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Measuring the carbon footprint of wine tourism and cellar door sales

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A B S T R A C T

The wine industry has been dedicating increasing efforts to considering the sustainability of the environment. Various approaches have been implemented to reduce the industry's carbon footprint. With over 40 million wine tourists globally, cellar door operations have become an important distribution channel, especially for the financial sustainability of small and medium-sized wineries, but this component has not been addressed in existing environmental life cycle assessments. This paper presents a methodology for measuring the carbon footprint of wine tourism and cellar door sales based on a combination of the bottom-up and the top-down approaches. In the case of Australia, we find both domestic and international wine tourism lead to substantially higher carbon emissions than the standard wine distribution channels. The difference can be more than 100 fold per bottle of wine. In addition, the benchmarking analysis indicates that cellar door sales may become the most carbon intensive component across all life cycle stages of wine. This information offers an opportunity to evaluate the environmental trade-offs that maybe involved in obtaining the numerous benefits of wine tourism, and to consider ways of minimizing wine tourism-related carbon emissions in the future.

1. Introduction

Wine producers can select from a range of distribution channels and logistical arrangements to provide consumers with access to their wines. Although considerable research efforts have been devoted to assessing the environmental impact of most of these distribution channels, little attention has been paid to determining the carbon footprint generated by wine tourists. In this paper, we address this knowledge gap relating to the carbon footprint of wine sales to tourists, and we show that existing analyses of the wine industry have substantially underestimated its environmental impact by not including these direct-to-consumer sales.

The choice of distribution channels can influence the competitiveness of individual wine producers in terms of brand name, perceived wine quality, accessible markets, and financial returns (Monday and Wood-Harper, 2015). Depending on the producers' preferences and the applicable wine laws, the wine may be shipped to retail outlets, such as wine shops, or, in what is often referred to as the 3-tier system, the producers ship the wine to a wholesaler, such as an importer or distributor, which, in turn, transports the wine to retailers (Amienyo et al., 2014; Cholette and Venkat, 2009). In both of these cases, consumers purchase the wine from brick and mortar retailers and carry it with them to the place of consumption. A final distribution option involves direct-to-consumer (DTC) sales, with the wine producer selling and transporting the wine directly to the ultimate consumer. There are two types of direct-to-consumer transactions. If the purchase is made via the telephone or internet, the wine will be shipped by the wine producer directly to the consumer. Alternatively, in the case of direct-to-consumer sales to wine tourists, often referred to as "cellar door" sales, the consumer has travelled to the winery, where the wine is purchased and delivered in person. The consumer then carries the wine to the place of consumption.

Wineries are regional attractions that can motivate tourists to travel to visit wine producers, taste the wines and experience "the attributes of a grape wine region" (Hall et al., 2000). Wine tourism allows wine producers to engage directly with guests through tours of the vineyards and winery, wine tastings, and other wine-related activities. In addition to offering tourists the opportunity to purchase wine during their visits, the wine producers will invite the tourists to become members of the producers' wine club, with the goal of fostering a long-term customer relationship. Wine tourism therefore is often pivotal to the success of other direct-to-consumer channels,

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such as wine clubs and direct online sales (Bruwer et al., 2014b; Montaignen and Coelho, 2012). Moreover, wine tourism can be especially important for the economic sustainability of small and medium size wineries by reducing their reliance on intermediaries (Bruwer et al., 2014b; Donnelly and Mercer, 2015; Monday and Wood-Harper, 2015).

The eight-leading wine-producing countries recorded over 40 million wine tourist arrivals in 2016 (Mintel Group Ltd, 2017). In Australia, the world's fifth largest wine-producing nation, and the country on which we have focused in this study, over three million tourists visit wineries each year, with over one million of them travelling from a different country (Wine Australia, 2018). The numbers of wine tourists in Australia have increased by nearly 300% over the last twenty years (Cambourne and Macionis, 2000), and are likely to increase further under the government's 2017 multi-year $50 million (AU) Export and Regional Wine Support Package, which has been designed to promote Australia as a prime destination for international wine tourism (Wine Australia, 2019a).

1.1. Literature review and research gap analysis

Life-cycle assessment (LCA) has been the preferred method of addressing the issue of carbon emissions of the wine industry, as it offers the opportunity to assess the environmental impacts of all stages associated with a product's production and consumption (Rugani et al., 2013). A comprehensive "cradle to grave" life-cycle analysis of wine involves seven stages, starting from vineyard planning, through viticulture and grape growing, wine making, to packaging, transport and retail distribution, storage and consumption, and finally the end of life process.

In recent years, the question of how the transport and retail distribution stage can influence the carbon emissions of the wine industry has received increasing attention because of the growing popularity in Europe, North America and China of wines from distant locations, such as Australia, New Zealand, and Argentina (Waste & Resources Action Programme, 2007). The carbon emissions relating to the transport and distribution of the wines have been traced through a 3-tier distribution system by summing the distance the wines are transported in light of the specific energy performance of the various types of vehicles (Cholette and Venkat, 2009). Accordingly, the carbon intensity is determined by mode of transport (rail, freight, air), the transport distance, and the weight of the wine bottles and packaging (Amienyo et al., 2014; Reich-Weiser et al., 2010; Waste and Resources Action Programme, 2007).

Wine tourism and cellar door operations act essentially an alternative "transportation and distribution" stage within these life-cycle analyses. Instead of the wines being shipped by wine producers to distributors or retail stores in order to reach consumers, wine tourists essentially serve as the "transporters" by travelling to and from the wineries' tasting rooms in order to access the wines. Even though cellar door sales have emerged as an especially important sales and distribution channel for wineries in the past decade (Wine Australia, 2018), few studies have examined their carbon emissions. Cholette and Venkat (2009) is one of the very few; in viewing cellar door distribution as an alternative route for delivering wine to consumers, they only considered road transport, however. That research assessed the carbon emissions of personal vehicles travelling for a round trip of 72 km between customers' point of origin and the wineries. As we demonstrate below, cellar door operations can create a much more significant carbon footprint than the land transport that has been modeled, especially where wine tourism involves international travel and hotel stays.

Although some existing studies of the environmental impact of wine distribution channels have mentioned the need to consider the effects of wine tourism, no accepted method of analysis has been developed. One study noted that "consumer transportation to purchase wine might be a relatively important stage and thus should not be neglected" (Neto et al., 2013), but it was not included in that analysis. Another study pointed out that, while "the high carbon intensity associated with consumer driving is troublesome from a policy perspective," it is "the least traceable" source of emissions in the wine production and distribution process (Cholette and Venkat, 2009). A more recent life cycle analysis modeled consumer transportation emissions by assuming that the trip to the winery consists of "a 5 km round-trip distance in a small gasoline powered vehicle," and concluded that, in at least one environmental impact category (ozone depletion potential), the 5 km transportation exceeded "all other life cycle stages combined" (Point et al., 2012). This model, which incorporates a relatively short drive to a local winery, suggests that both domestic and international wine tourists, many of whom travel a great deal further than 5 km, could be a source of very significant quantities of carbon emissions that have not been accounted for in existing studies.

In summary, there is a gap in the literature. Carbon emissions associated with direct-to-consumer sales to wine tourists have not been adequately addressed in the wine tourism literature (Montella, 2017; Poitras and Donald, 2006), wine industry supply chain studies (Harris et al., 2018; Varsei and Polyakovskiy, 2017), or life cycle analyses (Ferrara and De Feo, 2018; Navarro et al., 2017; Rugani et al., 2013). To provide a methodology for estimating the carbon footprint of both domestic and international wine tourism, we have adapted methods developed in the climate change and sustainable tourism literature (Becken et al., 2003; Gössling et al., 2005; Lenzen et al., 2018) specifically for the wine industry. We have then applied that methodology to a dataset that we have compiled from Australian tourism records. We then compare our calculations of the carbon footprint of cellar door sales to U.K. wine tourists in Australia to the results of previous life cycle studies of the carbon emissions resulting from wine shipped from wineries in Australia to consumers in the U.K.

2. Materials and methods

The interconnected nature of wine tourism and cellar door operations requires a holistic approach to assess its environmental impact. A complete wine-tourism journey, especially for international tourists, involves numerous activities, only some of which relate to wine. A life-cycle perspective of wine tourism is therefore needed to map the relationship between visitor travel behaviors and wine purchases. Kuo and Chen (2009) emphasized that the life cycle of the "tourism product" starts when the journey starts and ends when the trip is completed. This perspective encompasses all components of a journey in a tourism life-cycle analysis, taking into account the emissions associated with transportation, lodging, dining, shopping and other recreational activities (Lenzen et al., 2018). In this paper, we adopt the wine life-cycle analysis perspective, and employ a three-step calculation approach to identify the carbon footprint of the cellar door distribution channel. The assessments begin in Step 1 with an analysis of the CO2 emissions for all travel-related products and services that are used along with the winery visit. In Step 2, we propose an allocation procedure to calculate the extent to which the carbon emissions are attributable to the winery. The final Step 3 converts the carbon emissions of cellar door operations from a per visitor basis to a per bottle basis (750 ml). This conversion allows the carbon footprint (CF) generated by cellar door transactions to be benchmarked against the CF associated with other distribution channels.

Step 1: calculation of total trip emissions

To assess tourism carbon emissions, two distinct approaches have been developed in the literature: the activity-based and the consumption-based methods (Becken and Patterson, 2006), both of which play a role in the cellar door carbon footprint methodology developed in this paper. The activity-based method, referred to as the bottom-up approach, estimates tourism emissions based on the types of products and services one traveller will consume on a journey. Visitor behavior is measured by a series of trip components, or physical units. Typically, passenger kilometer (pkm) is employed for transportation, room-night usage is compiled for accommodation, and per visit energy use is calculated based on the nature of the recreational activities, ranging from low emissions activities, such as cycling, to higher emissions activities, such as motorized water sports (Becken and Patterson, 2006; Dawson et al., 2010). The carbon footprint calculated in accordance with the activity-based approach is the total of the emissions generated by each component based on the itinerary, visitor volume and the carbon intensity per product. If one visitor spends 3 nights in a hotel, takes part in 6 recreational activities and flies 200 km round trip, the bottom-up approach involves multiplying the hotel emissions factor per room night by 3, and adding both the average emissions factor per recreational activity times 6 and the per kilometer emissions factor times 200.

The key advantage of the bottom-up approach is that it establishes a direct, precise and detailed linkage among the travel patterns in specific physical units and their related carbon emissions. Although the bottom-up approach allows researchers to pinpoint emissions hot spots by type of activity, and to predict the incremental change in emissions if alternative products or activities are chosen (Becken et al., 2003; Gössling et al., 2005; Peeters and Landré, 2011), compiling carbon emissions based solely on visitor activities presents a considerable challenge for macro level data analyses (WTO-UNEP-WMO, 2008). Uncertainty and estimation errors increase when consumers' preferences for different tourism goods and services are highly heterogeneous. As the user volume in physical units increases (e.g., total kilometers travelled by each transport mode and total meals consumed), the bottom-up approach can become too complex and unmanageable. While scenarios can be adopted to reduce the complexity, variations in itineraries and purchasing patterns among consumers make it difficult to accurately complete the carbon footprint analysis. For example, a thorough life-cycle analysis for an international wine tourism visit to France would require very detailed per trip information such as, "a New Zealand citizen flies to Bordeaux for 5 nights, travels locally by public transport for 200 km, consumes 16 meals, participates in 5 winery tastings and purchases 10 bottles of wine, 2 items of clothing, and 5 boxes of chocolates." This example demonstrates the degree of complexity involved in gathering the relevant data across all wine tourists, thus accurate making scenario modelling extremely difficult.

Alternatively, the consumption-based, or top-down approach, is typically the preferred method for examining tourism emissions. It is based on the assumption that the expenditure of money on particular items will lead to more emissions from that producing sector (Becken and Patterson, 2006; Sun, 2014). Calculating the total emissions generated by tourists involves multiplying visitor spending on different items by the corresponding energy/emissions coefficient per dollar. The first parameter, tourist consumption, is a proxy for the amount of products and services consumed on the journey. The second parameter, the emissions factor per dollar output, is calculated from the environmentally extended input-output (EEIO) model, which is based on the fact that the nation's whole economic output and total contributions to pollution are partitioned among different sectors (Miller and Blair, 2009; Wiedmann, 2009). Equipped with a clear mapping of the interindustry linkages, the input-output model is capable of assessing the direct emissions that are produced by the tourism-related industries, as well as the indirect emissions attributable to other firms in the relevant supply chains (Miller and Blair, 2009).

As with the activity-based method, the consumption-based approach has its own limitations and estimation errors. It assumes that there is a linear relationship between consumption and emissions for each sector without differentiating the emissions ratios within various categories, such as services (resorts vs. campgrounds), transportation equipment (Boeing 777 vs. Boeing A340), energy type (wind power vs. coal), and operational and infrastructure efficiency (Gossling, 2011; Peeters et al., 2009; Upham et al., 2009). For example, $500 spent in a coal-powered resort is assumed to generate the same emissions as $500 spent on a camping ground equipped with solar panels. Overall, assessing tourism's carbon footprint via the top-down approach cannot achieve 100% accuracy, but the error margin is manageable. At a global scale, an assessment of tourism's carbon footprint based on the top-down consumption approach and the input-output models is within ±7% of the estimates at the 95% level of confidence (Lenzen et al., 2018).

The consumption-based or top-down approach is, therefore, recommended as the primary vehicle for calculating the carbon footprint of wineries' cellar door sales for the following reasons. First, visitor consumption data is regularly collected and reported by destination management organizations, ensuring the availability of high-quality data. The segmentation of visitors is also feasible through constructing individual spending profiles by key attributes, such as the destination, place of origin, travel purpose, and first/repeat visitors. This creates an opportunity for a customized carbon footprint calculation that could be used by individual wine producers that are aware of the composition of the visitors to their cellar door or that plan to attract visitors from specific markets. Second, with the greater availability of global input-output databases in recent years, such as EORA, EXIOBASE, GTAP-MRIO, and WIOD, the emissions factor by sector are available for many countries (Inomata and Owen, 2014). This provides the basis for converting visitor consumption to carbon emissions.

In the following case study of Australia cellar door operations, a mixed-mode method that combines activity-based and consumption-based approaches has been employed, as first proposed by Sun and Pratt (2014) in the tourism context. International aviation emissions are estimated using the activity-based approach, and other tourism emissions are evaluated via the consumption-based method (Equation (1)).

$$
\begin{aligned}
\text{Ttip emissions} &= CO_2 \text{ by international aviation} + CO_2 \text{ by consumption within Australia} \\
&= \text{miles between two gateway airports} * \text{emission coefficient per mile} \\
&\quad + \sum_{i=1}^{n} \text{spending}_i * \text{emission coefficient per dollar}_i \qquad (1)
\end{aligned}
$$

where *i* represents different sectors.

Handling international aviation emissions separately is critical to the accuracy of the overall estimation, especially in the context of Australia. Air transport is the most carbon intensive component in the journey, especially with respect to long-haul intercontinental flights (Dubois and Ceron, 2006; Peeters et al., 2006; Perch-Nielsen et al., 2010; Smith and Rodger, 2009). On a global scale, long-distance travel by air between the five major world tourism regions represents only 2.2% of all tourist trips, but contributes 16% of the total global tourism-related CO2 emissions (WTO-UNEP-WMO, 2008). In addition, because of Australia's remote location, the international aviation emissions of tourism accounts for 49% of Australia's national tourism carbon footprint (Dwyer et al., 2010b). Accordingly, the activity-based approach in evaluating international aviation emissions has been selected for this study, which takes into account the aviation miles in flight, the transfer point, and the energy efficiency of the airlines operating the Australian routes. This calculation approach ensures a high level estimation accuracy (Becken and Shuker, 2019; Gössling et al., 2015). For other travel products and services within Australia, the consumption-based approach is used to approximate emissions based on spending levels.

Step 2: allocation of trip emissions to winery visits

Since tourism is an agglomerated experience, allocation is an important concept in the tourism literature, with the goal of identifying the contribution of a particular site, event, agency or policy in the overall tourism development picture (Crompton, 1995; Dwyer et al., 2010a). The Lancaster's product characteristic approach (Lancaster, 1966) in consumer demand theory sets the foundation for the concept of allocation. The Lancaster theory assumes that all goods possess characteristics relevant to the choices that people make, and individuals differ in their reactions to different characteristics (Lancaster, 1966). In other words, consumers choose a bundle of goods which generates the optimal combination of attributes to yield a maximum utility. By holding other factors unchanged, modifying one attribute would reveal consumer preference with respect to that particular factor, e.g., how important political stability is in the traveller's revisit attention (Seddighi and Theocharous, 2002) and how wine production influences tourists' length of stay (Barros and Machado, 2010).

The underlying logic of the allocation process is to identity how important the site, event, agency or policy is in the visitors' decision-making process; in particular, whether the activity (or attribute) being evaluated is the primary purpose for visitors who otherwise would not have made the trip. Trip purpose is therefore the decisive factor in allocation, especially with respect to "new money" associated with tourism (Frechtling, 2006; Stynes and White, 2016). New money is defined as those expenditures that would not have been spent if the evaluated subject did not exist. The general practice is to treat the trip-related expenditures of primary-purpose visitors as new money, and, thus, for each day of the trip, 100% of their spending is included; if the visit is categorized as a "non-primary purpose" trip, the expenditures related only to one-day or one half-day will be included (Stynes et al., 2000).

Analogous to the "new money" principle, we argue that the emissions associated with the whole trip should be allocated to cellar door operations if tourists indicate that visiting wineries is their primary purpose for the trip, an important attribute in the overall tourism package. For those dedicated wine tourists, their trips would not have been made if the wine tourism activities did not exist. For tourists who are merely "interested" or "accidental" wine tourists, the emissions relating to a half-day of the trip is allocated to the cellar door. This is based on the assumption that a typical visit to one or more wineries lasts a few hours to half-a-day. The allocation formula is as follows:

Emissions for cellar door visit = whole trip emissions * Pct of dedicated wine visitors + half-day trip emissions * Pct of non-dedicated wine visitors (2)

Step 3. calculation of trip emissions per bottle purchased at cellar door

The first two steps estimate the carbon emissions on a per tourist basis. To benchmark the environmental performance of cellar door sales against other modes of distribution, it is necessary to covert the emissions calculation from a per visitor to a per bottle (750 ml) basis. This conversion requires information on the average bottles purchase per tourist during their cellar door visits (Eq. (3))

$$\text{Emissions per bottle purchased} = \frac{\textit{emissions for cellar door visit}}{\textit{average bottles purchased}} \quad (3)$$

3. Calculations

In this study, several parallel tourism scenarios have been employed to estimate the effects of domestic and international wine tourism on cellar door operations in Australia. The domestic case includes Australian tourists visiting wineries in Australia. For the international tourism scenario, we compare an LCA of wine tourists travelling from the United Kingdom to Australia to the LCA of wines exported from Australia to the United Kingdom. We have selected this particular international context in light of the current Australian government policy to encourage tourism from long-haul foreign markets to enhance Australian wine sales and exports. The UK is the number one destination for Australian wine exports by volume, accounting for a 23% market share of all UK imported wine in 2018 (Wine Australia, 2019b).

Both the domestic and international scenarios offer insights into wine tourism throughout the country. The National Visitor Survey (NVS) and the International Visitor Survey (IVS), which cover all tourist spending across Australia, offer the best data source to profile wine tourists. NVS surveys 120,000 residents aged 15 years and over each year, while IVS is designed to gather data from 40,000 departing, short-term international travelers annually (Tourism Research Australia, 2019). Spending profiles for wine tourists, defined as those who visited wineries, are analyzed across 18 categories,[1] including detailed spending information on transportation modes. In addition, tourists are asked to say how much they have spent at wineries for wine that they will take home. In this study, we employ the 2014 and 2015 NVS and IVS, as these are the latest and most comprehensive datasets available.

We use the World Input-Output Database (WIOD) to document energy use, carbon emissions, and monetary output for Australia (Timmer et al., 2015). This allows us to calculate how much carbon

[1] Domestic airfares, international airfares, package tours, organised tours, rental vehicles, petrol, taxi and local public transport, long distance public transport, accommodation, food and drink, shopping, entertainment, gambling, education, other expenditures, motor vehicles, registration fees, and phone, and postage.

dioxide (direct effect) is produced per Australian dollar of sales across 40 sectors. The year 2011 is the reference point, as this is the latest available data.

The tourists' responses to a question regarding their trip purposes are used to determine the share of the overall trip emissions that will be allocated to the winery visits. For inbound tourism, dedicated wine tourists are defined as those who have visited Australian wineries during their trip and have reported that "to experience Australia's food, wines and wineries" is the primary purpose for their trip. Data is directly sourced from the International Visitor Survey. For domestic tourism, the percentage of dedicated wine travelers was provided by Tourism Research Australia (2015). Secondary data from Bruwer et al. (2014a) is used to identify information regarding the "number of bottles bought" at wineries per visitor. This particular dataset contained responses of more than 3300 wine tourists at 79 wineries across 15 Australian wine regions, which provides a good profile of their purchasing behaviors across various wineries and regions.

The carbon emissions resulting from international aviation from the UK to Australia are analyzed through the International Civil Aviation Organization (ICAO) database. Two direct flights are currently available, London-Sydney and London-Melbourne, and these two origin-destination city pairs were entered to the International Civil Aviation Organization carbon emissions calculator (2019) to compute the carbon dioxide emissions per visitor during these particular flights. The database considers the fuel data, trip distance, aircraft type, occupancy rate and cabin class, all of which are route specific (ICAO, 2017). A weighted average amount of aviation emissions is then calculated based on the reported number of UK visitors arriving at Sydney and Melbourne, respectively. Our procedure provides a conservative estimate of the international aviation emissions of UK visitors flying to Australia because some of the visitors will arrive via indirect flights that involve one or more transfer stops, which would lead to more emissions than the direct flights that have been included.

4. Results

4.1. The carbon footprint of wine tourism and cellar door operations in Australia

Domestic tourism. Domestic wine tourists are analyzed separately for overnight and daytrips because each type of visit results in different spending and travel behaviors. Overnight wine tourists, on average, spend around 5 days on the trip, and 16% of them are dedicated wine visitors. Overnight wine tourists spend an average of $99 (10% of their trip expenditures) on wine purchased at wineries; in contrast, day visitors spend about $69 on wines, representing about half of their trip expenditure.

Under the consumption-based approach, domestic overnight wine tourists are estimated to produce 108 kg (kg) of carbon dioxide per person per trip, and 27.1 kg (25% of the total trip emissions) can be directly attributed to the cellar door visits. Domestic daytrip visitors have a much smaller impact on carbon dioxide – 16.2 kg for the whole trip, with 9.4 kg (58%) allocated to the cellar door. Even overnight visitors purchase more wines, this factor is not able to even out the larger emissions associated with their cellar door visits. In the end, the per bottle estimates associated with overnight visitors are about 6.8 kg per 750 ml bottle purchased, doubling the amount of emissions for day trip visitors (3.4 kg).

Evaluating both economic and carbon performance of two domestic segments allows us to compare visitor markets in terms of carbon efficiency – how much emissions are produced in order to generate one dollar spending through cellar door sales. Overnight tourists, on average, produce 0.27 kg CO2e per dollar spending while day visitors generate 0.14 kg CO2e per dollar, a 101% difference. The discrepancy in carbon efficiency across groups would amount to a larger emission difference when total tourism spending is considered.

International tourism. UK wine tourists exhibit a very different travel pattern from domestic wine tourists as (1) their trip emissions are very high as a result of intercontinental air travel, (2) they report high spending with a lengthy stay in Australia, and (3) the dedicated wine UK visitors only constitute a very small share (1.3%) of this market. These factors determine the carbon emissions associated with their visits to wineries' cellar doors, which is around 50 kg per person per trip. This is about five times higher than a domestic daytrip wine visitor (9.4 kg) and two times higher than a domestic overnight wine visitor (27.1 kg). Because UK visitors tend to spend less to purchase wine than domestic tourists, this wine-purchasing factor elevates their emissions per bottle to 23.6 kg/750 ml bottle. These results suggest that the environmental burden of UK wine tourism to Australia generates 3.5 times more emissions than if the wineries were to sell the same bottles to domestic wine tourists.

4.2. Benchmarking against existing wine LCA analyses

Since wineries can adopt multiple distribution channels and logistical arrangements, contrasting the environmental impact of wine tourism with other methods for shipping wine to domestic and international markets can highlight the trade-offs involved. In the case of inbound tourism, we have compared the carbon emissions associated with selling one bottle of wine to a UK wine tourist in a cellar door sale to exporting the bottle directly to the UK, where it is then sold to a UK resident. We have made a similar comparison for the domestic market, as well.

Fig. 1 shows the carbon emissions for the various distribution channels that may be employed in the wine transport and distribution stage. The average transport emissions for the standard transportation to retailers is 0.15 kg per 750 ml bottle if wines are transported using cask or 0.20 kg per bottle if transported in bottles (Abbott et al., 2016). Increasing domestic wine tourism facilitates direct-to-consumer sales but the carbon emissions per bottle that are associated with the visit to wineries is about 17–23 times larger than the alternative of transporting the wine to retailers. The carbon intensive nature of wine tourism is even more significant for international wine tourists. The emissions generated by transporting Australian wine to the UK market are estimated to be around 0.27–0.43 kg per 750 ml bottle, depending on whether the wine is transported in bulk and whether lightweight glass bottles are used (Waste & Resources Action Programme, 2007). By comparison, flying a UK visitor to Australia for wine tourism will produce 23.6 kg CO2 per bottle, which increases the carbon emissions 54 to 88-fold. These 6 distribution options are shown in Fig. 1. Transporting wines to domestic wholesalers or retailers in bulk using casks produces the least amount of carbon dioxide (0.15 kg) during the transport and distribution stage, while cellar door sales to a UK visitor are significantly less environmentally friendly (23.6 kg), a more than 100-fold difference.

Note. Non-cellar door transport emissions in Australia is provided by Abbott et al. (2016), and transport emissions for exporting Australian wine to UK is sourced from Waste & Resources Action Programme (2007). The variation in carbon emissions associated with cellar door operations is caused by the variation in wine-purchasing patterns (please see Table 1).

The second benchmarking analysis illuminates the carbon-intensive nature of wine tourism in comparison with different stages in the overall life-cycle analysis – allowing us to compare the impact of distribution channels with viticultural activities,

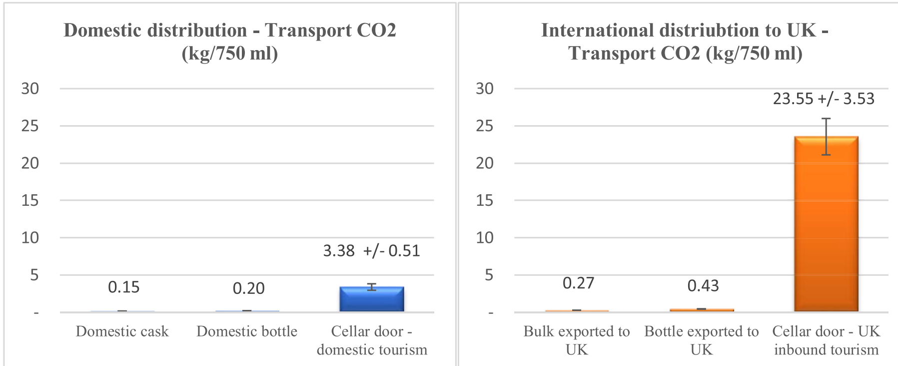

Fig. 1. Transport emissions (carbon dioxide per bottle) for different distribution channels in Australia.

Table 1
Trip behaviors and carbon emissions for domestic wine tourists and UK wine visitors to Australia.

Per person	Domestic overnight wine tourists	Domestic day trip wine tourists	UK wine visitor to Australia
Total spending (AUD)	$1041	$145	$5796
Expenditure on wine purchased at wineries	$99	$69	$53
Average length of stay (days)	4.8	1.0	28.4
Type of wine visitors			
Dedicated wine visitor	16%	16%	1%
Interested/accidental wine visitor	84%	84%	99%
Step 1: Total trip carbon emissions			
Domestic CO2 in Australia (kg)	108.0	16.2	381.4
International aviation CO2 (kg)	0.0	0.0	1580.9
Total direct CO2	108.0	16.2	1962.3
Step 2: Attribution of responsibility to cellar doors			
CO2 per visitor (kg)			
Dedicated wine visitor	108.0	16.2	1962.3
Interested/accidental wine visitor (half day)	11.2	8.1	24.0
Weighted CO2 per visitor to cellar doors (kg)	27.1	9.4	50.0
Step 3: Carbon emission per bottle			
Average price per bottle			
Mean	24.8	24.8	24.8
Sensitivity (15% upward)	28.6	28.6	28.6
Sensitivity (15% downward)	21.1	21.1	21.1
Average bottles purchased			
Mean	4.0	2.8	2.1
Sensitivity (15% upward)	3.5	2.4	1.8
Sensitivity (15% downward)	4.7	3.3	2.5
Emissions per bottle of wine purchased (kg)			
Mean	6.8	3.4	23.6
Sensitivity (15% upward)	7.8	3.9	27.1
Sensitivity (15% downward)	5.8	2.9	20.0

winemaking, packaging, and end of life processes. The benchmark target is a global indicator of the carbon emissions produced for each of the 7 life-cycle analysis wine stages across major wine producing regions worldwide (Rugani et al., 2013). This baseline shows that the global average carbon footprint per bottle of wine is about 2.17 ± 1.34 kg, of which the transport and distribution stage typically contributes about 0.25 ± 0.29 kg. In comparing our results to the global profile, cellar door operations are the most carbon intensive component within the wine life-cycle process, at least 7 times higher than packaging and end-of-life processes, which traditionally have the highest carbon intensity (Fig. 2). This finding demonstrates the degree to which wine tourism and cellar door operations greatly increase the carbon emissions per bottle of wine, thus highlighting the substantial environmental costs associated with the development of wine tourism. Moreover, this finding indicates that for wine producers focused on the cleaner production goals of developing an “integrative preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment,” an assessment of the carbon emissions associated with wine tourism should be included in any comprehensive sustainability plan.

5. Discussion and conclusions

To date, studies of the wine industry have not developed a methodology for assessing the carbon footprint of the over 40 million tourists whose cellar door purchases constitute an alternative to the standard sales and distribution channels that have been included in existing LCA studies. In this paper, we have created such a methodology, and we have applied it to the case of wine tourism in Australia. In doing so, we have shown that cellar door sales associated with both domestic and international wine tourism lead to substantially higher carbon emissions than any other distribution channels. In particular, this paper shows that cellar door wine sales to tourists are the most carbon intensive element of the wine life-cycle process, with carbon generation levels seven or more times higher than the next highest component — packaging and end-of-life processes. On a per bottle basis, the

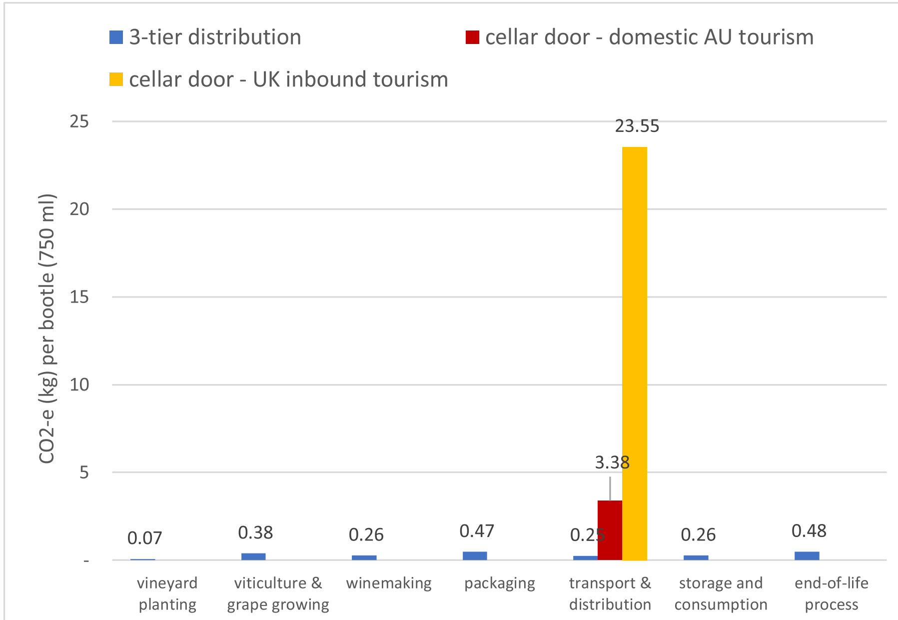

Fig. 2. Carbon emissions of wine tourism in Australia and the average carbon footprint of wine per life cycle phase. Note. The carbon footprint of wine per life cycle phase is sourced from Rugani et al. (2013), which averages 35 wine LCA studies.

largest carbon footprint in a "cradle to grave" life-cycle analysis is attributable to sales to international tourists, which are responsible for a more than 100 fold increase in carbon generation versus domestic sales via standard retailing stores. Ranked by the carbon emissions intensity per bottle sold, selling wines via traditional retailing stores has the smallest environmental impact, followed by cellar door sales to domestic wine tourists and to international wine tourists. We believe that this methodology and these observations should be of interest not only to allow for more comprehensive life-cycle analyses of the wine industry in the future, but also to provide information about potential emissions "hotspots" to wine producers, consumers and policymakers.

Although this paper has focused on the challenges cellar door sales create for environmental sustainability, it is important to note that wine tourism is also associated with numerous potential benefits, including making significant contributions to the economic and social sustainability of many wine producing regions (Forbes et al., 2020; Gómez et al., 2019). As a recent report on Australian cellar door sales observes, "the cellar door is the sales channel where wineries have the most control," and it "yields the highest financial return on wine sold compared with other channels (Bruwer et al., 2014a). Wine tourism's benefits extend to the surrounding region as well. The UN World Tourism Organization (2016) has emphasized the fact that wine tourism has "evolved into a key element for both emerging and mature tourism destinations in which tourists can experience the culture and lifestyle of destinations while fostering sustainable tourism development" (Georgia Declaration of Wine Tourism). An economic impact study of the United States wine industry has identified "more than $17.6 billion in tourist expenditures benefit [ing] local communities" (Wine America, 2017). Local food and wine products also symbolize the place and culture of the destination, allowing tourists to embark on an authentic travel experience that can motivate them to revisit the destination, to communicate the benefits of visiting the region to others (Sims, 2009), and, upon returning home, to continue to purchase the region's wines. A sustainable inflow of visitor volume can also be critical to the survival of many small and medium sized wineries, both as wine producers, and as tourism enterprises, which supports the cultural preservation and social stability of rural communities.

The standard point of view in profiling the environmental impact of winery operations is to address the energy, water, and waste management of existing cellar door facilities, and the accreditation system is designed with these indicators in mind (Flores, 2018; Santiago-Brown et al., 2014). Unlike other wine LCA processes, which are under the control of the wine producers, we suggest that the primary factors influencing the emissions related to cellar door operations depend on consumer travel behaviors and their motivation – how many products/services they consume at the destination and at the winery for wine purchases, the distance travelled and the modes of transportation, and the primary purpose of the journey. Although these choices are made by the consumers, wine producers play an important role in motivating wine tourists to visit, as do national and regional wine tourism policies, such as Australia's $50 million Export and Regional Wine Support Package. Such policies, which are designed to promote wine and other types of tourism by attracting high-yield visitors from distant markets are likely to be based on powerful financial rationales. Our paper identifies the potential environmental costs associated with tailoring wine tourism policies solely through an economic lens. We believe that the methodology for assessing the carbon footprint of cellar door wine sales that has been developed in this paper will offer an opportunity for future studies to evaluate the environmental trade-offs that maybe involved in obtaining the numerous benefits of domestic and international wine tourism, and to consider ways of minimizing wine tourism-related carbon emission in the future.

Wine is the "world's most valuable crop" (Wolkovich et al., 2018). As agricultural enterprises, wine producers are deeply reliant on the right balance of sunlight, rain, warmth and cooling influences (Hannah et al., 2013; van Leeuwen and Darriet, 2016). Over the past few decades, the wine industry has dedicated increasing efforts to considering the sustainability of the environment, which is an essential element of its business. A significant amount of attention has been focused on the viticultural portion of wine production, that is, the direct impact of grape growing on the vineyard environment, including “the fossil fuel consumption needed for agricultural machinery in field operations,” as well as various soil management practices and the use of chemical pesticides and fertilizers (Ferrara and De Feo, 2018). Studies have also identified issues relating to solid waste management and “energy and water efficiency” in the wineries where the harvested grapes are converted into wine (Chiriaco et al., 2019; Point et al., 2012). More recently, comprehensive supply chain and life cycle analyses have mapped the environmental impacts from the grape on the vine to the wine on the consumer’s table by including the packaging, distribution, sales and consumption processes as well (Navarro et al., 2017; Neto et al., 2013; Ponstein et al., 2019; Trombly and Fortier, 2019; Varsei and Polyakovskiy, 2017). It is now time to add a consideration of the environmental impact of wine tourism to the industry’s comprehensive efforts towards sustainability.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Ya-Yen Sun: Conceptualization, Formal analysis, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Donald Drakeman:** Conceptualization, Writing - original draft, Writing - review & editing.

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