Carbon Footprint and Sulphur Emissions for International Wine Distribution using Alternative Routeing and Packaging Scenarios

Irina Harris[1a], Vasco Sanchez Rodrigues[a], Stephen Pettit[a], Anthony Beresford[a], Rodion Liashko[b]

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

Abstract

There is a large body of research related to carbon footprint reduction in supply chains and logistics from a wide range of sectors where the decarbonisation of freight transport is frequently explored from a single mode perspective and at domestic/regional level (Jardine, 2009; Maersk, 2013; Wiesmann, 2010). The decarbonisation of global freight transport chains needs to take into account a range of alternative transport modes and routes in addition to the decisions related to the alternative product packaging at source or closer to the demand points. This paper intends to address these shortcomings and the research presents a “gate to gate” carbon footprint and sulphur calculations methodology related to the distribution of wine from Australia and Italy to the UK.

The methodology adopted in this paper uses secondary data gathered from academic and industrial sources on the distribution of wine from source to market. These were used to evaluate the environmental impact of international wine transport to the UK from two sourcing areas: Italy and Australia. A number of options were evaluated to calculate the carbon footprint and sulphur emissions of alternative route, mode and packaging combinations. The estimation of CO_{2e} emissions incorporates three main elements - cargo mass, distance and transport mode whereas sulphur emissions are derived from actual ship routing, engine power and travel times. The decision made related to the bottling of wine either at source or destination is also integrated into the model. The key findings are: there are major differences between the environmental footprint of different routing 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 scenario using flexitank (Italy). With reference to sulphur, the lowest cost scenario among the sea maximising options is also the lowest value for sulphur emissions and the general pattern is that there seems to be a linear relationship between costs and emissions for European wine shipments. However, the sea maximising scenario (scenario 2) for Australian wine shipments to UK appears to have higher sulphur impact than alternative scenarios.

Keywords: international freight transport, wine port/node/route selection, CO_{2e} reduction, sulphur emissions

1. Introduction

As Christopher (2011) states, global supply chains, which cover long distances, can be very carbon-intensive. This notion can be directly applied to 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_2 where significant contributions are related to agricultural machines (9.3%) and products transportation (8.2%) (Ardente et al., 2006). At the same time, the distribution and 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 in the wine industry’s in general and its carbon footprint in particular are important targets for further development of wine industry within the concept of sustainable production 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, the carbon mitigation of maritime legs of freight transport was investigated by Qi and Song (2012) and Chen et al. (2014). However, the literature on port selection in international supply chains does not seem to incorporate other logistics operations in the estimation of CO_{2e}

[1] *Corresponding Author*

emissions of supply chains. One key aspect, which is not sufficiently well researched in literature, is how changes in packaging operations can bring efficiency improvements to freight transport movements by increasing the freight weight carried in transport movements from origin to destination. Another factor, which should be included in the assessment of how supply chains can reduce their carbon intensity, is inventory handling and packaging. As Murphy and Poist (2003) found, packaging and warehousing improvements initiatives can bring significant reductions in the overall carbon footprint of supply chains.

The objectives of this study, therefore, are: 1) to model the carbon footprint and sulphur emissions of the respective wine supply chains, and 2) to present a series of scenarios with alternative combinations of modes and nodes for movements from two geographically distinct areas – Europe and Australia – to the UK. The underlying reasons for selecting these two source regions are that one is a traditional wine production region, whereas the other is new world. A second reason is that 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. Thirdly, 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. For Europe, the exemplar country used is Italy as it is produces significant quantities of wine for export and it offers a diverse mix of potential routeings and methods of carriage, including both land only, and land –sea combinations. 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.

Australian and Italian wine imports represent 24.3% and 17.2% of the total volume of wine imported to the UK, according to recent statistics published by the UK Wine and Spirits Trade Association – WSTA (2014). Furthermore, in the case of Italy-UK distribution, there is a wide range of options available for freight transport movement, including road, rail or sea, or multimodal combinations, for example, cargo transported by train through the channel tunnel, or by container ship via Gibraltar and by road and ferry via Calais. However, most of the cargo moved within the UK is moved by road, which represents 89% of the total modal split in the freight transport market according to Eurostat (2012). The very large mode split road justifies the core practical purpose of the paper, which is to show other more carbon efficient ways of transporting imports from UK ports to destinations.

2. Literature

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. packaging, container handling) can be vital to enhancement of the supply chain performance. International freight transport literature mainly concentrates 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 decarbonizing each of the supply chain elements, which include supply chain processes such as production, inventory handling, freight transport and packaging. Early studies on the transport mode selection and route choice (e.g. Hayuth, 1986; 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. Another study with emphasis on both multimodal transport costs and on the carbon footprint of alternative automotive production locations was carried out by Nieuwenhuis et al. (2012). The alternative 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 economic to use a transport method other than road haulage. 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 multimodal, 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). It is also the case that 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 serving the customers in the best way possible to gain competitive advantage. However their perspective on sustainability efforts remains unclear, diminishing potential business improvements (Soosay et al., 2012). Moreover, 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 includes 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. Despite the plethora of LCA (life-cycle analysis) studies within the wine industry only a few focus on logistics provision within the supply chain even though improvements within the transport and storage of wine supply chain 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. According to the research, even though recent wine LCA highlights a wide selection of environmental issues, it is the carbon footprint that makes the largest impact in logistics provision and can therefore be used for mitigation strategies. It is especially valid when a large spread of results concerning carbon footprint of the distribution phase is observed in different LCA research based on location and the length of the supply chain (Colman and Päster, 2009; Daniel and Susan, 2009; Barry, 2011).

3. Wine Production

3.1 Wine Production in Italy

According to statistics estimated 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 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. 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, and 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 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.

3.2 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 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 that 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 discusses 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 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 areproduced. The indicator city used for production in this zone is Renmark.

4. 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, 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 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 containers can be used for transportation, with various characteristics and purposes. However this research is based on a container with a standard size and type: 20ft reefer unit. Such standardisation 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 distribution centre without being unstuffed.

Two different types of packaging are used: wine bottles and flexitank. In this case wine bottles are first packed in boxes and then stacked onto pallets, while bulk wine is either shipped in steel T1 ISO standard tank containers (very rarely) or Flexitanks that are fitted inside ordinary dry containers (British Glass, 2008). Depending on the container size and wine allotment stowage factor the amount of wine that can be transported may be restricted either by the container internal dimensions or by the shipment's weight.

4.1. Wine consumption

Table 1 shows the estimated quantities and percentages of wine consumption 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 one 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 by UK adult, the total number of alcohol units (8 units per 750ml bottle) are used in calculations related to each city.

Table 1: Wine consumed in thousands of 9 litre consignments per UK reference city (ONS, 2011; ONS, 2012)

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	9.35	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	5.12	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	5.63
								Sheffield	5.63
Scotland	5,328	84	4,475	19.0	10,629	95,657	10.88	Glasgow	5.44
								Edinburgh	5.44

4.2. Costs and CO_{2e} Emissions

Wine, when bottled, is a heavy cargo, both because of its density *per se*, and because of the weight of the glass. 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 2 presents the carbon coefficients expressed as carbon emission factors for all the main freight transport modes (CCWG, 2012). The table also shows the carbon coefficient or emission factors attributable to container handling (Geerlings and van Duin, 2011).

Table 2: CO_{2e} emissions coefficients (CCWG, 2012)

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 Line)	0.0070
Sea (Ship: Intra-Europe Trade Line)	0.0130
Barge	0.0310
Container handling	0.0002 (kg CO_{2e} per tonne)

Table 3 presents the figures related to the cost coefficients in £ per tonne-km for the three freight transport modes used in the study and the cost coefficient of the handling stage of the distribution of containers (Sanchez-Rodrigues et al., 2014; Sanchez-Rodrigues et al., 2015; Eurotunnel, 2015; private communication).

Table 3: 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/Ship to Barge	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 the similar order but road transport, with high unit operating costs, and the Channel tunnel, with very high fixed costs, are respectively 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 working 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/ ship to barge) for convenience. These were calculated based on 11 tonne average load per container. It is recognised that, in reality, costs can vary substantially from terminal to terminal and from port to port; such variations can be captured in future research.

4.3. Sulphur Emissions

An additional important pollutant derived from sea transport is that of sulphur. There have been various estimates of the amount of sulphur produced through the combustion of heavy fuel oil used in ocean transport. Agrawal et al. (2010) 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 sulphur emissions are 11.29g per kilowatt hour for gas phase and 0.35 g per kilowatt hour for the particulate phase of fuel burning. In order to convert these emission factors, the engine sizes for ships using the export routes were ascertained, shown in Appendix A. The grammes per kilowatt hour emission figure was then converted to total kg of sulphur per voyage and allocated to the number of containers on the relevant vessel. The kg of sulphur per TEU–km then was used to calculate the emissions per tonne - km, where an average of 11 tonnes of wine cargo per container was assumed.

Table 4: Exports of Italian wine to the UK by source region and reference city (Italian Wine Central, 2015)

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		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	33.5	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		

4.4. Description of the scenarios

Two wine sourcing countries, which import significant volume of wine to the UK, are included in the study, namely Australia and Italy. The selection of these two sourcing countries can firstly be justified because Australia and Italy are the first and third ranked countries that import significant volumes of wine to the UK. Australian wine represents 24.3% of the total wine imported by the UK while Italian wine represents 17.2% of the total, according to recent statistics published by the Wine and Spirits Trade Association - WSTA (2014). In addition, Italian annual wine import volume is very close in volume to French wine, which represents

17.2%. of imports. However, the reason why Italian wine is selected for the modelling over French wine is because the distribution from Italy to the UK offers a wider range of scenarios than France-to-UK distribution.

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

Table 4 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 was sourced from Italian Wine Central (2015). The European ports used in the study were La Spezia, Port of Le Havre and Port of Rotterdam. It is assumed that bottling of the wine took place at different bottling plants, depending on the scenario (refer to the Table 5). In some scenarios, the bottling has been done 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}/ sulphur impacts of routeing variations from origins, via alternative ports and bottling plants to destinations using alternative packaging forms.

Table 5: Description of scenarios for Italy - UK wine distribution

Scenario	Main Transport Mode	Packaging	EU/UK points of exit/entry	Route
1A	Road	Bottles	Channel Tunnel	road (Supplier's Vineyard - Channel Tunnel) - train (Channel Tunnel) - road (Channel Tunnel - Destinations)
1B (h)		Flexitank	Channel Tunnel	Bottling Plant locations are nearest to Destinations - different demand proportions (depends on region) allocated to facilities: road (Supplier's Vineyard - Channel Tunnel) - train (Channel Tunnel) - road (Channel Tunnel - Bottling Plants (Avonmouth, Corby, Stanley, Runcorn) - road (Bottling Plants -Destinations)
2A	Rail	Bottles	Train (Milan, Hams Hall, Glasgow)	Different Rail Terminals for different Destinations: road (Supplier's Vineyard - Milan) - rail (Milan – Hams Hall - Glasgow) - road (Rail Terminal - Destinations)
2B		Bottles	Train (Milan, London, Hams Hall, Manchester, Glasgow)	Different Rail Terminals for different Destinations: road (Suppliers Vineyard - Milan) - rail (Milan - London - Hams Hall - Manchester -Glasgow) - road (Rail Terminal - Destinations)
2C (h)		Flexitank	Train (Milan, London, Hams Hall, Manchester, Glasgow)	Different Rail Terminals for different Bottling Plant locations: road (Supplier's Vineyard - Milan) - rail (Milan - London - Hams Hall - Manchester - Glasgow) - road (Rail Terminal - Bottling plants) - road (Bottling Plants - Destinations)
3A (h)	Sea/Water	Flexitank	EU : Port of Le Havre UK : Bristol Avonmouth Port	road (Supplier's Vineyard - Port of Le Havre) - sea (Port of Le Havre– Bristol Avonmouth Port) - road (Bristol Avonmouth Port - Avonmouth Plant) – road (Avonmouth Plant – Dest.)
3B		Bottles	EU: La Spezia ; UK: Port of Felixstowe	road (Supplier's Vineyard - La Spezia Port)- sea (La Spezia Port – Port of Felixstowe - road (Port of Felixstowe – Dest.)
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 (Supplier's Vineyard- La Spezia Port), then different demand proportions (depends on region) allocated to routes: 1) sea (La Spezia Port - Port of Le Havre) - sea (Port of Le Havre - Bristol Avonmouth Port) - road (Bristol Avonmouth Port - Avonmouth Plant) - road (Avonmouth Plant – Dest.) 2) sea (La Spezia Port - Port of Le Havre) - sea (Port of Le Havre - Port of Liverpool) - barge (Port of Liverpool - Runcorn Plant) - road (Runcorn Plant - Destinations) 3) sea (La Spezia Port – Port of Felixstowe) - road (Port of Felixstowe - Corby Plant) -road (Corby Plant - Destinations) 4) sea (La Spezia Port - Port of Rotterdam) - sea (Port of Rotterdam - Teesport) - road (Teesport - Stanley plant) - road (Stanley Plant - Destinations)
3D		Bottles	same as 3C	same as 3C, except there is no movement to the bottling plants

(h) hypothetical scenario

Table 5 presents the key elements of the scenarios used for Italy-UK wine distribution. 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 distances travelled by road, rail or water respectively. Scenarios 1, 2 and 3 include sub-scenarios with the purpose to include the bottling plants locations where alternative packaging (flexitank) is used. Traditionally, Italian wine is bottled in Italy, nevertheless the paper explores a "hypothetical" scenarios 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.

The principal option is to transport the wine by road to Calais, then to use the Channel Tunnel shutlle and then use the road to move the wine to the bottling facility or demand points. Alternative options are to move the wine to a railhead in Milan, then to 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 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 Roterdam. In the former case road transport is then used to move the wine to the destination/ or bottling plants, in the latter 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.

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

Table 6 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. Port Botany, Sydney which is used in this study. The UK market equates to around 18% of Australian wine exports.

Table 6: 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	
Other regions		629	

Table 7 outlines the key elements of the scenarios used for the Australian case study. Three main scenarios minimise the distances traveled by road, rail and water respectively. Also, scenarios 1 maximises the use of the road transport; whereas Scenarios 2 and 3 maximise sea and rail transport respectively where four bottling plants located closer to the destinations or consumption points.

In order to export wine from these regions, the closest logical port is Port Botany, Sydney. Movement of wine to the port is by road, as rail transport is not 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 – 1150km and Griffith – 570 km. The wine is then transferred to the ship where it is moved by scheduled liner container services to Europe. Here two options are explored. The first option is direct carriage to Felixstowe and subsequent road transport to the bottling facility at Avonmouth. In the second option, the proportion of demand is transshipment to Port of Le Havre and further sea transport to Bristol Avonmouth Port or Port of Liverpool; other routes include from Port of Felixstowe to Corby plant and Port of Rotterdam to Teesport and then to Stanley bottling plant. In the goods movement to 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 Port of Tilbury as an entry port to UK, then the wine is moved by rail trough Tilbury rail terminal to different bottling plants.

Table 7: Description of scenarios for Australia - UK wine distribution (flexitank)

Scenario	Main Transport Mode	International/UK points of exit/entry	Route
1A	Road	International: Port Botany UK: Port of Felixstowe	Bottling Plant locations are nearest to Destinations - different demand proportions (depends on region) allocated to Facilities: road (Supplier's Vineyard - Port Botany) - sea (Port Botany - Port of Felixstowe) - road (Port of Felixstowe - Bottling Plants (Avonmouth, Corby, Stanley, Runcorn) (relevant proportion of demand)) - road (Bottling Plants - Destinations)
1B		International: Port Botany UK: Port of Felixstowe	Bottling Plant location is closest to UK port of entry: road (Supplier's Vineyard - Port Botany) - sea (Port Botany - Port of Felixstowe) - road (Port of Felixstowe - Corby Plant) - road (Corby Plant - Destinations)
2	Sea	International: Port Botany Port of Le Havre Port of Rotterdam UK: Bristol Avonmouth Port; Port of Liverpool; Teesport; Port of Felixstowe;	Bottling Plant locations are nearest to Destinations - different demand proportions (depends on region) allocated to Facilities: road (Supplier'sVineyard – Port Botany) then different demand proportions (depends on region) allocated to following routes: 1) sea (Port Botany - Port of Le Havre) - sea (Port of Le Havre - Bristol Avonmouth Port) - road (Bristol Avonmouth Port - Avonmouth Plant) - road (Avonmouth Plant - Destinations) 2) sea (Port Botany - Port of Le Havre) - sea (Port of Le Havre - Port of Liverpool) - barge (Port of Liverpool - Runcorn Plant) - road (Runcorn Plant - Destinations) 3) sea (Port Botany - Port of Felixstowe) - road (Port of Felixstowe - Corby Plant) - road (Corby Plant - Destinations) 4) sea (Port Botany - Port of Rotterdam) - sea (Port of Rotterdam– Teesport) - road (Teesport - Stanley plant) - road (Stanley plant - Destinations)
3	Rail	International: Port Botany UK: Tilbury	Different Rail Terminals for different Bottling Plant locations (closest to Destinations): road (Suppliers Vineyard - Port Botany) - sea (Port Botany - Port of Tilbury), then different demand proportions (depends on region) allocated to following routes: 1) rail (Tilbury Terminal - Daventry Terminal) - road (Daventry Terminal -Corby Plant) - road (Corby Plant- Destinations) 2) rail (Tilbury Terminal- Avonmouth Terminal) - road (Avonmouth Terminal - Avonmouth Plant) - road (Avonmouth Plant- Destinations) 3) rail (Tilbury Terminal - Manchester Terminal) - road (Manchester Terminal - Runcorn Plant) - road (Runch Plant - Destinations) 4) rail (Tilbury Terminal - Cleveland Terminal) - road (Cleveland Terminal - Stanley Plant) - road (Stanley Plant - Destinations)

In order to export wine from these regions, the closest logical port is Port Botany, Sydney. Movement of wine to the port is by road, as rail transport is not 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 – 1150km and Griffith – 570 km. The wine is then transferred to the ship where it is moved by scheduled liner container services to Europe. Here two options are explored. The first option is direct carriage to Felixstowe and subsequent road transport to the bottling facility at Corby (or to four different bottling plants). In the second option, the proportion of demand is transshipment to Port of Le Havre and further sea transport to Bristol Avonmouth Port or Port of Liverpool; other routes include from Port of Felixstowe to Corby plant and Port of Rotterdam to Teesport and then to Stanley bottling plant. In the goods movement to 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 Port of Tilbury as an entry port to UK, then the wine is moved by rail trough Tilbury rail terminal to different bottling plants.

5. Findings

5.1 Case 1: Distribution of Italian wine to the UK

As can be seen from Table 8, it is striking that, in terms of distribution and handling costs per bottle, the most expensive scenario is four 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 (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, to which we refer to as a 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 8: Results, Italy - UK wine distribution

Scenario	£ per Bottle	kg CO_{2e} per Bottle	Sulphur (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 sulphur (Table 8), the lowest cost scenario among sea maximizing options is also the lowest for sulphur emissions. Similarly, the highest cost/emission route produces highest sulphur 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 in bottled or flexitank form, the larger the sulphur footprint and the more expensive the shipping, this reflects the fact that shipping costs and sulphur emissions increase roughly linearly with distance covered. Fuel usage is clearly is the distance related and emissions levels also reflect this usage.

Table 9: International flows, UK inland flows and handling components, Italy - UK wine distribution

Scenario	Cost (£)			CO_{2e} (kg CO_{2e})			Sulphur (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

From Table 9, 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 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 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 though the variations are less extreme. The variation in CO_{2e} footprint for the UK inland leg is fairly conservative (compare Scenario 3D with Scenario 1A).

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

Table 10 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.

Table 10: Results, Australia-UK wine distribution

Scenario	£ per Bottle	kg CO_{2e} per Bottle	Sulphur (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 11 again illustrates that, amongst the 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 sulphur, it can be seen in Scenario 2, the level of sulphur 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.

Table 11: International leg, UK inland leg and handling components, Australia-UK wine distribution

	Cost (£)			CO_{2e} (kg CO_{2e})			
Scenario	International leg	UK inland leg	Handling	International leg	UK inland leg	Handling	Sulphur (kg)
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

6. Conclusions

In this paper, as part of the analysis of the international wine distribution, a range of different scenarios were evaluated where different transport modes, routes, packaging forms were used. The methodology related to the CO_{2e} and sulphur emissions was 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. The international shipping leg in most of the 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. With reference to sulphur, the lowest cost scenario among the sea maximising options, also yields the lowest sulphur 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 maximising scenario (scenario 2) for Australian wine shipments to UK appears to have higher sulphur impact than alternative scenarios.

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Appendix A

Route	Ship	Containers	Engine kw	Days Sailing at 15 knots	Total kwh	Sulfur (total g, gas phase)	Sulfur (total g, part phase)	Total Sulfur (kg)	Sulfur (kg/teu)	Sulfur (kg teu/km)	Sulfur (kg tonne/km)
Route 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**
Route 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
Route Sydney to Le Havre											**0.00055696**
Sydney to Tannjung 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	469,779,610	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