelaide superzone and is bordered by the Limestone Coast zone to the south, the Far North zone to the north and by Victoria to the east. It includes the Riverland wine region where a large percentage of Australia's bulk and box wines are produced. The indicator city used for production in this zone is Renmark.

6. Research Methodology

An Excel based model (cost minimisation) was developed to model all scenarios discussed in this section. The input data used in the model are demand, source/bottling plant/destination locations, travel distances, multimodal cost structures, environmental factors, transport mode combinations, packaging forms (bottles/flexitanks) and port locations of exit from Italy and Australia and entry to UK. The UK ports used in the study are the main UK ports of entry for wine imports. These ports are the Port of Felixstowe, Bristol Avonmouth Port, Teesport and the Port of Liverpool. A different combination of ports is used for different scenarios depending on the objective of each scenario. In addition, four UK bottling plants that are currently used by UK grocery retailers are included in the study. These bottling plants are located in Avonmouth (Accolade Wine, 2015), Corby (The Chapel Down Winery, 2015), Stanley (Green Croft Company, 2015) and Runcorn (Lakeland, 2015).

There are many different forms of unitisation that can be used for wine transport, with various characteristics and purposes; for example, ISO containers adapted to carry specialised flexitanks for liquid transport, T1 ISO tank containers for wine, and palletised bottled wine transported in curtain-sided trailers. In reality, wine transport can be resolved into certain typical transport methods. Such standardisation has made it possible to utilise an intermodal approach towards the wine transportation, where the wine is loaded in containers and transported from a winery to a bottling plant and distribution centre without being unstuffed. The two principle types of packaging used are wine bottles and flexitank. In the first case wine bottles are first packed in boxes and then stacked onto pallets, while in the second bulk wine is shipped in flexitanks that are fitted inside ordinary dry containers (WRAP, 2008). Depending on the container's size and wine allotment stowage factor, the amount of wine that can be transported may be restricted either by the container's internal dimensions or by the shipment's weight.

From Australia, wine is primarily shipped in bulk form in flexitank containers, from the production region through to the bottling plant in the UK. Onward transport, i.e. local distribution, is by curtain-sider truck with the bottles now boxed and palletized. This means that additional weight is added to each consignment leaving the bottling plant in the form of glass. This is reflected in the modelling by adding an additional weight factor (0.585 kg/bottle) to represent an impact on costs and emissions. From Italy, due to regulatory control, the majority of wine production is bottled at source, the bottles are then boxed, palletised and moved by some combination of road, rail and sea. A minority of export wines, generally cheaper table wines, are not bottled at source but are shipped in flexitanks, as in the case of Australian wines. [2] In practice, the primary choice of unitisation is between driver accompanied curtain-sider trucks for door-to-door delivery, or standard ISO containers moving by multimodal combinations. As with Australian wine, an extra weight factor is used for local distribution.

For reasons of clarity and simplicity, this research simplifies the range of wine transport methods on the road leg of any transport solution to a standard unit i.e. a forty tonne truck carrying either a twenty foot ISO reefer container, or pulling a curtain-side trailer. This enables a like-for-like comparison of the performance of the routes to be made based using tonne-kilometres as a standard measure. While there may be marginal differences in the emissions from a fully-laden curtain-sider truck versus a comparable flat-bed truck carrying a fully loaded twenty foot container, such differences will be very small and are thus not considered in this analysis. In both cases the vehicles reach their weight limit before cubic capacity limits are reached, and weight is thus the main determinant of the trucks' fuel consumption and hence their CO_2e footprints.

6.1. Wine consumption

Table 2 shows the estimated quantities and percentages of wine consumed in the UK by region and sub-region reference city. The table illustrates large variations related to the wine consumption among different sub-regions in the UK. For example, London accounts for over a quarter of total UK wine consumption, where the main driver for high consumption is high population rather than the consumption rate.

A number of sources (ONS, 2011; ONS, 2012) are used to derive the percentage of wine consumed by each reference city in UK. Data related to the UK adult population, the average number of alcohol units consumed

[2] Wines which are commonly not bottled at source are cheaper varieties known as Vino da Tavola (table wine) which are normally mass-produced and primarily intended for local consumption. Such bulk-produced wines, if exported, are shipped in flexitanks for bottling close to market. The link between the label and the bottling location is therefore broken and the only requirement is that the label must indicate that the wine was produced in Italy.

by UK adult the total number of alcohol units (8 units per 750ml bottle) are used in calculations related to each reference city.

Table 2. Wine consumed in thousands of 9 litre consignments per UK reference city.

Region	Population (000's)	Adult population (%)	Adult population (000's)	Units of wine per week per avg. adult	Bottles of wine per week (000's)	9l per week (000's)	Wine consumed per region (%)	Sub-region (reference city)	Wine consumed per sub-region (%)
Inner & Greater London	7,612	82	6,242	16.1	12,562	113,054	12.86	London	28.07
South East-East Anglia	8,380	82	6,872	17.3	14,860	133,739	15.21		
South West & Wales	5,209	83	4,324	16.9	9,134	82,203	9.34	Exeter	4.67
								Swansea	4.67
East & West Midlands	10,624	82	8,712	17.7	19,275	173,471	19.73	Derby	19.73
North East	2,575	82	2,112	19.0	5,015	45,133	5.13	Newcastle	5.13
North West	6,876	82	5,638	21.6	15,223	137,005	15.58	Manchester	7.79
								Liverpool	7.79
Yorkshire & Humberside	5,213	82	4,275	20.6	11,008	99,071	11.27	Leeds	5.635
								Sheffield	5.635
Scotland	5,328	84	4,475	19.0	10,629	95,657	10.88	Glasgow	5.44
								Edinburgh	5.44

Source: ONS, 2011; ONS, 2012

6.2. Costs and CO_2e Emissions

Wine, when bottled, is a heavy cargo, both because of its liquid density *per se*, and because of the weight of the glass bottles itself. As a result, transport of wine by road has traditionally been weight limited rather than volume constrained with the result that containers used for wine transport are almost invariably fully laden in kilogramme terms although the containers are not full volumetrically. The consequence is that wine transport in bottled form has a substantial cost and carbon footprint whichever mode or modal combination is chosen. Table 3 presents the carbon coefficients expressed as carbon emission factors for all the main freight transport modes including an emissions factor for container handling when such an action is required (CCWG, 2014). The table also shows the carbon emission coefficients or emission factors attributable to container handling (Geerlings and van Duin, 2011).

Table 3. CO_2e emissions coefficients (CCWG, 2014).

Transport / Handling	Emission Factor (kg CO_2e/T-km)
Road (Heavy or Articulated Truck)	0.1150
Train	0.0264
Sea (Ship: Asia-North Europe Trade Lane)	0.0070
Sea (Ship: Intra-Europe Trade Lane)	0.0130
Barge	0.0310
Container handling	0.0002 (kg CO_2e per tonne)

Table 4 presents the figures related to the cost coefficients in £ per tonne-km for the three freight transport modes used in this study and the cost coefficient for the handling of containers (Sanchez-Rodrigues et al., 2014; Sanchez-Rodrigues et al., 2015; Eurotunnel, 2015; private communication). In the case of the Roll-On, Roll-Off alternatives (e.g. curtain-side trucks or Channel tunnel options), the intermodal charges are absorbed in the transport rate so do not appear as a separate handling charge.

Table 4. Costs related to transport and handling of containers.

Transport Method	£ per T-km	Handling Costs	£ per tonne
Road	0.15	Ship to road/Train to road	9.09
Rail	0.01	Ship to train	13.64
Rail (Channel Tunnel)	0.37		
Ship (Asia-North Europe Trade Line)	0.02		
Ship (Intra-Europe Trade Line)	0.03		
Water (Barge)	0.04		

It is notable that rail, ship and barge transport costs per tonne-km are all of a similar order. However, road transport with high unit operating costs, and the Channel tunnel with very high fixed costs, are both out of line with other transport modes in terms of cost per tonne-km. Channel tunnel cost calculations were carried out based on average vehicle flows, typical operating conditions and shoulder season pricing. Intermodal handling costs vary somewhat by method, but variations are not great. In this paper, it is assumed that handling costs per tonne are held at £9.09 (ship to road, train to road) and at £13.64 (ship to train) for convenience. They were calculated based on 11 tonnes average load per container. It is recognised that, in reality, operating costs, and therefore handling charges, can vary substantially from terminal to terminal and from port to port; such variations can be captured in future research.

6.3. Sulphate Emissions

In order to convert the sulphate emission factors detailed in section 4 into emission outputs, the engine sizes for ships using the export routes were ascertained, as shown in Appendix A. The grammes per kilowatt hour emission figure was then converted to total kilogrammes of sulphate per voyage and allocated to the number of containers on the relevant vessel. The kilogrammes of sulphate per TEU–km was then used to calculate the emissions per tonne - km, where an average of 11 tonnes of wine cargo per container was assumed. This aspect of the study is clearly unique to the sea transport legs of the scenarios considered and does not impact on routeing decisions where only road and /or rails are used.

6.4. Description of the scenarios

As detailed in Section 1, two wine sourcing countries, which import significant volume of wine to the UK, are included in the study, namely Australia and Italy. In terms of volume of wine imported Australia and Italy are the countries which provide the first and third largest UK wine import volumes (24.3% and 17.2% of the total) WSTA (2014). While Italian annual wine import volumes are close to those from France, Italian wine imports were selected, as distribution from Italy to the UK offers a wider range of modelling scenarios than France - UK distribution.

6.4.1. Case 1: Distribution of Italian wine to the UK

Table 5 details the volumes of wine produced in each region in the north of Italy and the proportion the Italian wine producers ship to the UK. All data were sourced from Italian Wine Central (2015). The European ports used in the study were La Spezia, Port of Le Havre and Port of Rotterdam. The proportions of wine exported to the UK in either bottles or flexitank will depend on the type of wine being exported. As explained in Section 5.1. only Vino da Tavola can be transported in bulk (flexitank) and bottled close to market. Hypothetical scenarios are therefore used assuming that bottling takes place at different bottling plants, depending on the scenario (refer to Table 6). In some scenarios, the bottling is undertaken at one location, in others, bottling is undertaken at several locations close to the destination points or close to the port of entry. The purpose of the scenarios is to calculate the cost/CO_2e/ sulphate impacts of routeing variations from origins, via alternative ports and bottling plants to destinations using alternative packaging forms.

Table 5. Exports of Italian wine to the UK by source region and reference city.

Region	Reference City	Total production (9 litre cases x 1 mln.)	Volume exported to the UK (9 litre cases x 1 mln.)	% allocation to regions of UK demand
Emilia-Romagna	Modena	75.0	33.5	27.10
Friuli-Venezia Giulia	Udine	12.0		4.34
Liguria	Genoa	0.5		0.18
Lombardy	Milan	14.0		5.06
Piedmont	Turin	29.0		10.48
Tuscany	Florence	30.0		10.84
Trentino-Alto Adige	Bolzano	16.0		5.78
Valle d'Aosta	Aosta	0.2		0.08
Veneto	Treviso	100.0		36.14
Total production in north of Italy		276.7		
Other regions		216.6		
Total		493.3		

Source: Italian Wine Central, 2015

Table 6 presents the key elements of the scenarios used for Italy-UK wine distribution and Figure 1 provides a diagrammatic representation of the model where dashed lines represent different routeing options. For example, in Scenario 1, a truck travels by road from suppliers through the Channel Tunnel (UK port/terminal) directly transporting wine bottles to the destination. In the alternative setting, the flexitank travels by road from supplier to the bottling plant, and then to destinations. In order to transport wine from the selected regions (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardy, Piedmont, Tuscany, Trentino-Alto Adige, Valle d'Aosta and Veneto), a number of alternative options are available. Three main scenarios were modelled to minimise the costs travelled by road, rail or water respectively. Scenarios 1, 2 and 3 include sub-scenarios with the purpose of including the bottling plants' locations where alternative packaging (flexitank) is used. Traditionally, Italian wine is bottled in Italy, potentially realistic scenarios are also constructed where the wine is shipped in flexitanks to UK bottling plants, and then transported to destinations. Sub-scenarios 2A and 2B also include variations related to the number of rail terminals. Similarly, sub-scenarios 3A and 3B introduce variations in the number of port terminals.

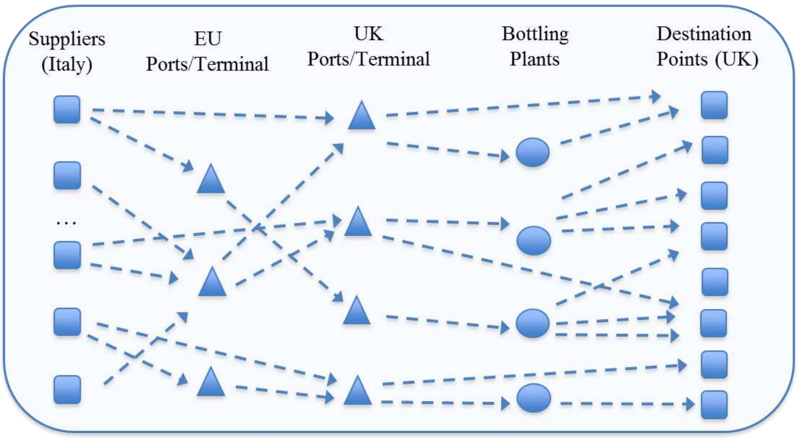

Figure 1. Model representation for Italy - UK wine distribution.

Table 6. Description of scenarios for Italy - UK wine distribution.

Scenario	Main Mode	Packaging	EU/UK exit/entry points	Route	Comment
1A	Road	Bottles	Channel Tunnel	• Road (Suppliers' Vineyard to Channel Tunnel) • Train (Channel Tunnel) • Road (Channel Tunnel to Destinations)	
1B (h)		Flexitank	Channel Tunnel	• Road (Suppliers' Vineyard to Channel Tunnel) • Train (Channel Tunnel) • Road (Channel Tunnel to Bottling Plants (Avonmouth, Corby, Stanley, Runcorn) • Road (Bottling Plants to Destinations)	Bottling Plant locations are nearest to Destinations - different demand proportions (depends on region) allocated to facilities:
2A	Rail	Bottles	Train (Milan, Hams Hall, Glasgow)	• Road (Suppliers' Vineyard to Milan) • Rail (Milan to Hams Hall to Glasgow) • Road (Rail Terminal to Destinations)	Different Rail Terminals for different Destinations
2B		Bottles	Train (Milan, London, Hams Hall, Manchester, Glasgow)	• Road (Suppliers' Vineyard to Milan) • Rail (Milan to London to Hams Hall to Manchester to Glasgow) • Road (Rail Terminal to Destinations)	Different Rail Terminals for different Destinations
2C (h)		Flexitank	Train (Milan, London, Hams Hall, Manchester, Glasgow)	• Road (Suppliers' Vineyard to Milan) • Rail (Milan to London to Hams Hall to Manchester to Glasgow) • Road (Rail Terminal to Bottling plants) • Road (Bottling Plants to Destinations)	Different Rail Terminals for different Bottling Plant locations
3A (h)	Sea	Flexitank	EU : Port of Le Havre; UK : Bristol Avonmouth Port.	• Road (Suppliers' Vineyard to Port of Le Havre) • Sea (Port of Le Havre to Bristol Avonmouth Port) • Road (Bristol Avonmouth Port to Avonmouth Plant) • Road (Avonmouth Plant to Destinations)	
3B		Bottles	EU: La Spezia; UK: Port of Felixstowe.	• Road (Suppliers' Vineyard to La Spezia Port) • Sea (La Spezia Port to Port of Felixstowe) • Road (Port of Felixstowe to Destinations)	
3C(h)		Flexitank	EU: La Spezia, Port of Le Havre, Port of Rotterdam; UK: Bristol Avonmouth Port, Port of Liverpool, Teesport, Port of Felixstowe.	Road (Suppliers' Vineyard to La Spezia Port), then: Route variation (i): • Sea (La Spezia Port to Port of Le Havre) • Sea (Port of Le Havre to Bristol Avonmouth Port) • Road (Bristol Avonmouth Port to Avonmouth Plant) • Road (Avonmouth Plant to Destinations) Route variation (ii): • Sea (La Spezia Port to Port of Le Havre) • Sea (Port of Le Havre to Port of Liverpool) • Barge (Port of Liverpool to Runcorn Plant) • Road (Runcorn Plant to Destinations) Route variation (iii): • Sea (La Spezia Port to Port of Felixstowe) • Road (Port of Felixstowe to Corby Plant) • Road (Corby Plant to Destinations) Route variation (iv): • Sea (La Spezia Port – Port of Rotterdam) • Sea (Port of Rotterdam to Teesport) • Road (Teesport to Stanley plant) • Road (Stanley Plant to Destinations)	Different demand proportions (depending on region) allocated to separate routes:
3D		Bottles	Same as 3C	Same as 3C, except there is no wine movement to the bottling plants	

(h) hypothetical scenario

The principal option is to transport the wine by road to Calais, then to use the Channel Tunnel shuttle before distributing the wine to the bottling facility or to demand points again by truck. Alternative options are to transport the wine to a railhead in Milan, then to a UK terminal from where road transport is used. The third alternative is to move the wine by road to the Port of La Spezia or the Port of Le Havre where sea transport can then be used to ship the wine to either Port of Felixstowe, Port of Le Havre or Port of Rotterdam. From Felixstowe road transport is then used to move the wine to the destination/ or bottling plants, in the latter cases further sea transport is required to reach an appropriate UK port. In this case, road transport is then used to complete the journey to the bottling plant and then to the destination.

6.4.2. Case 2: Distribution of Australian wine to the UK

Table 7 shows the volumes and percentages of wine grapes produced in the main Australian wine regions. The total global exports of Australian wine derived from this production volume for 2012 was 1.236 billion litres **(**Australian Bureau of Statistics, 2012), which converts to 137.4 million 9 litre cases. Of this 24.3 million 9 litre cases were exported to the UK via the Australian export ports e.g. the Port Botany, Sydney which is used in this study. The UK market equates to around 18% of Australian wine exports.

Table 7. Australian wine production by major regions (Department of Agriculture Fisheries and Forestry, 2012).

Region	Reference Point	Total Wine grape production Kilotonnes	%
Murray Darling Swan Hill	Swan Hill	381	39.0
Lower Murray	Renmark	339	34.7
Big Rivers	Griffith	258	26.3
Total production in regions included		978	100
Other Australian regions (excluded from study)		629	

Figure 2 provides a diagrammatic representation of the model where as Table 8 outlines the key elements of the scenarios used for the Australian case study and three main scenarios minimise the cost traveled by road, rail and water respectively. The flexitank is only used in modeling Australian scenarios because of the standard practice where heavy bottles do not need to be shipped over longer distances. Also, Scenarios 1a and 1b maximise the use of the road transport; whereas Scenarios 2 and 3 maximise sea and rail transport respectively where four bottling plants are located closer to the destinations or consumption points are used.

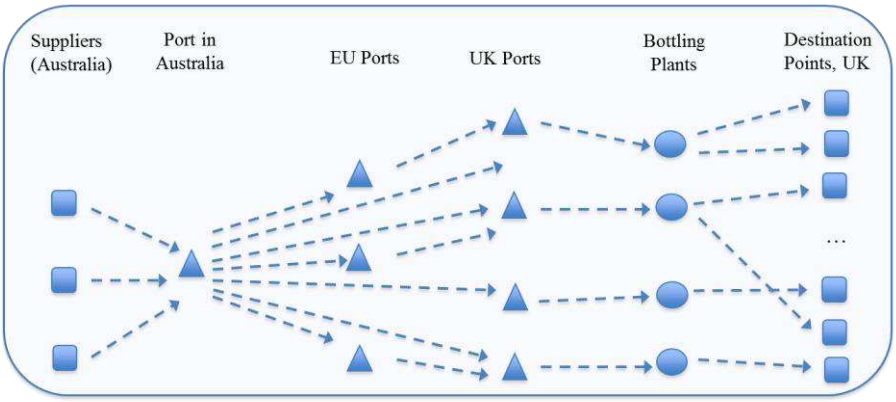

Figure 2. Model representation for Australia - UK wine distribution.

For the export of wine from these regions, the closest logical port is Port Botany, Sydney. Movement of wine to the port is by road, as rail transport may not be available, and thus considerable road transport distances are required. The road distances to Port Botany from the exemplar cities are Swan Hill - 920 km, Renmark – 1150 km and Griffith – 570 km. The wine is then transferred to the ship where it is moved by scheduled liner container services to Europe. Here three options are explored. The first option is direct carriage to Port of Felixstowe and subsequent road transport of relevant demand proportions to the bottling facilities at

Avonmouth, Corby, Stanley and Runcorn. In the sub-scenario (Scenario 1B), the wine is moved from Port of Felixstowe to the bottling facility at Corby, closest facility to the port of entry. In the second option, some transshipments take place at the Port of Le Havre. Volumes are then split proportionally according to demand and further sea transport follows to Bristol Avonmouth Port or Port of Liverpool; other routes include those from the Port of Felixstowe to the Corby bottling plant and the Port of Rotterdam to Teesport and then to the Stanley bottling plant. For routeing via the Port of Liverpool, further water transport by barge is required to move the wine to the bottling facility at Runcorn. The rail scenario (Scenario 3) uses the Port of Tilbury as an entry port to UK; the wine is then moved by rail through the Tilbury rail terminal to different bottling plants according to market location.

Table 8. Description of scenarios for Australia - UK wine distribution (flexitank).

Scenario	Main Mode	EU/UK exit/entry points	Route	Comment
1A	Road	International: Port Botany; UK: Port of Felixstowe.	• Road (Suppliers' Vineyard to Port Botany) • Sea (Port Botany to Port of Felixstowe) • Road (Port of Felixstowe to Bottling Plants (Avonmouth, Corby, Stanley, Runcorn) (relevant proportion of demand)) • Road (Bottling Plants to Destinations)	Bottling Plant locations are nearest to destinations - different demand proportions (depends on region) allocated to facilities.
1B *(h)*		International: Port Botany; UK: Port of Felixstowe.	• Road (Suppliers' Vineyard to Port Botany) • Sea (Port Botany to Port of Felixstowe) • Road (Port of Felixstowe to Corby Plant) • Road (Corby Plant to Destinations)	Bottling Plant location is closest to UK point of entry.
2	Sea	International : Port Botany, Port of Le Havre, Port of Rotterdam; UK: Avonmouth Port, Port of Liverpool, Teesport, Port of Felixstowe.	• Road (Suppliers' Vineyard to Port Botany) then different demand proportions (depends on region) allocated to following routes: Route Variation (i): • Sea (Port Botany to Port of Le Havre) • Sea (Port of Le Havre to Bristol Avonmouth Port) • Road (Bristol Avonmouth Port to Avonmouth Plant) • Road (Avonmouth Plant to Destinations) Route Variation (ii): • Sea (Port Botany to Port of Le Havre) • Sea (Port of Le Havre to Port of Liverpool) • Barge (Port of Liverpool to Runcorn Plant) • Road (Runcorn Plant to Destinations) Route Variation (iii): • Sea (Port Botany to Port of Felixstowe) • Road (Port of Felixstowe to Corby Plant) • Road (Corby Plant to Destinations) Route Variation (iv): • Sea (Port Botany to Port of Rotterdam) • Sea (Port of Rotterdam– Teesport) • Road (Teesport to Stanley plant) • Road (Stanley plant to Destinations)	Bottling Plant locations are nearest to Destinations
3	Rail	International : Port Botany ; UK: Port of Tilbury.	• Road (Suppliers' Vineyard to Port Botany) • Sea (Port Botany to Port of Tilbury), then different demand proportions allocated to following routes: Route Variation (i): • Rail (Tilbury Terminal to Daventry Terminal) • Road (Daventry Terminal to Corby Plant) – • Road (Corby Plant to Destinations) Route Variation (ii): • Rail (Tilbury Terminal to Avonmouth Terminal) – • Road (Avonmouth Terminal to Avonmouth Plant) • Road (Avonmouth Plant to Destinations) Route Variation (iii): • Rail (Tilbury Terminal to Manchester Terminal) • Road (Manchester Terminal to Runcorn Plant) • Road (Runcorn Plant to Destinations) Route Variation (iv): • Rail (Tilbury Terminal to Cleveland Terminal) • Road (Cleveland Terminal to Stanley Plant) • Road (Stanley Plant to Destinations)	Different Rail Terminals for different Bottling Plant locations (closest to destinations).

(h) hypothetical scenario

7. Findings

7.1 Case 1: Distribution of Italian wine to the UK

As can be seen from Table 9, it is striking that, in terms of distribution and handling costs per bottle, the most expensive scenario is five times more costly than the cheapest route. Similarly, the carbon footprint of the most environmentally intrusive route is four times as great as the footprint of the route with the smallest environmental impact. Just as striking is the very strong positive relationship between the environmental footprint and economic costs of the nine scenarios. That is to say, the most expensive routes in commercial terms are road based (wine in bottles, Scenario 1A) and scenario 3D, that is the sea maximizing scenario (bottles) where the cargo enters the UK through four different ports. Conversely, the cheapest options all involve substantial rail transport and the packaging is in both flexitank and bottle form. The most cost effective route (Scenario 2C) is a flexitank movement which is referred to as the hypothetical scenario because traditionally wine is shipped only in bottles across the European Union (including Italy) for regulatory reasons. It is noteworthy that Scenario 2C also carries the lowest emissions value. Although this is a hypothetical case, these findings suggest that use of flexitanks for wine transport within Europe could be both cheaper and environmentally less intrusive. On the other hand, Scenario 2B is also very low in costs and emissions and this scenario uses bottles during the transportation.

Table 9. Results, Italy - UK wine distribution – Cost, CO_2e and Sulphate.

Scenario	£ per Bottle	kg CO_2e per Bottle	Sulphate (kg per Bottle)
Scenario 1A	0.37	0.26	-
Scenario 1B (h)	0.23	0.16	-
Scenario 2A	0.14	0.11	-
Scenario 2B	0.11	0.10	-
Scenario 2C (h)	0.08	0.07	-
Scenario 3A (h)	0.23	0.16	0.000260199
Scenario 3B	0.31	0.16	0.002292172
Scenario 3C (h)	0.32	0.18	0.002056422
Scenario 3D	0.43	0.29	0.004135012

(h) hypothetical scenario

With regard to sulphate output, the lowest cost scenario among sea maximizing options is also the lowest for sulphate emissions. Similarly, the highest cost/emission route produces the highest sulphate output. The number of data points however (only four) restricts the value of this particular part of the research. Nonetheless, it is clear that the further the ships travel, carrying the wine in either bottled or flexitank form, the larger the sulphate footprint and the more expensive the shipping; this reflects the fact that shipping costs and sulphate emissions increase roughly linearly with distance covered. Fuel usage is clearly is the distance related and emissions levels also reflect this usage. Figure 3 presents the outputs from the model in terms of CO_2e and sulphate emissions on a kilogramme per bottle basis.

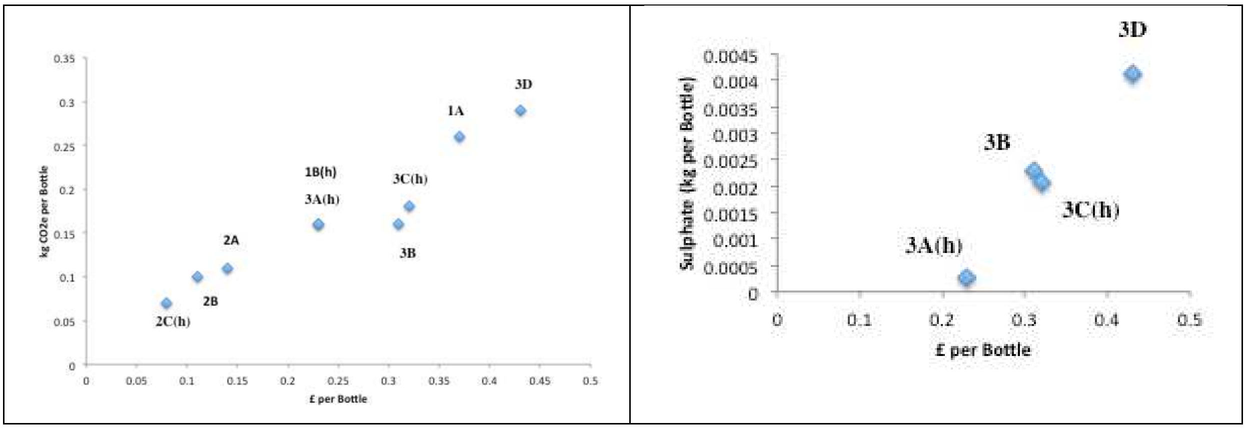

Figure 3. Italy - UK wine distribution kg CO_2e per Bottle versus cost per Bottle by scenario.

From Table 10, it can be seen that, in almost all cases, the big majority of the transport costs is incurred in the international leg (transport and shipment of the wine from country of origin to the UK port) and the minority of costs are incurred between the UK port and the final destinations. An exception is the route via train in the hypothetical scenario (Scenario 2C) where an international leg and UK leg are almost equal in terms of transport costs. This pattern is repeated in the case of CO_2e, which again broadly reflects the linear relationship between carbon emissions and transport distances. What is also notable is that the most expensive scenario in terms of its international leg cost is an order of magnitude more expensive than the lowest cost international leg (Scenario 3D vs Scenario 2C). For CO_2e emissions, the pattern is repeated, although the variations are less extreme. The variation in CO_2e footprint for the UK inland leg is fairly conservative (comparing Scenario 3D with Scenario 1A).

Table 10. International flows, UK inland flows and handling components, Italy - UK wine distribution.

Scenario	Cost (£)			CO_2e (kg CO_2e)			Sulphate (kg)
	International flows	UK inland flows	Handling	International flows	UK inland flows	Handling	
Scenario 1A	119,316,545	30,509,021		81,900,630	22,644,856		-
Scenario 1B (h)	67,031,767	26,912,080		46,011,590	19,975,082		-
Scenario 2A	29,202,294	16,339,895	9,757,636	27,187,117	15,347,345	181	-
Scenario 2B	26,550,151	9,227,046	9,757,636	29,092,190	11,471,464	181	-
Scenario 2C (h)	14,903,838	11,989,728	5,481,818	16,318,739	11,488,260	101	-
Scenario 3A (h)	64,456,009	23,129,400	5,481,818	45,840,149	17,167,445	101	104,600
Scenario 3B	87,506,847	28,036,939	9,757,636	45,210,912	20,809,991	181	921,453
Scenario 3C (h)	97,177,925	14,722,796	15,297,218	60,029,561	10,927,607	283	826,682
Scenario 3D	134,450,170	11,405,490	26,534,346	107,851,911	8,465,551	491	1,662,275

(h) hypothetical scenario

7.2 Case 2: Distribution of wine from Australia to the UK

Table 11 lists the cost per bottle and carbon footprint data for the four scenarios related to wine shipment from Australia to UK. There is very little difference between these scenarios where all wine was shipped in flexitanks, and where the overall geometry of the movements is very similar. Again, the train option provided the lowest figures in terms of costs and emissions, where a train from Tilbury travels to different bottling plants. Figure 4 presents the outputs from the model in terms of CO_2e and sulphate emissions on a kilogramme per bottle basis.

Table 11. Results, Australia-UK wine distribution – Cost, CO_2e and Sulphate.

Scenario	£ per Bottle	kg CO_2e per Bottle	Sulphate (kg per Bottle)
Scenario 1A	0.50	0.25	0.0081755
Scenario 1B	0.51	0.25	0.0081755
Scenario 2	0.51	0.23	0.0124222
Scenario 3	0.48	0.22	0.0084408

Table 12 again illustrates that, amongst the four scenarios, the international leg is virtually constant in terms of its cost and CO_2e footprint. However, the UK inland leg varies by roughly a factor of two for both cost and CO_2e emissions between the lowest and highest costs/emissions. Both for cost and carbon emissions, the international leg is dominant. From a UK perspective, there also should be a focus on reducing the UK inland leg that will link to congestion reduction and commensurate improvements in carbon output. In terms of sulphate, it can be seen in Scenario 2, the level of sulphate emissions is higher compared to CO_2e emissions, suggesting that there appears to be a trade-off between the two key pollutant types that needs to be investigated further in future research.

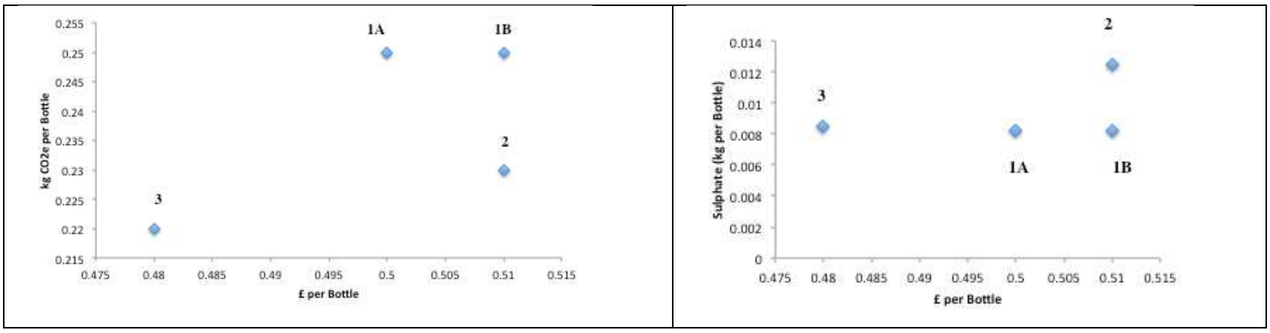

Figure 4. Australia - UK wine distribution kg CO_2e per Bottle versus cost per Bottle by scenario.

Table 12. International leg, UK inland leg and handling components, Australia-UK wine distribution.

Scenario	Cost (£)			CO_2e (kg CO_2e)			Sulphate (kg)
	International leg	UK inland leg	Handling	International leg	UK inland leg	Handling	
Scenario 1A	123,982,298	17,554,780	3,974,073	58,524,749	13,029,768	74	2,382,611
Scenario 1B	123,982,298	19,884,931	3,974,073	58,524,749	14,759,288	74	2,382,611
Scenario 2	126,530,052	10,673,368	11,089,798	59,643,188	7,922,026	205	3,620,238
Scenario 3	120,544,725	9,725,141	8,941,664	57,208,159	8,267,855	147	2,459,927

8. Conclusions and Managerial Implications

8.1 Summary

The global nature of the wine consumption and production industry offers opportunities to examine the respective supply chains in terms of their structure and operating conditions taking account of a wide range of parameters. By fixing the demand area to mainland Britain and by reducing the supply points to two countries, northern Italy and Australia, the data set was controlled, enabling greater rigor to be applied in the analysis, in turn making the findings more meaningful. Several components of the analysis exhibit linear variation, e.g. distance, time, cost and transport derived CO_2e**.** Other components, e.g. ports of exit and entry, bottling plant locations, and method of carriage, act as specific decision variables. Of particular interest and a focal point of this paper, is the comparative carbon footprint of the case supply chains and different forms of distribution channel. The paper informs practitioners, especially specialist wine service logistics providers, and policy makers, of the interplay between overt commercial considerations and less visible environmental metrics.

In this paper, as part of the analysis of the international wine distribution, a range of different scenarios was evaluated where different transport modes, routes, packaging forms were used. The methodology related to the CO_2e and sulphate emissions is discussed. Data from two wine trade routes, namely Australia – UK and Italy – UK, were gathered from shipment companies using real distances, ship services and engine configurations. From the analysis, it is shown that there are major differences between the environmental footprint of different routing and packaging scenarios. Specifically, it is shown that at a macro level, the international shipping leg in most cases has a much larger footprint (CO_2e) than the inland transport legs within the UK except in the hypothetical case of the rail scenario using flexitank, where the deep sea shipping and the inland movement yield to similar impact. At the micro level, small cost savings and/or reductions in CO_2e, can be garnered from alterations in routeing to or from ports of entry or by means of switching from one port to another; additional savings can be gleaned from, for example, minor routeing adjustments to avoid road congestion or other inefficiencies. With reference to sulphate, the lowest cost scenario among the sea maximizing options, also yields the lowest sulphate emissions value and the general pattern is that there appears to be a linear relationship between costs and emissions for European wine shipments though with considerable variation. The sea maximizing scenario (scenario 2) for Australian wine shipments to UK appears to have higher sulphate impact than alternative scenarios.

The use of specialist containers for wine, termed flexitanks, appears to offer significant savings in terms of cost per litre per transport kilometer. The savings appear however to be primarily due to the elimination of carriage of bottles (which represent a significant proportion of the freight weight) rather than to improved economics *per se*. An important element of this, which cannot be ignored, is the regulatory framework relating to the large scale export of wine from traditional supply regions such as southern Europe which prevents the bottling of bulk wine at close-to-market locations. This in turn implies that such a regulatory constraint into market inefficiency will have significant unit cost implications.

8.2. Managerial implications and further research opportunities

This research highlights several areas of importance from the perspective of wine supply chains. Primarily, the research increases the level of understanding of operational aspects of specialist international supply chains, especially from the point of view of cost disaggregation and environmental foot printing. As the research embraces several operational alternatives, both real and hypothetical, it acts as a useful managerial information tool whose main value is the provision of moderated outputs from realistic operational inputs. It has no corporate, subjective or functional bias. The modelling is flexible and it therefore has value well beyond the featured cases as the foot printing techniques can be readily applied to other regions, other types of cargo, other transport forms or other supply chain structures.

Another key factor that managers need to consider is the role that SECAs play, since these have led to some organisational and tactical modifications in shipping operations (Fathom Shipping, 2013). Although Cullinane and Bergqvist (2014) suggest that SECAs can have a considerable impact on maritime freight transport operations, it is important to consider SECAs as a constraint in international supply networks. Specifically, in terms of limiting vessel speed and shipping lead-time, modern supply chains are time sensitive and SECA restrictions can increase the risk of delay in delivery to final destinations.

The transport and distribution of wine into the UK is clearly extremely complex both logistically and in terms of the implied carbon footprint. This exploratory paper therefore points towards a variety of areas for future research. In order to broaden and enrich the dataset, and to test the relationships under a wider range of conditions, additional wine exporting source regions, alternative ports of loading and discharge, and constraints imposed or benefits obtained by the use of alternative bottling plant locations, could be added to the base data and model. Analysis of imports from, for example, additional world wine regions such as Chile, South Africa and California would enable the CO_2e footprint of long, but differing supply chains to be evaluated. These more extensive import flows would enable more variation in ship size and speeds to be incorporated, in turn opening opportunities for more detailed analysis of the sulphates derived from fuel burn on the maritime leg to be carried out. This would strengthen the analysis and increase the value of the potential findings.

In particular, the opportunity to estimate the economic and environmental impacts of the use of the Panama Canal in wine freight transportation, including other metrics suggested by Rodrigue (2010). Furthermore, other alternative ports could be included in the modelling to establish how the unique characteristics of wine as a type of cargo could influence the selection of loading and offloading ports in the international wine distribution network, since, as found by Malchow and Kanafani (2004), cargo type is one of the most influential factors in port selection. In addition, as stated by Garcia et al. (2012), internal metrics used by bottling plants can influence the performance of wine distribution networks; therefore, it would be pertinent to introduce operational metrics in the modelling as a potential influential factor in the selection of wine bottling plants.

Differing supply chain structures and modal combinations could also be incorporated into the data set and solutions tested for carbon efficiency. Collection of data for wine supplied from a wider range of European regions, e.g. north, central and southwest Europe, would enable a more rigorous estimation of environmental foot printing of medium and short haul wine import activities to be undertaken. The wide variety of routeing options over land, or combining land with short sea, would lead to a much richer data set and potentially increased confidence in results. Specifically, the level of traffic congestion along the routes used to move wine to ports in exporting countries and to transport wine from ports in the importing country can be an influential factor in route selection in international wine distribution systems. Short sea shipping can also be considered as an alternative to inland routes to evaluate its impact on traffic congestion levels as well as other freight transport metrics included in this study.

The range of options concerning wine routeing and forms of carriage presented in this paper are informative, and contribute to a better understanding of international wine transport embracing both commercial metrics and the CO2 footprint of respective routes which can be used as a proxy measure of external impact. This paper considered flexitank options for both Italian and Australian wine. However, the Italian scenario is hypothetical given current European regulations whereby certain types of wines must be bottled at source. Should however deregulation occur then, as suggested by Amienyo et al. (2014), on average 67% more wine could be transported by shipping wine in flexitanks or ISO tanks, compared to standard shipping containers for palletised, bottled wine.

8. References

Accolade Wine, 2015. www.accolade-wines.com [Accessed: 5 June 2015].

Agrawal, H., Welch, W.A., Henningsen, S., Miller, J.W., Cocker D.R., III, 2010. Emissions from main propulsion engine on container ship at sea. Journal of Geophysical Research: Atmospheres 115 (D23).

Alvarez-SanJaime, O., Cantos-Sánchez, P., Moner-Colonques, R. and Sempere-Monerris, ., 2013. Vertical integration and exclusivities in maritime freight transport. Transportation Research Part E: Logistics and Transportation Review 51, 50–61.

Amienyo, D., Camillen, C., Azapagic, A., 2014. Environmental impacts of consumption of Australian red wine in the UK. Journal of Cleaner Production 72, 110-119.

Ardente, F., Beccali, G., Cellura, M., Marvuglia, A., 2006. POEMS: a case study of an Italian wine-producing firm, Environmental Management 38 (3), 350-364.

Atkinson, L., 2013. Smart shoppers? Using QR codes and green smartphone apps to mobilize sustainable consumption in the retail environment. International Journal of Consumer Studies 37(4), 387-393.

Australian Bureau of Statistics, 2012. Australian Wine and Grape Industry, 2011–2012. Available at: <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/1329.0Main%20Features22011-12?opendocument&tabname=Summary&prodno=1329.0&issue=2011-12&num=&view= > [Accessed 15 June 2015]

Barry, M.T., 2011. Life Cycle Assessment and the New Zealand Wine Industry: A tool to support continuous environmental improvement, Massey University, Wellington, New Zealand. Fathom

Benedetto, G., 2013. The environmental impact of a Sardinian wine by partial Life Cycle Assessment. Wine Economics and Policy 2, 33-41.

Beresford, A.K.C., 1999. Modelling Freight Transport Costs: A Case Study of the UK-Greece Corridor. International Journal of Logistics Research and Applications 2(3), 229-246.

Beresford, A.K.C., Pettit, S.J., 2009. A geographical perspective on port performance in the United Kingdom. In: Notteboom, T, Ducruet, C, and de Langen, P (eds.) Ports in Proximity: Competition and Coordination among Adjacent Seaports, Transport and mobility series, Farnham: Ashgate, 209-224.

Bontekoning, Y.M., Macharis C., Trip, J.J., 2004. Is a new applied transportation research field emerging? -A review of intermodal rail-truck freight transport literature. Transportation Research Part A: Policy and Practice 38(1), 1–34

Clean Cargo Working Group (CCWG), 2014. Global Maritime Trade Lane Emissions Factors, BSR Report, Available at: <http://www.bsr.org/reports/BSR_CCWG_Trade_Lane_Emissions_Factors.pdf>. [Accessed: 5 June 2015].

Chen, K., Yang, Z., Notteboom, T., 2014. The design of coastal shipping services subject to carbon emission reduction targets and state subsidy levels. Transportation Research Part E: Logistics and Transportation Review 61, 192–211.

Cholette, S., Venkat, K, 2009. The energy and carbon intensity of wine distribution: A study of logistical options for delivering wine to consumers. Journal of Cleaner Production 17 (16), 1401-1413.

Christ, K.L., Burritt, R.L., 2013. Critical Environmental Concerns in Wine Production: An Integrative Review. Journal of Cleaner Production 53, 232-242.

Christopher, M., 2011. Logistics and supply chain management. Harlow: Pearson.

Colman, T., Päster, P., 2009. Red, White, and 'Green': The Cost of Greenhouse Gas Emissions in the Global Wine Trade. Journal of Wine Research 20(1), 15-26.

Cullinane, K., Bergqvist, R., 2014. Emission control areas and their impact on maritime transport, Transportation Research Part D – Transport and Environment, 28, 1-5.

Daniel, J.F., Susan, L.G., 2009. Searching for competitive advantage through sustainability; A qualitative study in the New Zealand wine industry. International Journal of Physical Distribution & Logistics Management 39 (10), 841-860.

Department of Agriculture Fisheries and Forestry, 2012. Australia wine grape projections to 2013-2014.

EPA (United States Environmental Protection Agency), 2007. Modeling sulphur oxides (Sox) emissions transport from ships at sea, EPA420-R-07-009.

Eurostat, 2012. Modal split of inland freight transport, 2002 and 2012 (% of total inland tonne-km), Available at: <http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Modal_split_of_inland_ freight_ transport,_2002_and_2012_(%C2%B9)_(%25_of_total_inland_tkm)_YB15.png> [Accessed 2 October, 2015]

The European Chemical Industry Council (Cefic), 2011. Guidelines for measuring and managing CO_2 emissions from freight transport operations, Available at: <http://www.cefic.org/Documents/IndustrySupport/Transport-and-Logistics/Best%20Practice%20 Guidelines%20-%20General%20Guidelines/Cefic-ECTA%20Guidelines%20for%20measuring%20 and%20managing%20CO2%20emissions%20from%20transport%20operations%20Final%2030.03.2011.pdf> [Accessed: 5 June 2015].

European Commission, 2014. Core Network Corridors, Progress Report of The European Coordinators. TENtec Reporting. http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/brochures_images/ CorridorsProgrReport_version1_2014.pdf [Accessed: 5 June 2015]

European Commission, 2016. Emissions from Maritime Transport, Available at <http://ec.europa.eu/environment/air/transport/ships.htm> [Accessed: 10th May 2016]

European Commission, 2005, Commission Staff Working Paper, Annex to: The Communication on Thematic Strategy on Air Pollution and The Directive on "Ambient Air Quality and Cleaner Air for Europe" Impact Assessment, COM (2005) 446 final} and COM (2005) 447 final

Eurotunnel, 2015. Fair finder. http://www.eurotunnel.com/uk/home/ [Accessed: 1 June 2015]

Fathom Shipping, 2013. Emission Control Areas: The Guide – Part 2 Onboard Manual, 25. Available at: <http://fathomshipping.com/userfiles/files/ab061a7561adb66a975e391 c53909421.pdf>

Fearne, A., Soosay, C., Stringer, R., Umberger, W., Dent, B., Camilleri, C., Henderson, D., Mugford, A., 2009. Sustainable value chain analysis: A Case Study of South Australian wine, Adelaide Thinkers in Residence, Government of South Australia, Available at: http://www.fcrn.org.uk/sites/default/files/ Sustainable_value_chain_analysis_-_Case_Study.pdf [Accessed: 5 June 2015]

Fusi, A., Guidettia, R., Benedetto, G., 2014. Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment. Science of The Total Environment, 472, 989–1000.

Garcia, F., Marchetta, M., Camargo, M., Morel, L., Forradellas, R., 2012. A framework for measuring logistics performance in the wine industry, International Journal of Production Economics 135 (1), 284–298.

Garnett, T., 2007. The alcohol we drink and its contribution to the UK's GHG emissions: A discussion paper. Centre For Environmental Strategy, University of Surrey.

Green Croft Company, 2015. greencroftbottling.com [Accessed: 5 June 2015].

Gonzalez, M., Trujillo, L., 2008. Reforms and infrastructure efficiency in Spain's container ports. Transportation Research Part A: Policy and Practice 42, 243–257.

Geerlings, H., van Duin, R., 2011. A new method for assessing CO_2 emissions from container terminals: a promising approach applied in Rotterdam. Journal of Cleaner Production 19, 657 – 666.

HMSO, 2012, Sulphur emissions by ships - Transport Committee, Available at http://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/1561/156105.htm [Accessed 10th May 2016]

Hua G., Chenga, T., Wang, S., 2010. Managing carbon footprints in inventory management. International Journal of Production Economies 132 (2), 178–185.

Italian Wine Central, 2015. Italian Wine Production per Region. Available at: http://italianwinecentral.com/italian-wine-exports-by-destination/ [Accessed: 5 June 2015].
Jardine, C, 2009. Calculating carbon emissions of flights, Environmental Change Institute, Oxford University, pp. 19.
Jonkeren, O., Rietveld, P., Ommeren, J., 2007. Climate change and inland waterway transport: welfare effects of low water levels on the river Rhine. Journal of Transport Economics and Policy 41 (3), 387 – 411.
Jonkeren O., Jourquin, B., Rietveld, P., 2011. Modal split effects of climate change: the effect of low water levels on the competitive position of inland waterway transport in the river Rhine area. Transportation Research Part A 45(10), 1007-1019.
Lakeland, 2015. www.lakeland.co.uk/WineMaking [Accessed: 5 June 2015].
Leachman, R., 2008. Port and modal allocation of waterborne containerized imports from Asia to the United States. Transportation Research Part E: Logistics and Transportation Review 44, 313–331.
Leslie, D., Riemer, S., 1999. Spatializing commodity chains. Progress in Human Geography 23 (3), 401 – 420.
Maersk, L., 2013. Sustainability Progress Update, Maersk Line.
Malchow, M.B., Kanafani, A., 2004. A disaggregate analysis of port selection. Transportation Research Part E: Logistics and Transportation Review 40 (4), 317 – 337.
McKinnon, A., 1989. Physical Distribution Systems, Routledge, London, pp. 316.
McKinnon, A.C., Cullinane, S., Browne, M., Whiteing, A., 2010. Green Logistics - Improving the environmental sustainability of logistics, London: Kogan Page.
Murphy, P.R., Poist, R.F., 2003. Green perspectives and practices: a "comparative logistics" study. Supply Chain Management: An International Journal 8 (2), 122-131.
Murphy, P., Daley, L., Dalenberg, D., 1991. Selecting links and nodes in international transportation: an intermediary's perspective. Transportation Journal 31 (2), 33–40.
Neto, B., Dias, A., Machado, M., 2013. Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution. The International Journal of Life Cycle Assessment, 18 (3), 590-602.
Nieuwenhuis, P., Beresford, A., Choi, A. K.Y., 2012. Shipping or local production? CO2 impact of a strategic decision: An automotive industry case study, International Journal of Production Economics, 140(1), 138–148.
Nieuwenhuis, P., 2012. The Challenge of decarbonizing the car. In: Nilsson, M.E.A. (ed.) Paving the Road to Sustainable Transport. London: Routledge Ltd., 17-39.
Office for National Statistics (ONS), 2011. Population Estimates for UK, England and Wales, Scotland and Northern Ireland, Mid-2010, Available at: <http://www.ons.gov.uk/ons/ publications/re-reference-tables.html?edition=tcm%3A77-231847.>
Office for National Statistics (ONS), 2012. Drinking Habits Amongst Adults - UK Regions, Health and Social Care, Published on 17th December.
Oro, K., Pritchard, B., 2011. The evolution of global value chains: displacement of captive upstream investment in the Australia - Japan beef trade. Journal of Economic Geography 11, 709 - 729.
Pattara, C., Raggi, A., Cichelli, A., 2012. Life Cycle Assessment and Carbon Footprint in the Wine Supply-Chain. Environmental Management 49,1247–1258
Piecyk, MI, McKinnon, AC, 2010. Forecasting the Carbon Footprint of Road Freight Transport in 2020. International Journal of Production Economics 128 (1), 31-42.
Pizzigallo, A., Granai, C., Borsa, S., 2008. The joint use of LCA and emergy evaluation for the analysis of two Italian wine farms. Journal of Environmental Management, 86 (2), 396-406.
Point, E., Tyedmers, P., Naugler, C., 2012. Life cycle environmental impacts of wine production and consumption in Nova Scotia. Canada, Journal of Cleaner Production 27, 11-20.
Qi, X., Song, D.S., 2012. Minimizing fuel emissions by optimizing vessel schedules in liner shipping with uncertain port times. Transportation Research Part E: Logistics and Transportation Review 48, 863–880.
Rodrigue, J.-P., 2010. Factors Impacting North American Freight Distribution in View of the Panama Canal Expansion, The van Horne Institutes, Hofstra University, Available at: <http://people.hofstra.edu/jean-paul_rodrigue/downloads/Panama%20Canal%20Study%202011%20Final.pdf>
Rugani, B., Vázquez-Rowe, I., Benedetto, R., Benetto, E., 2013. A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector. Journal of Cleaner Production 54, 61-77.

Sanchez-Rodrigues, V., Beresford, A.K.C., Pettit S.J., Battacharya S., Harris, I., 2014. Assessing the cost and CO_2e impacts of rerouteing UK import containers. Transport Research Part A: Policy and Practice 61, 53-67.
Sanchez Rodrigues V.; Pettit S., Harris I., Beresford A.K.C., Piecyk M., Yang Z., Ng A., 2015. UK supply chain carbon mitigation strategies using alternative ports and multimodal freight transport operations. Transportation Research Part E 78, 40–56.
Soosay, C., Fearne, A., Dent, B., 2012. Sustainable value chain analysis – a case study of Oxford Landing from "vine to dine". Supply Chain Management: An International Journal 17(1), 68-77.
Steven, A., Corsi, T.M., 2012. Choosing a port: An analysis of containerized imports into the US. Transportation Research Part E: Logistics and Transportation Review 48, 881–895.
Suykens, F., Van de Voorde, E., 1998. A Quarter of a Century of Port Management in Europe: Objectives and Tools. Maritime Policy and Management, 25(3), 251-261.
Sundarakania, B., de Souza, R., Goh, M., Wagner, S., Manikandan, S., 2010. Modelling carbon footprints across the supply chain. International Journal of Production Economics, 128 (1), 43–50.
The Chapel Down Winery, 2015. www. chapeldown.com [Accessed: 5 June 2015].
Tongzon, J., 2001. Efficiency measurement of selected Australian and other international ports using data envelopment analysis. Transportation Research Part A: Policy and Practice 35, 107-122.
Tongzon, J.L., 2009. Port choice and freight forwarders. Transportation Research Part E: Logistics and Transportation Review 45, 186–195.
Twede D., Clarke, R.H., Tait, J.A., 2000. Packaging postponement: A global packaging strategy. Packaging Technology & Science, 13, 103-115.
Vázquez-Rowe, I., Rugani, B., Benetto, E., 2013. Tapping carbon footprint variations in the European wine sector. Journal of Cleaner Production 43, 146–155.
Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, M., Feijoo, G., 2014. Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production 65, 330–341.
Wiesmann, A., 2010. Slow steaming – a viable long-term option? Wartsila Technical Journal 2, 49-51.
Wine and Spirit Trade Association (WSTA), 2014. Market overview - UK wine and spirits, http://wsta.co.uk/publications-useful-documents/71-wsta-market-overview-2014/file [Accessed on 2nd October, 2015]
WRAP, 2008. Final report: GlassRite: wine. Bulk shipping of wine and its implications for product quality British Glass. [Online]. Available at: http://www2.wrap.org.uk/downloads/Bulk_shipping_wine_quality_May_08.1278caa3.5386.pdf

Appendix A

Route	Ship	Containers	Engine (Kw)	Days sailing (at 15 knots)	Total Kwh	Total Sulphate (g, gas phase)	Total Sulphate (g, particulate phase)	Total Sulphate (Kg)	Sulphate (Kg / teu)	Sulphate (Kg / teu / km)	Sulphate (Kg / tonne / km)
Sydney to Teesport											**0.00112915**
Sydney to Tanjung Pelepas	Safmarine Nomazwe	3,700	45,588	11	12,035,232	135,877,769	4,212,331	140,090.10	37.86	0.00501552	0.00045596
Tanjung Pelpas to Rotterdam	Munkebo Maersk	18,300	64,000	24	36,864,000	416,194,560	12,902,400	429,096.96	23.45	0.00146166	0.00013288
Rotterdam to Teesport	Gerda	373	3,825	1	91,800	1,036,422	32,130	1,068.55	2.86	0.00594347	0.00054032
Sydney to Tilbury	ANL Windarra	2,805	36,560	34	29,832,960	336,814,118	10,441,536	347,255.65	123.80	0.00547782	**0.00049798**
Sydney to Felixstowe											**0.00046455**
Sydney to Tanjung Pelepas	Maersk Virginia	4,824	43,070	11	11,370,480	128,372,719	3,979,668	132,352.39	27.44	0.00363442	0.00033040
Tanjung Pelpas to Felixstowe	Mary Maersk	18,270	64,000	24	36,864,000	416,194,560	12,902,400	429,096.96	23.49	0.00147565	0.00013415
Sydney to Le Havre											**0.00055696**
Sydney to Tanjung Pelepas	Maersk Virginia	4,824	43,070	11	11,370,480	128,372,719	3,979,668	132,352.39	27.44	0.00363442	0.00033040
Tanjung Pelepas to Le Havre	MSC Lawrence	12,400	72,240	24	41,610,240	469,779,609	14,563,584	484,343.19	39.06	0.00249218	0.00022656
Sydney to Liverpool											**0.00062001**
Sydney to Le Havre	CMA CGM Auckland	2,492	21,650	34	17,666,400	199,453,656	6,183,240	205,636.90	82.52	0.00365160	0.00033196
Le Havre to Liverpool	Pengalia	690	7,200	1	172,800	1,950,912	60,480	2,011.39	2.92	0.00316854	0.00028805
La Spezia to Felixstowe	MSC Samantha	5,711	64,351	6	9,266,544	104,619,282	3,243,290	107,862.57	18.89	0.00475379	**0.00043216**
La Spezia to Rotterdam											**0.00172119**
La Spezia to Felixstowe	MSC Samantha	5,711	64,351	6	9,266,544	104,619,282	3,243,290	107,862.57	18.89	0.00475379	0.00043216
Felixstowe to Rotterdam	MSC Samantha	5,711	64,351	1	1,544,424	17,436,547	540,548	17,977.10	3.15	0.01417929	0.00128903
La Spezia to Le Havre	MSC Samantha	5,711	64,351	6	9,266,544	104,619,282	3,243,290	107,862.57	18.89	0.00506349	**0.00046032**
Le Havre to Avonmouth	CMA CGM Victoria	280	3,825	1	91,800	1,036,422	32,130	1,068.55	3.82	0.00532253	**0.00048387**
Liverpool to Runcorn	Barge	366	3,825		11,475	129,553	4,016	133.57	0.36	0.00729885	**0.00066353**