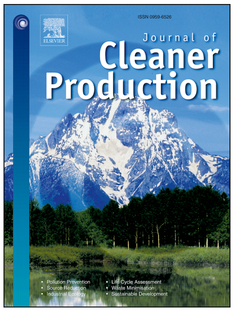

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The carbon footprint appraisal of local visitor travel in Brazil: a case of the Rio de Janeiro-São Paulo itinerary

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Abstract

Tourism transportation contributes substantially to the global carbon footprint. This contribution is predicted to enlarge, especially in 'emerging' tourism markets, and hence urgent carbon mitigation is necessary. Effective mitigation is determined by reliable carbon footprint assessments whose number is however limited, particularly for developing countries with growing tourism. This study applied the life cycle assessment (LCA) based method to appraise the carbon significance of various transport modes between Rio de Janeiro and São Paulo, the key itinerary for travel with leisure and tourism purposes by local residents and overseas visitors in Brazil. Given the envisaged rise in biofuel use in the Brazilian transportation sector, this study is unique in that it evaluated the carbon reduction potential offered by biofuel. The study demonstrated that overland public transport represents the most carbon-efficient mode of local transportation. It further highlighted the crucial role of biofuel in minimising the carbon intensity of transportation between Rio de Janeiro and São Paulo. Policy-making and managerial recommendations were put forward to facilitate more climate-benign local transportation practices.

Keywords:

Carbon footprint; Climate change; Tourism transport; Local visitor travel; Life Cycle Assessment (LCA); Brazil

Highlights:

- We apply a life cycle assessment (LCA) based method to estimate the carbon footprint of local visitor transport in Brazil
- We account for the mitigation potential offered by biofuel
- We find overland transport to be most climate-benign
- We demonstrate substantial carbon savings achieved via application of biofuel
- Managerial and policy-making recommendations to facilitate more carbon efficient local transport practices in Brazil are devised

1. INTRODUCTION

Brazil, alongside South Africa, China, India and Russia, is part of the BRICS group countries. These are known as large emerging markets, also in terms of domestic, inbound and outbound tourism (United Nations World Tourism Organisation – UNWTO 2011). For instance, circa 5.8 million international tourist arrivals were registered for Brazil in 2013 while in 2014 this number grew to 6.4 million (UNWTO 2014). The substantial recent increase in Brazilian tourism is primarily attributed to the hosting of the 2014 FIFA World Cup (Brazil 2015; EFE 2014). Given that Brazil will host the Olympic and Paralympic Games in 2016, it is estimated that, in subsequent years, the national tourism industry will attract at least another million of inbound and a similar number of domestic tourists per year (Gaier 2014).

While inbound tourism in Brazil, especially as facilitated by recent mega sports events, is growing, the geographical distribution of international arrivals within the country remains unequal. The cities of Rio de Janeiro and São Paulo represent the mainstay of international tourist demand (Brazil 2014a; Ministério do Turismo 2013). For instance, among the estimated 6.4 million international tourists received by the country in 2014, circa 1.6 million entered the country via Rio de Janeiro and further 2.2 million - via São Paulo, thus accounting for about 59% of the total number of international tourist arrivals to Brazil (Brazil 2015). It is not unusual for many tourists to then travel between these two cities as they represent the key tourist destinations in the country (Brazil 2014a). The Rio de Janeiro - São Paulo connection therefore represents the most important transportation artery in Brazil from the standpoint of inbound tourism.

The Rio de Janeiro - São Paulo transportation connection is also crucial in terms of domestic tourism. This is because Rio de Janeiro and São Paulo are among the largest cities in the southern hemisphere (São Paulo 2011) that possess substantial economic and social power. Aside from São Paulo being the richest and most populous state in Brazil with circa 44 million residents (IBGE 2012), of the US$ 1.77 trillion Brazilian GDP (IBGE, 2012) generated by the 26 States and the Federal District, US$ 728.6 billion or 43.9% was contributed by the states of Rio de Janeiro (11.5%) and São Paulo (32.4%). The socio-economic significance of the two cities has determined large demand for transportation between Rio de Janeiro and São Paulo. It is therefore understandable why, annually, the transportation itinerary between these two cities is served by more than 3 million passenger trips operated by domestic overland transport modes (Brazil 2014a) and circa 7.7 million passenger journeys operated by domestic air (Amadeus 2013).

While tourism growth in Brazil generates substantial economic benefits, it also imposes a number of negative effects. Greenhouse gas (GHG) emissions produced in the result of increased international and domestic visitor travel is often referred to as one of the most significant issues associated with tourism (see, for example, Peeters *et al.* 2007; Peeters and Dubois 2010; Scott *et al.* 2010). This carbon impact should be minimised to facilitate progress of the tourism industry in Brazil towards the goal of environmental sustainability.

Carbon impact appraisal and its mitigation represent one of the most rapidly developing subject areas in tourism research. While a number of studies have been conducted to evaluate the contribution of tourism to the global carbon footprint, the geographical scope of analysis has been limited largely to developed countries (Dickinson *et al.* 2013). To-date, research on the topic in question as applied within the context of developing economies and economies in transition has been scarce which hinders development of effective carbon impact mitigation measures that would account for the specificity of the political and socio-economic situation in these countries (Dillimono and Dickinson 2015). The need for a pronounced, more in-depth study stream on carbon footprint of the tourism industry and its particular elements/sub-sectors in countries of the Global South has been repeatedly recognised (Meng *et al.* 2016; Zaman *et al.* 2016).

This study aims to assess the carbon significance of popular transportation options utilised by tourists in Brazil. The Rio de Janeiro - São Paulo connection is employed as a proxy for carbon footprint appraisal due to the strategic role it plays in inbound and domestic Brazilian tourism. The ultimate goal of this study is to highlight the most and least carbon efficient transportation options within the itinerary in question with a view to inform tourism and environmental policies in Brazil aiming to facilitate more climate-friendly travel practices. It is argued that while fuel and energy matrices alongside transportation development models and public transport infrastructures vary from country to country, an overview of the transportation connection between these major Brazilian cities, when properly adopted, may provide a basis for establishing more carbon-benign transportation choices in other geographical and socio-cultural contexts, particularly in other BRICS countries.

The paper applies a Life Cycle Assessment (LCA)-based methodology of carbon impact appraisal to estimate the carbon implications of visitor travel between Rio de Janeiro and São Paulo. It discloses the direct as well as the indirect GHG emissions associated with the main transportation modes, with a view to reveal mitigation opportunities and develop recommendations for policy-making and managerial intervention. The study is unique in that it represents the first known attempt to appraise the carbon significance of tourism transportation between two major cities in a developing country situated in Latin America where tourism is on the rise. Another unique feature of this study is in that it looks into the use of biofuel and strives to assess the carbon reduction potential of this technology for different transportation options.

The paper begins with a brief overview of the inter-linkages between tourism and climate change; it also highlights the major recent developments in the field of carbon footprint appraisal in tourism. It further introduces the main transport connections between the cities of Rio de Janeiro and São Paulo. Subsequently, the article analyses the carbon footprint associated with each transportation option considered. The paper concludes with recommendations for tourism and environmental management and policy-making.

2. TOURISM AND ENVIRONMENTAL SUSTAINABILITY

To-date, environmental impacts have been referred to as one of the key negative implications of tourism (Collins *et al.* 2009; Gössling 2002), especially in terms of carbon footprint generation (Gössling 2009; Hamilton *et al.* 2005). The tourism industry is responsible for about 5% of the global carbon footprint where tourism transport holds the primary contribution (UNWTO 2007). Visitor travel makes a significant input into the high carbon intensity of tourism (Collins *et al.* 2009) which can be as high as 50-97.5% of the total GHG emissions attributed to the industry (Gössling 2000). The global carbon share of tourism is set to grow due to the projected rise in consumer demand for travel, especially in developing countries of Asia and South America (Scott *et al.* 2016; UNWTO 2014).

Given the substantial, and yet growing, contribution of tourism to global climatic changes, its urgent mitigation is paramount (UNWTO 2007). Effective mitigation relies upon accurate and holistic carbon impact assessments of different tourism elements and its particular products (Becken and Patterson 2006). This topic is gradually evolving as an established object of research scrutiny with seminal contributions made by Becken and Patterson (2006); Becken and Simmons (2002); Becken *et al.* (2001); Collins *et al.* (2009); Filimonau *et al.* (2014); Gössling (2000); Gössling *et al.* (2002; 2005); Peeters and Schouten (2006); Peeters *et al.* (2007); Schianetz *et al.* (2007). Since tourists are considered the key stakeholders to trigger the carbon impacts attributed to the tourism industry, an increasingly larger number of studies have recently been looking into voluntary changes in tourist behaviour as a means to achieve carbon mitigation (see, for instance, Dickinson *et al.* 2013; Higham *et al.* 2015). It has been established that tourists are generally unaware about the carbon ramifications of their travel choices; furthermore, the public are generally unwilling to change their holidaying patterns and make them more climate-friendly (Cohen and Higham 2011; Gössling *et al.* 2012; Hares *et al.* 2010). The application of market-based tools (for instance, carbon taxes and charges) has also been reviewed as well as has the use of various technological solutions, including environment-benign aircraft design, improved air traffic management and biofuel use (Grote *et al.* 2014; McKercher *et al.* 2010; Peeters *et al.* 2016). The studies have found that while these can be effective, they should be applied with caution due to the substantial political and financial implications (Kivits *et al.* 2010; Tol 2007). There is a general consensus in academic literature that none of the above carbon impact mitigation approaches are likely to succeed in the absence of accurate and comprehensive estimates of the carbon significance attached to each tourism element and its particular products (Filimonau *et al.* 2011a; Schianetz *et al.* 2007).

To establish the precise magnitude of tourism’s carbon footprint, reliable assessment methods are necessary (Schianetz *et al.* 2007). Recently, substantial progress has been made in this regard and extensive efforts have been applied to improve the methodological base of carbon impact appraisal in tourism (Cerutti *et al.* 2016). As a result, the quality of existing methods has been enhanced and a number of new, more advanced carbon impact assessment approaches have evolved, thus enabling more accurate and comprehensive carbon footprint estimates. The issue of tourism product’s life cycle related GHG emissions has become the focus in the growing number of studies (see, for instance, Filimonau *et al.* 2011a; 2011b; 2013; 2014; Schianetz *et al.* 2007) as this assessment approach provides a more holistic overview of the carbon significance of the tourism industry and identifies more opportunities for mitigation intervention.

The carbon implications of tourism in BRICS countries are particularly important due to the continued growth of the industry in question in developing markets. The carbon footprint attributed to tourism activities in these countries should be diligently assessed to develop effective carbon abatement measures. This notwithstanding, with a few notable exceptions (Cheng *et al.* 2013; Meng *et al.* 2016; Tang *et al.* 2014), there is no evidence of comprehensive studies on this topic as reported in peer-reviewed academic literature, especially in the context of Brazil. This paper aims to plug this knowledge gap by applying a method of LCA to appraise the carbon implications of transport between the key tourist destinations in Brazil, the cities of Rio de Janeiro and São Paulo. This analysis is paramount as the Rio de Janeiro - São Paulo transportation connection is an example of a popular visitor travel itinerary in developing countries. Among Brazilian States, São Paulo is the main source of tourists for Rio de Janeiro, representing 14.8% of the volume of domestic tourists and 22.2% of the domestic tourism revenue generated in the state (Brazil 2014a). Both Rio de Janeiro and São Paulo attract substantial flows of international tourists which further underlines the importance of this study.

3. TRANSPORT BETWEEN RIO DE JANEIRO AND SÃO PAULO

Air transport, overland inter-city bus and car represent the currently available options for tourist transportation between Rio de Janeiro and São Paulo. The railway that used to connect the two cities in the past is currently under development. The original plan was to start operating the new, improved high-speed train service between Rio de Janeiro and São Paulo before the 2014 FIFA World Cup and the 2016 Summer Olympic Games; however, due to various reasons, the opening of the service has been postponed until 2020 (Salgado 2014). Train connection is envisaged to increase tourist flows in both cities which underlines its strategic importance for tourism development in Brazil (Brazil 2014). To ensure comprehensive analysis, this study looked into existing transportation options between Rio de Janeiro and São Paulo and also considered the future train connection. In total, four different travel transport modes were reviewed and limited by their respective points of origin and destination (Table 1 and Figure 1).

[Insert Table 1 here]

[Insert Figure 1 here]

Aside from conducting the carbon footprint assessment of the means of transportation driven by conventional fuels, this study also performed an analysis of biofuel. This is because with the advent of biofuel technology in 1993 and the advancements in national transportation regulations in 2002, Brazil had become a global benchmark in the use of biofuels in transportation whose future growth is predicted (Osório 2014).

3.1 Scope of Analysis

Each transport mode assumed that a São Paulo middle class family, comprising of three people (two parents and one child), would choose to travel to Rio de Janeiro over the weekend with leisure and tourism purposes. There is an overnight stay in Rio de Janeiro followed by a return journey home.

While acknowledging the carbon footprint from tourist accommodation which, according to UNWTO (2007) can be significant, it was excluded from analysis. This is due to the focus of this study on the GHG emissions attributed to local tourism transportation in Brazil. This is also because there is evidence showing that, when traveling with tourism and leisure purposes in Brazil, 62.8% domestic tourists prefer staying with friends and relatives, while commercial tourist accommodation accounts for only 25% of the domestic travel market (Brazil 2014a).

Another item excluded from analysis was tourist activities. This is due to the lack of data on this element of tourism in Brazil and because, according to UNWTO (2007), tourist activities make a minor contribution to the total GHG emissions from the industry. It is acknowledged that more research on the carbon significance of tourist activities would improve the precision of carbon impact appraisals. This represents a promising research avenue which is however beyond the scope of this study.

Transport Mode 1: Traveling by Car

The Brazilian transport system has traditionally been based on the use of road networks (FETRANSPOR 2012). The state of São Paulo, for example, has the largest road transport system in the country and the largest quantity of bi-directional roads in Latin America (Martins *et al.* 2013). It is home to circa 12% of private car registrations in Brazil (DETRAN-SP 2013). The 11.8 million residents of São Paulo are served by nearly one car for every two people; this is much higher than the national average figure, i.e. one vehicle per 4.4 inhabitants (Reis 2014). This has found reflection in the substantial popularity of car travel with tourism and leisure purposes in Brazil. It accounts for 44.1% of domestic trips, surpassing bus, at 26.9%, and aircraft, at 17% (Brazil 2014a). The average occupancy for car travel in Brazil is 75% and the maximum load factor is four, which also holds true for the trip between Rio de Janeiro and São Paulo examined in this study. This is based on the national data from the Brazilian Ministry of Tourism (Brazil, 2014a).

The main advantages of car travel are the speed and flexibility. The most important section of the road connection between Rio de Janeiro and São Paulo is the 429 km of the Presidente Dutra highway (BR-116). It is considered the most important highway in Brazil, not only because it links the country's two major urban centers, but also because it traverses one of the country's most prosperous regions (Santos and Silveira 2001).

For this transport mode, using a family car of medium size, two fuel options were considered (Table 1). First, a vehicle powered by "Brazilian gasoline", which has approximately 25% of biofuel in its composition, was reviewed. Second, a biofuel vehicle driven by a fuel of biological origin from non-fossil feedstock, i.e. sugarcane was analysed. Data from the Brazilian National Association of Automobile Manufacturers (ANFAVEA 2014) show that, in 2013, of the 3,579,903 Brazilian licensed light vehicles, 88.5% were flex, using Compressed Natural Gas (CNG) and/or biofuel. Vehicles powered by diesel fuel current account for 6.2% of the total car fleet in Brazil, while 5.3% use gasoline. The contribution of electric vehicles is negligible. It is expected that the share of private vehicles powered by biofuel in Brazil will grow in the future (ANFAVEA 2014).

Soares *et al.* (2009) look into the carbon mitigation potential associated with the use of Brazilian sugarcane. When assessing the "pure" gasoline, "Brazilian gasoline" and ethanol and using the "pure" gasoline as the base reference, Soares *et al.* (2009) find that "Brazilian gasoline" generates 19.25% less direct GHG emissions. The use of ethanol brings about a reduction of 80.2% in direct GHG. This information will be used in Section 4.

Transport Mode 2: Traveling by Bus

The trip between the Tietê bus terminal, the largest in Latin America, and the Novo Rio bus terminal (429 km) takes six hours, including a technical stop for twenty minutes (Google Maps 2015). It is the most commonly used interstate route in Brazil (2.93% of the national market) with 1,471,974 direct passengers a year (ANTP 2013). Indirectly, with an intermediate stop, it holds 3.24% of the national market (1,631,552 passengers). In other words, annually, between these two cities, traditional interstate tour buses alone carry more than three million passengers, or more than 6% of the total bus passenger market in Brazil (ANTP 2013). The average occupancy on this route, served by six Brazilian companies, is 61% (based on the capacity of 46 seats) (ANTT 2012). At peak times and in high tourist season, the occupancy rates approach 95% (ABRATI 2011).

For this transport mode, buses using different types of fuel were considered (Table 1). The first transport mode is based on analysis of the carbon footprint associated with fossil-based diesel. The second transport mode considers a journey on a bus driven by a mixture of biofuel and pure diesel. This mixture was introduced by the Brazilian Government through a 2005 law which prescribed that diesel fuel should contain at least 2% of biofuel content (Barroso and Alves 2008). Four further fuel options were considered within this item: B7, B10, B20 and B100, each of which represents a percentage blending of biofuel with pure diesel (FETRANSPOR 2012). The B7 blend, for example, which is currently in force in Brazil, has 7% biodiesel content in the fossil-based diesel mix, which yields a 5% reduction in GHG emissions. The Brazilian fuel B100 is 100% biodiesel-based, according to DELTACO_2 & CENA (2013), and is able to reduce the GHG emissions by 70% compared to European diesel. This blend is currently under trial (Brazil 2013), while the B20 blend has been approved to meet the sustainability commitments made to the Brazilian government for the 2016 Olympic Games in Rio de Janeiro (FETRANSPOR 2012).

Biodiesel is produced in Brazil from a variety of raw materials (Brazil 2013). Between 2005 and 2012 the country produced and consumed 11 billion liters of biodiesel (Brazil 2013). Biodiesel can reduce emissions of hydrocarbons, carbon monoxide and particulate material, but it can lead to a small increase in NOx (McCormick *et al.* 2006). According to Brazil (2013), the use of the B7 fuel blend in the country has brought about an annual reduction of 7.3 million tons of CO_2e emissions. When deployed, B10 will represent a saving of 10.4 million tons of CO_2e per year, a 7.3% reduction on the original emissions; B20, to be introduced in 2020, will save about 20.8 million tons, a 14.5% decrease in GHG (Brazil 2013; DELTACO_2 & CENA 2013). Such percentage reductions will be used in Section 4.

Transport Mode 3: Traveling by Air

It is estimated that, annually, there are more than 190 million domestic air trips in Brazil (Brazil 2014a). The air transport mode is served by five Brazilian companies that largely operate Boeing 737, a popular short- to medium-haul distance aircraft (Decolar 2015). The occupancy rate used in this study corresponds to the annual average of the main Brazilian airlines which, in 2013, for domestic flights, was equal to 79.15% of the 176 seats (ABEAR 2014). The most important route for Brazilian commercial flights is known as the "Rio-São Paulo Air Bridge" (Amadeus 2013). This connection with 7.7 million passengers per annum is the third busiest route in the world, behind the Jeju-Seoul route in South Korea (10.16 million), and the Sapporo-Tokyo route in Japan (8.21 million) (Amadeus 2013). Furthermore, São Paulo is the main gateway for domestic and inbound tourists in Brazil, through the Guarulhos International Airport, and many tourists bound for Rio de Janeiro make connections or stopovers in the city. In 2013, 36 million passengers (incoming and outgoing) went through this airport alone; 23.5 million domestic and 12.5 million international (GRU Airport 2014). In 2011, Rio de Janeiro received 15.7 million domestic air travel passengers which is the second largest number in the country after São Paulo. According to IPEA (2013), increased purchasing power in Brazil has enabled a gradual public shift from road transportation to air travel. This is likely to intensify future air passenger traffic between Rio de Janeiro and São Paulo.

Short-haul flights are more carbon intense than long haul flights when calculated per passenger km, due to the significant amounts of GHG emissions produced during the takeoff and landing stages of the flight (Filimonau *et al.* 2014). The flying distance between Rio de Janeiro and São Paulo is 357 km (short-haul) and an average flight between Santos Dumont airport (SDU) and Congonhas airport (CGH) takes circa 38 minutes. These airports are smaller airports in central locations, with expansion limited by the city boundaries. It is this prime location and the passenger traffic in the Rio de Janeiro - São Paulo connection that make them the chosen points of reference for air transportation in this study. Recently, passengers have begun using alternative airports in São Paulo and Rio de Janeiro, such as São Paulo-Guarulhos International (GRU), Rio de Janeiro-Galeão International (GIG) and Viracopos-Campinas International (VCP) (Figure 1). Although these airports are more distant, with attractive pricing options, they are growing in popularity (Fariello 2013). Today, approximately 120 daily flights connect São Paulo and Rio de Janeiro through their respective airports, according to the Brazilian National Civil Aviation Agency (ANAC 2011); this represents 5% of the total seats available on all domestic routes. There are a number of other airports in both cities; these, however, can only handle smaller aircraft and have therefore been excluded from analysis since they account for only a marginal proportion of passengers.

In this transport mode, three types of fuel were considered (Table 1). The first option would be the traditional aviation fuel, which contains no added biofuel. In Brazil, about 7 billion liters of traditional jet fuel are consumed annually, producing about 17.5 million tons of GHGs (EPA 2004). In the second option, a mixture of traditional jet fuel and biofuels was assessed, yielding an overall reduction of 65% in direct GHG emissions (Vera e Silva *et al.* 2013). The third option is based on an alternative blend of traditional fuels and biofuels, with an overall reduction in direct GHG emissions of up to 80%. These fuel blends have been repeatedly tested (ATAG 2014). While aviation biofuels have not yet become mainstream in Brazil, the tests have shown promising results. It is anticipated that the Brazilian aviation industry will broaden its use of biofuels in the future as part of its commitment to reduce the carbon footprint from flying by 50% by 2050 (compared to the 2005 level) (Brazil 2013).

With the steady growth in the passenger flow between Rio de Janeiro and São Paulo, there is a need for alternative transportation modes where rail connection represents a promising option. The alternative of building more airports and increasing the aircraft fleet in Brazil is not physically, economically, geographically or environmentally favourable (Fariello 2013).

Transport Mode 4: Traveling by Train

According to Camacho (1998), the Rio de Janeiro - São Paulo rail connection is not new as it had been used for long in the past. For over a hundred years, there had been a rail link between the country's two major cities. However, on October 31st, 1998, the railway link between these cities was suspended; the increased competition from airlines had played an important role in this decision (Camacho 1998).

At the beginning of the 21st century, there were negotiations about building a new link, this time for high-speed trains (HST) connecting Rio de Janeiro and São Paulo. The idea was based on a 2004 São Paulo state government project to connect the VCP Airport to the state capital. The new technical feasibility study on the preliminary layout for the HST included connecting Campinas, São Paulo and Rio de Janeiro in one 518 km line with nine stations (BNDES 2011).

According to Salgado (2014), the new high-speed rail project between Rio de Janeiro and São Paulo should have been completed by the beginning of the 2014 FIFA World Cup to be in full operation for the 2016 Olympic and Paralympic Summer Games. The deadline was not met and a new completion date has now been set for 2020. When completed, the project will connect three of the country's major international airports Galeão (Rio de Janeiro), Guarulhos (São Paulo) and Viracopos (São Paulo) via high-speed railway.

The project assumes that the 430 km route between the central zone of Rio de Janeiro, and the northern zone of São Paulo, will be covered in approximately 93 minutes, depending on interim stops. It is expected that trains will be operated at speeds of up to 350 km/h and handles an annual flow of 30 million passengers, at prices stipulated to be competitive with air transport (ANTT 2014).

For this transport mode, the occupancy rate and the carbon intensity values reflect those for the Eurostar international trains of the European network (DEFRA 2010). These data were employed due to the lack of country-specific and/or Latin American data which is a limitation of this study. This is because the Eurostar trains consume energy that is mainly produced by nuclear power. According to the International Energy Agency (IEA 2014), during 2012, the French energy matrix obtained 43.3% of its energy from nuclear sources and only 8.8% came from renewable sources. In contrast, Brazil obtained only 1.5% of its energy from nuclear sources and 41.3% from renewable sources (IEA 2014). This notwithstanding, the Eurostar data are deemed more suitable for the Brazilian context given they are less reliant on fossil fuel.

4. CARBON FOOTPRINT APPRAISAL METHOD

The study has chosen to apply a modified Life Cycle Assessment (LCA) method for carbon footprint appraisal of various travel transport modes between Rio de Janeiro and São Paulo. LCA has been repeatedly recognised as one of the most advanced methods for environmental impact assessment; it has been broadly employed in the different contexts and recently introduced to tourism (Filimonau *et al.* 2011a; Michailidou *et al.* 2016; Schianetz *et al.* 2007). The key advantage of LCA is in that it oversees a 'totality' of environmental impacts that arise at various stages of a product's life cycle, starting with extraction of raw materials and finishing with product disposal (Frischknecht and Rebitzer 2005). In other words, LCA has the capability to account for the environmental impacts that are defined as 'direct' (i.e. those arising from product use) and 'indirect' (i.e. those attributed to the non-use phases of a product's life cycle) (Berners-Lee *et al.* 2011; also see Filimonau *et al.* 2013 for a detailed overview of the 'direct' and 'indirect' carbon footprint as generated by various tourism products). There is growing evidence demonstrating that the 'indirect' environmental impacts can be substantial and, in some cases, they can even surpass the magnitude of the 'direct' environmental effects which underlines the importance of their thorough investigation (Chwieduk 2003). All this contributes to the true comprehensiveness and accuracy of the LCA method which positively differentiates it from alternatives and determines a steady growth of its applications in a number of disciplines and subject areas, including tourism (De Camillis *et al.* 2010).

Despite the comprehensiveness of analysis, the LCA method has a number of shortcomings that hamper its broader adoption by the sector. Substantial costs of LCA datasets and their irregular updates are arguably the key drawbacks of the method (Filimonau *et al.* 2014; Schianetz *et al.* 2007). To partially address the shortcomings of LCA as applied in the tourism sector, Filimonau *et al.* (2014) proposed to merge the traditional LCA method with the GHG emissions assessment tool developed for corporate reporting by the UK's Department for Environment, Food and Rural Affairs (DEFRA) (https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting#conversion-factors-2016). The latter tool is free to use and undergoes regular updating. The new, combined method would capitalise upon the ability of LCA to provide estimates of the 'indirect' GHG emissions with the capacity of the DEFRA's approach to generate more current assessments of the 'direct' carbon footprint. A detailed overview of the potential offered by a new method is beyond the scope of this study but can be found in Filimonau *et al.* (2013; 2014). The hybrid, LCA-DEFRA method is deemed to represent a better suited tool for analysis in this study. While it is not flawless, it is arguably the most comprehensive and accurate tool for carbon impact appraisal currently available in the tourism field which determines its application in this study.

To assess the carbon footprint for the different transport modes between Rio de Janeiro and São Paulo, the carbon intensity coefficients were first derived. The Ecoinvent database and the GaBi LCA software were employed to derive the carbon footprint coefficients to calculate the 'indirect' GHG emissions attributed to the capital assets and transportation infrastructure while the DEFRA's GHG emission factors were utilised to estimate the 'direct' and 'indirect' carbon footprint as produced by various types of transportation fuels (Table 2). GaBi is popular commercial LCA software (GaBi, 2016). It employs a range of tailor-made life-cycle databases to estimate the magnitude of environmental impacts attached to products and services, where the Ecoinvent database represents the key informant. The Ecoinvent database is a major life-cycle inventory which has for a prolonged period of time been applied in LCA analysis. To enhance the quality of analysis, the data from the Ecoinvent database can be supplemented with more precise, country-specific figures, retrieved from national inventories and previous studies, subject to their availability (Frischknecht and Rebitzer 2005).

[Insert Table 2 here]

Literature suggests that, due to high heterogeneity of tourism products, it is often difficult to derive an appropriate functional unit for the industry's carbon impact appraisal studies (Filimonau *et al.* 2011a). For this particular project, a functional unit was defined as 'a return weekend journey between Rio de Janeiro and São Paulo made by one traveller with tourism and leisure purposes'. The choice of such a broad functional unit was deliberate as it enables integration of other tourism elements (for example, accommodation and activities) that have been excluded in this study but whose analysis is planned in future work on this project. The carbon footprint was recorded in kilograms of carbon dioxide equivalent (kg CO_2e). This is the official unit of carbon footprint estimates as prescribed by the Intergovernmental Panel on Climate Change (IPCC 2007).

5. RESULTS AND DISCUSSION

The study shows that among the four transport modes considered with variations in different types of fuel, the most carbon-benign is the use of bus driven by B100 biofuel (Table 3 and Figure 2). This is in line with literature finding that overland modes of transport make the lowest input into global climatic changes (see, for instance, Filimonau *et al.* 2014; Peeters *et al.* 2007). The key disadvantage of this transport mode is the travel time which equates to six hours (one way). The second most carbon efficient transport mode is the high speed train (HST) whose GHG emissions are two-fold compared to the carbon footprint associated with B100 buses but, concurrently, significantly lower than the GHG emissions attributed to other transport modes. Again, this is in line with literature reporting on carbon impact appraisal studies of railway transportation as conducted in other geographical contexts (Barrett and Scott 2003; Sovacool and Brown 2010). In this analysis it is worth considering that comfort and time will be relevant to the passengers' travel decisions. The HST transport mode is more preferred in this case due to relatively short travel time, i.e. 1.5 hours. Despite clear carbon benefits demonstrated by the B100 bus transport mode, these can be negated by long travel times which also imply less time available to tourists to spend at a destination.

[Insert Table 3 here]

[Insert Figure 2 here]

Transport Mode “3a” (kerosene-driven flights) is most carbon intense which mirrors evidence reported elsewhere and outlines a primary mitigation opportunity (Peeters and Dubois 2010; Peeters *et al.* 2007). Importantly, biofuel driven flights are found to generate less GHG emissions than cars powered by the conventional fuel. This is an important finding signifying the crucial role of biofuel technology in reducing the carbon intensity of local visitor travel in Brazil. This demonstrates that all transport modes used in Transport Modes 2 (inter-city bus) and 4 (HST) should be politically preferred over Transport Modes “1a” (car driven by conventional gasoline) and “3a” (kerosene-driven flights) which have higher rates of energy intensity and GHG emissions. These latter two transport modes, when analysed from the perspective of biofuels, become more carbon-benign and yet the carbon savings associated with the use of the bus, with or without biofuel, or HST are more pronounced.

From the carbon footprint standpoint, the use of biodiesel is beneficial and broader application of this technology in Brazil should be encouraged. More in-depth analysis is however required to assess the viability of biofuel use in a country as there are a number of further, non-carbon related “indirect” issues attributed to its application, such as environmental (for example, land use changes); social (for instance, poverty and labour costs); and economic (for example, independence of foreign markets) (Almeida *et al.* 2007; Martinelli and Filoso 2008). While these are outside the scope of this study, it is argued that careful analysis is required to inform decision-making on whether or not to adopt transportation biofuels more broadly in Brazil.

The study indicates that, in 2020, when HST will have become operational, this mode of transport must be stimulated since it represents a more carbon effective means of transportation. This is particularly important as there is growing evidence demonstrating that HST can successfully compete with air transport on short-haul distance (Martin *et al.* 2014). Moreover, the Eurostar experience demonstrates that train journeys can be comfortable as well as cost and time efficient; these factors can therefore attract increased passenger numbers, also within city boundaries (Hickman *et al.* 2010). The accessibility potential (i.e.

its ability to avoid road traffic) offered by HST is another factor which can be capitalised upon when promoting railway transportation between Rio de Janeiro and São Paulo. It may be particularly appealing for business and family travelers for who the time and convenience considerations are of prime importance (Cao *et al.* 2013).

Bus, despite being the most climate friendly option, has the longest travel time and offers limited comfort. To enhance its appeal, measures should be undertaken to tackle these challenges. This can be achieved, for example, via free Wi-Fi and installation of power sockets alongside contemporary entertainment systems onboard. Interestingly, the carbon impact appraisal results for Transport Mode "1a" (car driven by conventional gasoline) are similar to Transport Mode "3a" (kerosene-driven flights) which shows that long car journeys should be discouraged due to the large volumes of GHG emissions they produce. These are disproportionally high given the low occupancy of private cars compared to aircrafts. Hence, tourists concerned about the carbon footprint and seeking to reduce it should therefore strive for replacement of car journeys with bus or train (when it becomes available). To enable this modal shift, appropriate incentives should be introduced, both on the supply and demand side.

Cost is another factor which impacts tourist decision-making (Table 3). It varies greatly from one transportation mode to another and its role should therefore be more diligently examined in a separate study aiming to better understand the factors contributing to local travel decision-making in Brazil. Future work should employ eco-efficiency analysis as a tool to link the carbon impacts of tourists to their spend (Sun and Pratt 2014).

When analysing the 'indirect' GHG emissions, the study shows that air travel based on biofuel is the largest contributor of the 'indirect' carbon footprint which amounts to 55.5% of the total carbon significance attributed to this means of transportation (Figure 2). The bus powered by diesel fuel has the lowest 'indirect' emissions (11.6% of the total), which is in line with literature (Filimonau *et al.* 2014; Schafer and Victor 1999). This is an important finding for engineers responsible for conducting technical feasibility studies and justifying the choice of more carbon efficient transport modes. Until now, the use of biofuels has traditionally been considered the most beneficial. This is primarily due to the lack of methods capable of accounting for the 'indirect' GHG emissions. The hybrid LCA-based method applied in this study reveals the importance of the 'indirect' carbon footprint and underlines the necessity of taking it into account when developing new transportation planning proposals. Yet, the ‘indirect’ emissions revealed in this paper are rather approximate as they do not take into account the increased carbon footprint associated with radiative forcing effect, enlarged NOx generation and land use changes (Gössling and Peeters 2007).

For comparison purposes, the Brazilian GHG emissions totaled 1,488 mt CO_2e in 2012 (IMAFLORA 2014). Considering the population estimate of 198.7 million people (IBGE 2012), each Brazilian resident would generate an average of 7,488 kg CO_2e per annum or 20.51 kg CO_2e per day. This number corresponds to the carbon intensity of a return leisure- or tourism-related journey ‘São Paulo-Rio de Janeiro’ on a high speed train, one of the most carbon-benign means of transportation between the two cities.

6. CONCLUSIONS

The literature on tourism’s carbon impacts indicates that tourist transport is the largest contributor to the industry’s GHG emissions. Technology is envisaged to play an increasingly important role in the mitigation of the carbon footprint attributed to tourism- and leisure-related travel. Within various technological solutions, biofuel is often considered a viable tool to tackle this issue.

To effectively mitigate the carbon impacts from tourist transport, accurate assessments of its GHG emissions are necessary. These should include not only the ’direct‘, or operational, but also the ’indirect‘, or non-operational, life cycle related, footprint. The inclusion of both ’direct‘ and ’indirect‘ GHG emissions provides a more holistic outlook, thus enabling better understanding of the areas in which carbon mitigation intervention is required. Research which has set out to tackle this challenge is yet scarce and should be reinforced. Furthermore, the geographical scope of application covered by existing studies is narrow due to its focus on developed economies and should be extended, particularly towards developing countries and emerging markets where tourism is on the rise.

This study extended the scope of the LCA application in tourism from Europe, Australia and North America to Brazil, a growing BRICS market and an emerging tourist destination in Latin America. The case of local transportation between the cities of Rio de Janeiro and São Paulo, the busiest Brazilian transportation artery, was considered in order to identify the most carbon efficient transportation options. The results indicated that air and road transportation (by car) are the transport modes with the largest carbon footprint while bus and train represent the least carbon intense means of transportation. Bus and train travel should therefore be encouraged by local decision-makers, particularly from the standpoint of reducing the travel times and increasing passenger comfort.

The outcome of this study can be used by Brazilian decision-makers as a basis for policy intervention designed to facilitate more carbon-benign modes of tourism- and leisure-related transportation within the country. It can also be disseminated to local tour operators and travel agents who could make this information available to tourists. Given the evidence that environmental awareness of tourists is growing, the results of this study may appeal to those tourists who take account of the carbon impacts associated with their travel choices. Scientifically grounded information on the carbon footprint attributed to different transport mode should be made available to tourists, and tourism and hospitality providers at a destination may consider offering discounts to those visitors who have opted for more carbon efficient transportation options to reach a destination.

Given the important role played by biofuel technology in mitigating the carbon impacts from transportation, Brazilian decision-makers should facilitate its more rapid adoption. To this end, market-based instruments can be utilised. For instance, financial incentives can be given to the public purchasing biofuel-driven cars; concurrently, higher taxes can be assigned to the most carbon intense vehicles. As train represents one of the carbon efficient means of transportation between Rio de Janeiro and São Paulo, it should be made operational as soon as possible while its use should be encouraged. Subsidies can be provided to HST operators to maintain cheaper fares and enhance its competitiveness with airlines. If the above is unfeasible, given significant reductions in the carbon footprint from flying demonstrated by biofuel technology, the airlines that use the blends of biofuel in their aircraft should be given tax incentives.

In addition to the reduction of the carbon footprint from national transportation, biofuel may play an important role in socio-economic development of Brazil. Brazil has strong agricultural traditions; this implies it has an opportunity to become a leading supplier of raw materials and technology for non-fossil fuels, subject to careful considerations given to the socio-cultural and economic implications of this technology. More intense biofuel production in Brazil will minimise the dependence of the country on external fossil fuel supply.

Lastly, this study shows that the ‘indirect’ carbon footprint from transportation is significant and should not therefore be excluded from analysis. This suggests that policy-making interventions designed to mitigate the carbon significance of tourism should not only seek to reduce the ‘direct’, or operational, impacts, but should also concentrate on the ‘indirect’, non-operational effects. This does not only apply to carbon impact assessment of local transportation in Brazil, but also holds true for any developed or developing country, especially for other BRICS states, where tourism in general and the local transportation market in particular are growing.

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The carbon footprint appraisal of local visitor travel in Brazil: a case of the Rio de Janeiro-São Paulo itinerary

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Abstract

Tourism transportation contributes substantially to the global carbon footprint. This contribution is predicted to enlarge, especially in 'emerging' tourism markets, and hence urgent carbon mitigation is necessary. Effective mitigation is determined by reliable carbon footprint assessments whose number is however limited, particularly for developing countries with growing tourism. This study applied the life cycle assessment (LCA) based method to appraise the carbon significance of various transport modes between Rio de Janeiro and São Paulo, the key itinerary for travel with leisure and tourism purposes by local residents and overseas visitors in Brazil. Given the envisaged rise in biofuel use in the Brazilian transportation sector, this study is unique in that it evaluated the carbon reduction potential offered by biofuel. The study demonstrated that overland public transport represents the most carbon-efficient mode of local transportation. It further highlighted the crucial role of biofuel in minimising the carbon intensity of transportation between Rio de Janeiro and São Paulo. Policy-making and managerial recommendations were put forward to facilitate more climate-benign local transportation practices.

Keywords:

Carbon footprint; Climate change; Tourism transport; Local visitor travel; Life Cycle Assessment (LCA); Brazil

Highlights:

- We apply a life cycle assessment (LCA) based method to estimate the carbon footprint of local visitor transport in Brazil
- We account for the mitigation potential offered by biofuel
- We find overland transport to be most climate-benign
- We demonstrate substantial carbon savings achieved via application of biofuel
- Managerial and policy-making recommendations to facilitate more carbon efficient local transport practices in Brazil are devised

1. INTRODUCTION

Brazil, alongside South Africa, China, India and Russia, is part of the BRICS group countries. These are known as large emerging markets, also in terms of domestic, inbound and outbound tourism (United Nations World Tourism Organisation – UNWTO 2011). For instance, circa 5.8 million international tourist arrivals were registered for Brazil in 2013 while in 2014 this number grew to 6.4 million (UNWTO 2014). The substantial recent increase in Brazilian tourism is primarily attributed to the hosting of the 2014 FIFA World Cup (Brazil 2015; EFE 2014). Given that Brazil will host the Olympic and Paralympic Games in 2016, it is estimated that, in subsequent years, the national tourism industry will attract at least another million of inbound and a similar number of domestic tourists per year (Gaier 2014).

While inbound tourism in Brazil, especially as facilitated by recent mega sports events, is growing, the geographical distribution of international arrivals within the country remains unequal. The cities of Rio de Janeiro and São Paulo represent the mainstay of international tourist demand (Brazil 2014a; Ministério do Turismo 2013). For instance, among the estimated 6.4 million international tourists received by the country in 2014, circa 1.6 million entered the country via Rio de Janeiro and further 2.2 million - via São Paulo, thus accounting for about 59% of the total number of international tourist arrivals to Brazil (Brazil 2015). It is not unusual for many tourists to then travel between these two cities as they represent the key tourist destinations in the country (Brazil 2014a). The Rio de Janeiro - São Paulo connection therefore represents the most important transportation artery in Brazil from the standpoint of inbound tourism.

The Rio de Janeiro - São Paulo transportation connection is also crucial in terms of domestic tourism. This is because Rio de Janeiro and São Paulo are among the largest cities in the southern hemisphere (São Paulo 2011) that possess substantial economic and social power. Aside from São Paulo being the richest and most populous state in Brazil with circa 44 million residents (IBGE 2012), of the US$ 1.77 trillion Brazilian GDP (IBGE, 2012) generated by the 26 States and the Federal District, US$ 728.6 billion or 43.9% was contributed by the states of Rio de Janeiro (11.5%) and São Paulo (32.4%). The socio-economic significance of the two cities has determined large demand for transportation between Rio de Janeiro and São Paulo. It is therefore understandable why, annually, the transportation itinerary between these two cities is served by more than 3 million passenger trips operated by domestic overland transport modes (Brazil 2014a) and circa 7.7 million passenger journeys operated by domestic air (Amadeus 2013).

While tourism growth in Brazil generates substantial economic benefits, it also imposes a number of negative effects. Greenhouse gas (GHG) emissions produced in the result of increased international and domestic visitor travel is often referred to as one of the most significant issues associated with tourism (see, for example, Peeters *et al.* 2007; Peeters and Dubois 2010; Scott *et al.* 2010). This carbon impact should be minimised to facilitate progress of the tourism industry in Brazil towards the goal of environmental sustainability.

Carbon impact appraisal and its mitigation represent one of the most rapidly developing subject areas in tourism research. While a number of studies have been conducted to evaluate the contribution of tourism to the global carbon footprint, the geographical scope of analysis has been limited largely to developed countries (Dickinson *et al.* 2013). To-date, research on the topic in question as applied within the context of developing economies and economies in transition has been scarce which hinders development of effective carbon impact mitigation measures that would account for the specificity of the political and socio-economic situation in these countries (Dillimono and Dickinson 2015). The need for a pronounced, more in-depth study stream on carbon footprint of the tourism industry and its particular elements/sub-sectors in countries of the Global South has been repeatedly recognised (Meng *et al.* 2016; Zaman *et al.* 2016).

This study aims to assess the carbon significance of popular transportation options utilised by tourists in Brazil. The Rio de Janeiro - São Paulo connection is employed as a proxy for carbon footprint appraisal due to the strategic role it plays in inbound and domestic Brazilian tourism. The ultimate goal of this study is to highlight the most and least carbon efficient transportation options within the itinerary in question with a view to inform tourism and environmental policies in Brazil aiming to facilitate more climate-friendly travel practices. It is argued that while fuel and energy matrices alongside transportation development models and public transport infrastructures vary from country to country, an overview of the transportation connection between these major Brazilian cities, when properly adopted, may provide a basis for establishing more carbon-benign transportation choices in other geographical and socio-cultural contexts, particularly in other BRICS countries.

The paper applies a Life Cycle Assessment (LCA)-based methodology of carbon impact appraisal to estimate the carbon implications of visitor travel between Rio de Janeiro and São Paulo. It discloses the direct as well as the indirect GHG emissions associated with the main transportation modes, with a view to reveal mitigation opportunities and develop recommendations for policy-making and managerial intervention. The study is unique in that it represents the first known attempt to appraise the carbon significance of tourism transportation between two major cities in a developing country situated in Latin America where tourism is on the rise. Another unique feature of this study is in that it looks into the use of biofuel and strives to assess the carbon reduction potential of this technology for different transportation options.

The paper begins with a brief overview of the inter-linkages between tourism and climate change; it also highlights the major recent developments in the field of carbon footprint appraisal in tourism. It further introduces the main transport connections between the cities of Rio de Janeiro and São Paulo. Subsequently, the article analyses the carbon footprint associated with each transportation option considered. The paper concludes with recommendations for tourism and environmental management and policy-making.

2. TOURISM AND ENVIRONMENTAL SUSTAINABILITY

To-date, environmental impacts have been referred to as one of the key negative implications of tourism (Collins *et al.* 2009; Gössling 2002), especially in terms of carbon footprint generation (Gössling 2009; Hamilton *et al.* 2005). The tourism industry is responsible for about 5% of the global carbon footprint where tourism transport holds the primary contribution (UNWTO 2007). Visitor travel makes a significant input into the high carbon intensity of tourism (Collins *et al.* 2009) which can be as high as 50-97.5% of the total GHG emissions attributed to the industry (Gössling 2000). The global carbon share of tourism is set to grow due to the projected rise in consumer demand for travel, especially in developing countries of Asia and South America (Scott *et al.* 2016; UNWTO 2014).

Given the substantial, and yet growing, contribution of tourism to global climatic changes, its urgent mitigation is paramount (UNWTO 2007). Effective mitigation relies upon accurate and holistic carbon impact assessments of different tourism elements and its particular products (Becken and Patterson 2006). This topic is gradually evolving as an established object of research scrutiny with seminal contributions made by Becken and Patterson (2006); Becken and Simmons (2002); Becken *et al.* (2001); Collins *et al.* (2009); Filimonau *et al.* (2014); Gössling (2000); Gössling *et al.* (2002; 2005); Peeters and Schouten (2006); Peeters *et al.* (2007); Schianetz *et al.* (2007). Since tourists are considered the key stakeholders to trigger the carbon impacts attributed to the tourism industry, an increasingly larger number of studies have recently been looking into voluntary changes in tourist behaviour as a means to achieve carbon mitigation (see, for instance, Dickinson *et al.* 2013; Higham *et al.* 2015). It has been established that tourists are generally unaware about the carbon ramifications of their travel choices; furthermore, the public are generally unwilling to change their holidaying patterns and make them more climate-friendly (Cohen and Higham 2011; Gössling *et al.* 2012; Hares *et al.* 2010). The application of market-based tools (for instance, carbon taxes and charges) has also been reviewed as well as has the use of various technological solutions, including environment-benign aircraft design, improved air traffic management and biofuel use (Grote *et al.* 2014; McKercher *et al.* 2010; Peeters *et al.* 2016). The studies have found that while these can be effective, they should be applied with caution due to the substantial political and financial implications (Kivits *et al.* 2010; Tol 2007). There is a general consensus in academic literature that none of the above carbon impact mitigation approaches are likely to succeed in the absence of accurate and comprehensive estimates of the carbon significance attached to each tourism element and its particular products (Filimonau *et al.* 2011a; Schianetz *et al.* 2007).

To establish the precise magnitude of tourism's carbon footprint, reliable assessment methods are necessary (Schianetz *et al.* 2007). Recently, substantial progress has been made in this regard and extensive efforts have been applied to improve the methodological base of carbon impact appraisal in tourism (Cerutti *et al.* 2016). As a result, the quality of existing methods has been enhanced and a number of new, more advanced carbon impact assessment approaches have evolved, thus enabling more accurate and comprehensive carbon footprint estimates. The issue of tourism product's life cycle related GHG emissions has become the focus in the growing number of studies (see, for instance, Filimonau *et al.* 2011a; 2011b; 2013; 2014; Schianetz *et al.* 2007) as this assessment approach provides a more holistic overview of the carbon significance of the tourism industry and identifies more opportunities for mitigation intervention.

The carbon implications of tourism in BRICS countries are particularly important due to the continued growth of the industry in question in developing markets. The carbon footprint attributed to tourism activities in these countries should be diligently assessed to develop effective carbon abatement measures. This notwithstanding, with a few notable exceptions (Cheng *et al.* 2013; Meng *et al.* 2016; Tang *et al.* 2014), there is no evidence of comprehensive studies on this topic as reported in peer-reviewed academic literature, especially in the context of Brazil. This paper aims to plug this knowledge gap by applying a method of LCA to appraise the carbon implications of transport between the key tourist destinations in Brazil, the cities of Rio de Janeiro and São Paulo. This analysis is paramount as the Rio de Janeiro - São Paulo transportation connection is an example of a popular visitor travel itinerary in developing countries. Among Brazilian States, São Paulo is the main source of tourists for Rio de Janeiro, representing 14.8% of the volume of domestic tourists and 22.2% of the domestic tourism revenue generated in the state (Brazil 2014a). Both Rio de Janeiro and São Paulo attract substantial flows of international tourists which further underlines the importance of this study.

3. TRANSPORT BETWEEN RIO DE JANEIRO AND SÃO PAULO

Air transport, overland inter-city bus and car represent the currently available options for tourist transportation between Rio de Janeiro and São Paulo. The railway that used to connect the two cities in the past is currently under development. The original plan was to start operating the new, improved high-speed train service between Rio de Janeiro and São Paulo before the 2014 FIFA World Cup and the 2016 Summer Olympic Games; however, due to various reasons, the opening of the service has been postponed until 2020 (Salgado 2014). Train connection is envisaged to increase tourist flows in both cities which underlines its strategic importance for tourism development in Brazil (Brazil 2014). To ensure comprehensive analysis, this study looked into existing transportation options between Rio de Janeiro and São Paulo and also considered the future train connection. In total, four different travel transport modes were reviewed and limited by their respective points of origin and destination (Table 1 and Figure 1).

[Insert Table 1 here]

[Insert Figure 1 here]

Aside from conducting the carbon footprint assessment of the means of transportation driven by conventional fuels, this study also performed an analysis of biofuel. This is because with the advent of biofuel technology in 1993 and the advancements in national transportation regulations in 2002, Brazil had become a global benchmark in the use of biofuels in transportation whose future growth is predicted (Osório 2014).

3.1 Scope of Analysis

Each transport mode assumed that a São Paulo middle class family, comprising of three people (two parents and one child), would choose to travel to Rio de Janeiro over the weekend with leisure and tourism purposes. There is an overnight stay in Rio de Janeiro followed by a return journey home.

While acknowledging the carbon footprint from tourist accommodation which, according to UNWTO (2007) can be significant, it was excluded from analysis. This is due to the focus of this study on the GHG emissions attributed to local tourism transportation in Brazil. This is also because there is evidence showing that, when traveling with tourism and leisure purposes in Brazil, 62.8% domestic tourists prefer staying with friends and relatives, while commercial tourist accommodation accounts for only 25% of the domestic travel market (Brazil 2014a).

Another item excluded from analysis was tourist activities. This is due to the lack of data on this element of tourism in Brazil and because, according to UNWTO (2007), tourist activities make a minor contribution to the total GHG emissions from the industry. It is acknowledged that more research on the carbon significance of tourist activities would improve the precision of carbon impact appraisals. This represents a promising research avenue which is however beyond the scope of this study.

Transport Mode 1: Traveling by Car

The Brazilian transport system has traditionally been based on the use of road networks (FETRANSPOR 2012). The state of São Paulo, for example, has the largest road transport system in the country and the largest quantity of bi-directional roads in Latin America (Martins *et al.* 2013). It is home to circa 12% of private car registrations in Brazil (DETRAN-SP 2013). The 11.8 million residents of São Paulo are served by nearly one car for every two people; this is much higher than the national average figure, i.e. one vehicle per 4.4 inhabitants (Reis 2014). This has found reflection in the substantial popularity of car travel with tourism and leisure purposes in Brazil. It accounts for 44.1% of domestic trips, surpassing bus, at 26.9%, and aircraft, at 17% (Brazil 2014a). The average occupancy for car travel in Brazil is 75% and the maximum load factor is four, which also holds true for the trip between Rio de Janeiro and São Paulo examined in this study. This is based on the national data from the Brazilian Ministry of Tourism (Brazil, 2014a).

The main advantages of car travel are the speed and flexibility. The most important section of the road connection between Rio de Janeiro and São Paulo is the 429 km of the Presidente Dutra highway (BR-116). It is considered the most important highway in Brazil, not only because it links the country's two major urban centers, but also because it traverses one of the country's most prosperous regions (Santos and Silveira 2001).

For this transport mode, using a family car of medium size, two fuel options were considered (Table 1). First, a vehicle powered by "Brazilian gasoline", which has approximately 25% of biofuel in its composition, was reviewed. Second, a biofuel vehicle driven by a fuel of biological origin from non-fossil feedstock, i.e. sugarcane was analysed. Data from the Brazilian National Association of Automobile Manufacturers (ANFAVEA 2014) show that, in 2013, of the 3,579,903 Brazilian licensed light vehicles, 88.5% were flex, using Compressed Natural Gas (CNG) and/or biofuel. Vehicles powered by diesel fuel current account for 6.2% of the total car fleet in Brazil, while 5.3% use gasoline. The contribution of electric vehicles is negligible. It is expected that the share of private vehicles powered by biofuel in Brazil will grow in the future (ANFAVEA 2014).

Soares *et al.* (2009) look into the carbon mitigation potential associated with the use of Brazilian sugarcane. When assessing the "pure" gasoline, "Brazilian gasoline" and ethanol and using the "pure" gasoline as the base reference, Soares *et al.* (2009) find that "Brazilian gasoline" generates 19.25% less direct GHG emissions. The use of ethanol brings about a reduction of 80.2% in direct GHG. This information will be used in Section 4.

Transport Mode 2: Traveling by Bus

The trip between the Tietê bus terminal, the largest in Latin America, and the Novo Rio bus terminal (429 km) takes six hours, including a technical stop for twenty minutes (Google Maps 2015). It is the most commonly used interstate route in Brazil (2.93% of the national market) with 1,471,974 direct passengers a year (ANTP 2013). Indirectly, with an intermediate stop, it holds 3.24% of the national market (1,631,552 passengers). In other words, annually, between these two cities, traditional interstate tour buses alone carry more than three million passengers, or more than 6% of the total bus passenger market in Brazil (ANTP 2013). The average occupancy on this route, served by six Brazilian companies, is 61% (based on the capacity of 46 seats) (ANTT 2012). At peak times and in high tourist season, the occupancy rates approach 95% (ABRATI 2011).

For this transport mode, buses using different types of fuel were considered (Table 1). The first transport mode is based on analysis of the carbon footprint associated with fossil-based diesel. The second transport mode considers a journey on a bus driven by a mixture of biofuel and pure diesel. This mixture was introduced by the Brazilian Government through a 2005 law which prescribed that diesel fuel should contain at least 2% of biofuel content (Barroso and Alves 2008). Four further fuel options were considered within this item: B7, B10, B20 and B100, each of which represents a percentage blending of biofuel with pure diesel (FETRANSPOR 2012). The B7 blend, for example, which is currently in force in Brazil, has 7% biodiesel content in the fossil-based diesel mix, which yields a 5% reduction in GHG emissions. The Brazilian fuel B100 is 100% biodiesel-based, according to DELTACO_2 & CENA (2013), and is able to reduce the GHG emissions by 70% compared to European diesel. This blend is currently under trial (Brazil 2013), while the B20 blend has been approved to meet the sustainability commitments made to the Brazilian government for the 2016 Olympic Games in Rio de Janeiro (FETRANSPOR 2012).

Biodiesel is produced in Brazil from a variety of raw materials (Brazil 2013). Between 2005 and 2012 the country produced and consumed 11 billion liters of biodiesel (Brazil 2013). Biodiesel can reduce emissions of hydrocarbons, carbon monoxide and particulate material, but it can lead to a small increase in NOx (McCormick *et al.* 2006). According to Brazil (2013), the use of the B7 fuel blend in the country has brought about an annual reduction of 7.3 million tons of CO_2e emissions. When deployed, B10 will represent a saving of 10.4 million tons of CO_2e per year, a 7.3% reduction on the original emissions; B20, to be introduced in 2020, will save about 20.8 million tons, a 14.5% decrease in GHG (Brazil 2013; DELTACO_2 & CENA 2013). Such percentage reductions will be used in Section 4.

Transport Mode 3: Traveling by Air

It is estimated that, annually, there are more than 190 million domestic air trips in Brazil (Brazil 2014a). The air transport mode is served by five Brazilian companies that largely operate Boeing 737, a popular short- to medium-haul distance aircraft (Decolar 2015). The occupancy rate used in this study corresponds to the annual average of the main Brazilian airlines which, in 2013, for domestic flights, was equal to 79.15% of the 176 seats (ABEAR 2014). The most important route for Brazilian commercial flights is known as the "Rio-São Paulo Air Bridge" (Amadeus 2013). This connection with 7.7 million passengers per annum is the third busiest route in the world, behind the Jeju-Seoul route in South Korea (10.16 million), and the Sapporo-Tokyo route in Japan (8.21 million) (Amadeus 2013). Furthermore, São Paulo is the main gateway for domestic and inbound tourists in Brazil, through the Guarulhos International Airport, and many tourists bound for Rio de Janeiro make connections or stopovers in the city. In 2013, 36 million passengers (incoming and outgoing) went through this airport alone; 23.5 million domestic and 12.5 million international (GRU Airport 2014). In 2011, Rio de Janeiro received 15.7 million domestic air travel passengers which is the second largest number in the country after São Paulo. According to IPEA (2013), increased purchasing power in Brazil has enabled a gradual public shift from road transportation to air travel. This is likely to intensify future air passenger traffic between Rio de Janeiro and São Paulo.

Short-haul flights are more carbon intense than long haul flights when calculated per passenger km, due to the significant amounts of GHG emissions produced during the takeoff and landing stages of the flight (Filimonau *et al.* 2014). The flying distance between Rio de Janeiro and São Paulo is 357 km (short-haul) and an average flight between Santos Dumont airport (SDU) and Congonhas airport (CGH) takes circa 38 minutes. These airports are smaller airports in central locations, with expansion limited by the city boundaries. It is this prime location and the passenger traffic in the Rio de Janeiro - São Paulo connection that make them the chosen points of reference for air transportation in this study. Recently, passengers have begun using alternative airports in São Paulo and Rio de Janeiro, such as São Paulo-Guarulhos International (GRU), Rio de Janeiro-Galeão International (GIG) and Viracopos-Campinas International (VCP) (Figure 1). Although these airports are more distant, with attractive pricing options, they are growing in popularity (Fariello 2013). Today, approximately 120 daily flights connect São Paulo and Rio de Janeiro through their respective airports, according to the Brazilian National Civil Aviation Agency (ANAC 2011); this represents 5% of the total seats available on all domestic routes. There are a number of other airports in both cities; these, however, can only handle smaller aircraft and have therefore been excluded from analysis since they account for only a marginal proportion of passengers.

In this transport mode, three types of fuel were considered (Table 1). The first option would be the traditional aviation fuel, which contains no added biofuel. In Brazil, about 7 billion liters of traditional jet fuel are consumed annually, producing about 17.5 million tons of GHGs (EPA 2004). In the second option, a mixture of traditional jet fuel and biofuels was assessed, yielding an overall reduction of 65% in direct GHG emissions (Vera e Silva *et al.* 2013). The third option is based on an alternative blend of traditional fuels and biofuels, with an overall reduction in direct GHG emissions of up to 80%. These fuel blends have been repeatedly tested (ATAG 2014). While aviation biofuels have not yet become mainstream in Brazil, the tests have shown promising results. It is anticipated that the Brazilian aviation industry will broaden its use of biofuels in the future as part of its commitment to reduce the carbon footprint from flying by 50% by 2050 (compared to the 2005 level) (Brazil 2013).

With the steady growth in the passenger flow between Rio de Janeiro and São Paulo, there is a need for alternative transportation modes where rail connection represents a promising option. The alternative of building more airports and increasing the aircraft fleet in Brazil is not physically, economically, geographically or environmentally favourable (Fariello 2013).

Transport Mode 4: Traveling by Train

According to Camacho (1998), the Rio de Janeiro - São Paulo rail connection is not new as it had been used for long in the past. For over a hundred years, there had been a rail link between the country's two major cities. However, on October 31st, 1998, the railway link between these cities was suspended; the increased competition from airlines had played an important role in this decision (Camacho 1998).

At the beginning of the 21st century, there were negotiations about building a new link, this time for high-speed trains (HST) connecting Rio de Janeiro and São Paulo. The idea was based on a 2004 São Paulo state government project to connect the VCP Airport to the state capital. The new technical feasibility study on the preliminary layout for the HST included connecting Campinas, São Paulo and Rio de Janeiro in one 518 km line with nine stations (BNDES 2011).

According to Salgado (2014), the new high-speed rail project between Rio de Janeiro and São Paulo should have been completed by the beginning of the 2014 FIFA World Cup to be in full operation for the 2016 Olympic and Paralympic Summer Games. The deadline was not met and a new completion date has now been set for 2020. When completed, the project will connect three of the country's major international airports Galeão (Rio de Janeiro), Guarulhos (São Paulo) and Viracopos (São Paulo) via high-speed railway.

The project assumes that the 430 km route between the central zone of Rio de Janeiro, and the northern zone of São Paulo, will be covered in approximately 93 minutes, depending on interim stops. It is expected that trains will be operated at speeds of up to 350 km/h and handles an annual flow of 30 million passengers, at prices stipulated to be competitive with air transport (ANTT 2014).

For this transport mode, the occupancy rate and the carbon intensity values reflect those for the Eurostar international trains of the European network (DEFRA 2010). These data were employed due to the lack of country-specific and/or Latin American data which is a limitation of this study. This is because the Eurostar trains consume energy that is mainly produced by nuclear power. According to the International Energy Agency (IEA 2014), during 2012, the French energy matrix obtained 43.3% of its energy from nuclear sources and only 8.8% came from renewable sources. In contrast, Brazil obtained only 1.5% of its energy from nuclear sources and 41.3% from renewable sources (IEA 2014). This notwithstanding, the Eurostar data are deemed more suitable for the Brazilian context given they are less reliant on fossil fuel.

4. CARBON FOOTPRINT APPRAISAL METHOD

The study has chosen to apply a modified Life Cycle Assessment (LCA) method for carbon footprint appraisal of various travel transport modes between Rio de Janeiro and São Paulo. LCA has been repeatedly recognised as one of the most advanced methods for environmental impact assessment; it has been broadly employed in the different contexts and recently introduced to tourism (Filimonau *et al.* 2011a; Michailidou *et al.* 2016; Schianetz *et al.* 2007). The key advantage of LCA is in that it oversees a 'totality' of environmental impacts that arise at various stages of a product's life cycle, starting with extraction of raw materials and finishing with product disposal (Frischknecht and Rebitzer 2005). In other words, LCA has the capability to account for the environmental impacts that are defined as 'direct' (i.e. those arising from product use) and 'indirect' (i.e. those attributed to the non-use phases of a product's life cycle) (Berners-Lee *et al.* 2011; also see Filimonau *et al.* 2013 for a detailed overview of the 'direct' and 'indirect' carbon footprint as generated by various tourism products). There is growing evidence demonstrating that the 'indirect' environmental impacts can be substantial and, in some cases, they can even surpass the magnitude of the 'direct' environmental effects which underlines the importance of their thorough investigation (Chwieduk 2003). All this contributes to the true comprehensiveness and accuracy of the LCA method which positively differentiates it from alternatives and determines a steady growth of its applications in a number of disciplines and subject areas, including tourism (De Camillis *et al.* 2010).

Despite the comprehensiveness of analysis, the LCA method has a number of shortcomings that hamper its broader adoption by the sector. Substantial costs of LCA datasets and their irregular updates are arguably the key drawbacks of the method (Filimonau *et al.* 2014; Schianetz *et al.* 2007). To partially address the shortcomings of LCA as applied in the tourism sector, Filimonau *et al.* (2014) proposed to merge the traditional LCA method with the GHG emissions assessment tool developed for corporate reporting by the UK's Department for Environment, Food and Rural Affairs (DEFRA) (https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting#conversion-factors-2016). The latter tool is free to use and undergoes regular updating. The new, combined method would capitalise upon the ability of LCA to provide estimates of the 'indirect' GHG emissions with the capacity of the DEFRA's approach to generate more current assessments of the 'direct' carbon footprint. A detailed overview of the potential offered by a new method is beyond the scope of this study but can be found in Filimonau *et al.* (2013; 2014). The hybrid, LCA-DEFRA method is deemed to represent a better suited tool for analysis in this study. While it is not flawless, it is arguably the most comprehensive and accurate tool for carbon impact appraisal currently available in the tourism field which determines its application in this study.

To assess the carbon footprint for the different transport modes between Rio de Janeiro and São Paulo, the carbon intensity coefficients were first derived. The Ecoinvent database and the GaBi LCA software were employed to derive the carbon footprint coefficients to calculate the 'indirect' GHG emissions attributed to the capital assets and transportation infrastructure while the DEFRA's GHG emission factors were utilised to estimate the 'direct' and 'indirect' carbon footprint as produced by various types of transportation fuels (Table 2). GaBi is popular commercial LCA software (GaBi, 2016). It employs a range of tailor-made life-cycle databases to estimate the magnitude of environmental impacts attached to products and services, where the Ecoinvent database represents the key informant. The Ecoinvent database is a major life-cycle inventory which has for a prolonged period of time been applied in LCA analysis. To enhance the quality of analysis, the data from the Ecoinvent database can be supplemented with more precise, country-specific figures, retrieved from national inventories and previous studies, subject to their availability (Frischknecht and Rebitzer 2005).

[Insert Table 2 here]

Literature suggests that, due to high heterogeneity of tourism products, it is often difficult to derive an appropriate functional unit for the industry's carbon impact appraisal studies (Filimonau *et al.* 2011a). For this particular project, a functional unit was defined as 'a return weekend journey between Rio de Janeiro and São Paulo made by one traveller with tourism and leisure purposes'. The choice of such a broad functional unit was deliberate as it enables integration of other tourism elements (for example, accommodation and activities) that have been excluded in this study but whose analysis is planned in future work on this project. The carbon footprint was recorded in kilograms of carbon dioxide equivalent (kg CO_2e). This is the official unit of carbon footprint estimates as prescribed by the Intergovernmental Panel on Climate Change (IPCC 2007).

5. RESULTS AND DISCUSSION

The study shows that among the four transport modes considered with variations in different types of fuel, the most carbon-benign is the use of bus driven by B100 biofuel (Table 3 and Figure 2). This is in line with literature finding that overland modes of transport make the lowest input into global climatic changes (see, for instance, Filimonau *et al.* 2014; Peeters *et al.* 2007). The key disadvantage of this transport mode is the travel time which equates to six hours (one way). The second most carbon efficient transport mode is the high speed train (HST) whose GHG emissions are two-fold compared to the carbon footprint associated with B100 buses but, concurrently, significantly lower than the GHG emissions attributed to other transport modes. Again, this is in line with literature reporting on carbon impact appraisal studies of railway transportation as conducted in other geographical contexts (Barrett and Scott 2003; Sovacool and Brown 2010). In this analysis it is worth considering that comfort and time will be relevant to the passengers' travel decisions. The HST transport mode is more preferred in this case due to relatively short travel time, i.e. 1.5 hours. Despite clear carbon benefits demonstrated by the B100 bus transport mode, these can be negated by long travel times which also imply less time available to tourists to spend at a destination.

[Insert Table 3 here]

[Insert Figure 2 here]

Transport Mode “3a” (kerosene-driven flights) is most carbon intense which mirrors evidence reported elsewhere and outlines a primary mitigation opportunity (Peeters and Dubois 2010; Peeters *et al.* 2007). Importantly, biofuel driven flights are found to generate less GHG emissions than cars powered by the conventional fuel. This is an important finding signifying the crucial role of biofuel technology in reducing the carbon intensity of local visitor travel in Brazil. This demonstrates that all transport modes used in Transport Modes 2 (inter-city bus) and 4 (HST) should be politically preferred over Transport Modes “1a” (car driven by conventional gasoline) and “3a” (kerosene-driven flights) which have higher rates of energy intensity and GHG emissions. These latter two transport modes, when analysed from the perspective of biofuels, become more carbon-benign and yet the carbon savings associated with the use of the bus, with or without biofuel, or HST are more pronounced.

From the carbon footprint standpoint, the use of biodiesel is beneficial and broader application of this technology in Brazil should be encouraged. More in-depth analysis is however required to assess the viability of biofuel use in a country as there are a number of further, non-carbon related “indirect” issues attributed to its application, such as environmental (for example, land use changes); social (for instance, poverty and labour costs); and economic (for example, independence of foreign markets) (Almeida *et al.* 2007; Martinelli and Filoso 2008). While these are outside the scope of this study, it is argued that careful analysis is required to inform decision-making on whether or not to adopt transportation biofuels more broadly in Brazil.

The study indicates that, in 2020, when HST will have become operational, this mode of transport must be stimulated since it represents a more carbon effective means of transportation. This is particularly important as there is growing evidence demonstrating that HST can successfully compete with air transport on short-haul distance (Martin *et al.* 2014). Moreover, the Eurostar experience demonstrates that train journeys can be comfortable as well as cost and time efficient; these factors can therefore attract increased passenger numbers, also within city boundaries (Hickman *et al.* 2010). The accessibility potential (i.e.

its ability to avoid road traffic) offered by HST is another factor which can be capitalised upon when promoting railway transportation between Rio de Janeiro and São Paulo. It may be particularly appealing for business and family travelers for who the time and convenience considerations are of prime importance (Cao *et al.* 2013).

Bus, despite being the most climate friendly option, has the longest travel time and offers limited comfort. To enhance its appeal, measures should be undertaken to tackle these challenges. This can be achieved, for example, via free Wi-Fi and installation of power sockets alongside contemporary entertainment systems onboard. Interestingly, the carbon impact appraisal results for Transport Mode “1a” (car driven by conventional gasoline) are similar to Transport Mode “3a” (kerosene-driven flights) which shows that long car journeys should be discouraged due to the large volumes of GHG emissions they produce. These are disproportionally high given the low occupancy of private cars compared to aircrafts. Hence, tourists concerned about the carbon footprint and seeking to reduce it should therefore strive for replacement of car journeys with bus or train (when it becomes available). To enable this modal shift, appropriate incentives should be introduced, both on the supply and demand side.

Cost is another factor which impacts tourist decision-making (Table 3). It varies greatly from one transportation mode to another and its role should therefore be more diligently examined in a separate study aiming to better understand the factors contributing to local travel decision-making in Brazil. Future work should employ eco-efficiency analysis as a tool to link the carbon impacts of tourists to their spend (Sun and Pratt 2014).

When analysing the ‘indirect’ GHG emissions, the study shows that air travel based on biofuel is the largest contributor of the ‘indirect’ carbon footprint which amounts to 55.5% of the total carbon significance attributed to this means of transportation (Figure 2). The bus powered by diesel fuel has the lowest ‘indirect’ emissions (11.6% of the total), which is in line with literature (Filimonau *et al.* 2014; Schafer and Victor 1999). This is an important finding for engineers responsible for conducting technical feasibility studies and justifying the choice of more carbon efficient transport modes. Until now, the use of biofuels has traditionally been considered the most beneficial. This is primarily due to the lack of methods capable of accounting for the ’indirect’ GHG emissions. The hybrid LCA-based method applied in this study reveals the importance of the ‘indirect’ carbon footprint and underlines the necessity of taking it into account when developing new transportation planning proposals. Yet, the ‘indirect’ emissions revealed in this paper are rather approximate as they do not take into account the increased carbon footprint associated with radiative forcing effect, enlarged NOx generation and land use changes (Gössling and Peeters 2007).

For comparison purposes, the Brazilian GHG emissions totaled 1,488 mt CO_2e in 2012 (IMAFLORA 2014). Considering the population estimate of 198.7 million people (IBGE 2012), each Brazilian resident would generate an average of 7,488 kg CO_2e per annum or 20.51 kg CO_2e per day. This number corresponds to the carbon intensity of a return leisure- or tourism-related journey ‘São Paulo-Rio de Janeiro’ on a high speed train, one of the most carbon-benign means of transportation between the two cities.

6. CONCLUSIONS

The literature on tourism’s carbon impacts indicates that tourist transport is the largest contributor to the industry’s GHG emissions. Technology is envisaged to play an increasingly important role in the mitigation of the carbon footprint attributed to tourism- and leisure-related travel. Within various technological solutions, biofuel is often considered a viable tool to tackle this issue.

To effectively mitigate the carbon impacts from tourist transport, accurate assessments of its GHG emissions are necessary. These should include not only the ’direct‘, or operational, but also the ’indirect‘, or non-operational, life cycle related, footprint. The inclusion of both ’direct‘ and ’indirect‘ GHG emissions provides a more holistic outlook, thus enabling better understanding of the areas in which carbon mitigation intervention is required. Research which has set out to tackle this challenge is yet scarce and should be reinforced. Furthermore, the geographical scope of application covered by existing studies is narrow due to its focus on developed economies and should be extended, particularly towards developing countries and emerging markets where tourism is on the rise.

This study extended the scope of the LCA application in tourism from Europe, Australia and North America to Brazil, a growing BRICS market and an emerging tourist destination in Latin America. The case of local transportation between the cities of Rio de Janeiro and São Paulo, the busiest Brazilian transportation artery, was considered in order to identify the most carbon efficient transportation options. The results indicated that air and road transportation (by car) are the transport modes with the largest carbon footprint while bus and train represent the least carbon intense means of transportation. Bus and train travel should therefore be encouraged by local decision-makers, particularly from the standpoint of reducing the travel times and increasing passenger comfort.

The outcome of this study can be used by Brazilian decision-makers as a basis for policy intervention designed to facilitate more carbon-benign modes of tourism- and leisure-related transportation within the country. It can also be disseminated to local tour operators and travel agents who could make this information available to tourists. Given the evidence that environmental awareness of tourists is growing, the results of this study may appeal to those tourists who take account of the carbon impacts associated with their travel choices. Scientifically grounded information on the carbon footprint attributed to different transport mode should be made available to tourists, and tourism and hospitality providers at a destination may consider offering discounts to those visitors who have opted for more carbon efficient transportation options to reach a destination.

Given the important role played by biofuel technology in mitigating the carbon impacts from transportation, Brazilian decision-makers should facilitate its more rapid adoption. To this end, market-based instruments can be utilised. For instance, financial incentives can be given to the public purchasing biofuel-driven cars; concurrently, higher taxes can be assigned to the most carbon intense vehicles. As train represents one of the carbon efficient means of transportation between Rio de Janeiro and São Paulo, it should be made operational as soon as possible while its use should be encouraged. Subsidies can be provided to HST operators to maintain cheaper fares and enhance its competitiveness with airlines. If the above is unfeasible, given significant reductions in the carbon footprint from flying demonstrated by biofuel technology, the airlines that use the blends of biofuel in their aircraft should be given tax incentives.

In addition to the reduction of the carbon footprint from national transportation, biofuel may play an important role in socio-economic development of Brazil. Brazil has strong agricultural traditions; this implies it has an opportunity to become a leading supplier of raw materials and technology for non-fossil fuels, subject to careful considerations given to the socio-cultural and economic implications of this technology. More intense biofuel production in Brazil will minimise the dependence of the country on external fossil fuel supply.

Lastly, this study shows that the 'indirect' carbon footprint from transportation is significant and should not therefore be excluded from analysis. This suggests that policy-making interventions designed to mitigate the carbon significance of tourism should not only seek to reduce the 'direct', or operational, impacts, but should also concentrate on the 'indirect', non-operational effects. This does not only apply to carbon impact assessment of local transportation in Brazil, but also holds true for any developed or developing country, especially for other BRICS states, where tourism in general and the local transportation market in particular are growing.

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Table 1: Transportation scenarios under review

Scenario	Transport	Fuel type	Origin	Destination
1	Car (429 km one-way)	a. Brazilian gasoline	Tietê Bus Station	Novo Rio Bus Station
		b. Ethanol		
2	Inter-City Bus (429 km one-way)	a. Diesel		
		b. Biofuel B7		
		c. Biofuel B10		
		d. Biofuel B20		
		e. Biofuel B100		
3	Airplane (357 km one-way)	a. Kerosene	São Paulo/ Congonhas Airport (CGH)	Rio de Janeiro/ Santos Dumont Airport (SDU)
		b. Biofuel with 65% less GHG		
		c. Biofuel with 80% less GHG		
4	Rail (430 km one-way)	Electricity	Campo de Marte Railway Station (2020)	Leopoldina Railway Station (2020)

Table 2: Carbon intensity factor for transport between Rio and São Paulo

Transport mode in different scenarios	Direct GHG emissions factor estimated by DEFRA and indirect from the fuel chain, CO_2eq.	Capital goods and infrastructure factors related to indirect GHG emissions estimated by LCA, CO_2eq.	Total GHG emissions: Hybrid Method (DEFRA + LCA), CO_2eq.
Car ("Brazilian gasoline")	0.067 (78%)	0.019 (22%)	0.086[a] (100%)
Car (ethanol)	0.016 (46%)	0.019 (54%)	0.035[b] (100%)
Bus (Diesel)	0.0276 (88%)	0.0036 (12%)	0.0312 (100%)
Bus (B7)	0.02566 (87.7%)	0.0036 (12.3%)	0.02926[c] (100%)
Bus (B10)	0.02484 (87.3%)	0.0036 (12.7%)	0.02844[d] (100%)
Bus (B20)	0.02208 (85.9%)	0.0036 (14.1%)	0.02568[e] (100%)
Bus (B100)	0.00828 (69.7%)	0.0036 (30.3%)	0.01188[f] (100%)
Airplane (kerosene)	0.12 (80%)	0.03 (20%)	0.15 (100%)
Airplane (65% reduction of GHG)	0.042 (58.4%)	0.03 (41.6%)	0.072[g] (100%)
Airplane (80% reduction of GHG)	0.024 (44.5%)	0.03 (55.5%)	0.054[h] (100%)
Train	0.017 (72%)	0.0065 (28%)	0.0235 (100%)

[a] Reduction of 19.2% of the original value of direct GHG emissions (0.083) presented by Filimonau *et al.* (2014) based on Soares *et al.* (2009), retaining the value of the indirect contribution 0.019.

[b] Reduction of 80.2% of the original value of direct GHG emissions (0.083) presented by Filimonau *et al.* (2014) based on Soares *et al.* (2009), maintaining the value of the indirect contribution 0.019.

[c] Reduction of 5% of the original value of direct GHG emissions (0.0276) presented by Filimonau *et al.* (2014) based on DELTACO_2 & CENA (2013), maintaining the value of the indirect contribution 0.0036.

[d] Reduction of 7.3% of the original value of direct GHG emissions (0.0276) presented by Filimonau *et al.* (2014) based on DELTACO_2 & CENA (2013), maintaining the value of the indirect contribution 0.0036.

[e] Reduction of 14.5% of the original value of direct GHG emissions (0.0276) presented by Filimonau *et al.* (2014) based on DELTACO_2 & CENA (2013), maintaining the value of the indirect contribution 0.0036.

[f] Reduction of 70% of the original value of direct GHG emissions (0.0276) presented by Filimonau *et al.* (2014) based on DELTACO_2 & CENA (2013), maintaining the value of the indirect contribution 0.0036.

[g] Reduction of 65% of the original value of direct GHG emissions (0.12) presented by Filimonau *et al.* (2014) based on ATAG (2014), maintaining the value of the indirect contribution 0.03.

[h] Reduction of 80% of the original value of direct GHG emissions (0.12) presented by Filimonau *et al.* (2014) based on ATAG (2014), maintaining the value of the indirect contribution 0.03.

Table 3: Carbon footprint attributed to different travel scenarios

	Distance (round trip)	Time (one way)	Price (one way)	DEFRA+ LCA*	Total /person (Kg CO_2eq)
Scenario 1 - Travel by Car (***Use of "Brazilian gasoline" - containing 25% ethanol)***	858 km	4h30min	US$ 107.61[a]	0.086	**73.80**
Scenario 1 - Travel by Car (***Use of just ethanol)***			US$ 107.04[b]	0.035	**30.03**
Scenario 2 - Travel by Bus (***Use of just diesel)***		6h	US$ 34.77 - US$ 70.66[c]	0.0312	**26.77**
Scenario 2 - Travel by Bus (***Use of B7 fuel)***				0.02926	**25.11**
Scenario 2 - Travel by Bus (***Use of B10 fuel)***				0.02844	**24.40**
Scenario 2 - Travel by Bus (***Use of B20 fuel)***				0.02568	**22.03**
Scenario 2 - Travel by Bus (***Use of B100 fuel)***				0.01188	**10.19**
Scenario 3 - Travel by Airplane (***Use of traditional jet fuel)***	714 km	38min	US$ 48.22 - US$249.67[d]	0.15	**107.10**
Scenario 3 - Travel by Airplane (*Use of biofuel with 65% reduction of GHG emissions)*				0.072	**51.40**
Scenario 3 - Travel by Airplane (*Use of biofuel with 80% reduction of GHG emissions)*				0.054	**38.55**
Scenario 4 - Travel by Train	860 km	1h33min	US$ 90.30[e]	0.0235	**20.21**

[a] Daily car rental: US$ 52.83 per day (www.rentalcars.com) / Total toll amount in one direction US$ 15.21 (www.novadutra.com.br/tarifas) / 31 liters of Brazilian gasoline US$ 39.57 (www.precodoscombustiveis.com.br).

[b] Daily car rental: US$ 52.83 per day (www.rentalcars.com) / Total toll amount in one direction US$ 15.21 (www.novadutra.com.br/tarifas) / 40 liters of ethanol US$ 39.00 (www.precodoscombustiveis.com.br).

[c] Normal bus ticket, on average, US$ 34.77 or the ticket for "enhanced comfort" seats, US$ 70.66 (www.buscaonibus.com.br).

[d] Research conducted using immediate and remote dates/ ticket prices (www.submarinoviagens.com.br).

[e] The high speed train will have 60% of seats available for economy class (price displayed), according to the law (BNDES, 2011) and the maximum fare will be US$ 0.21 per km.

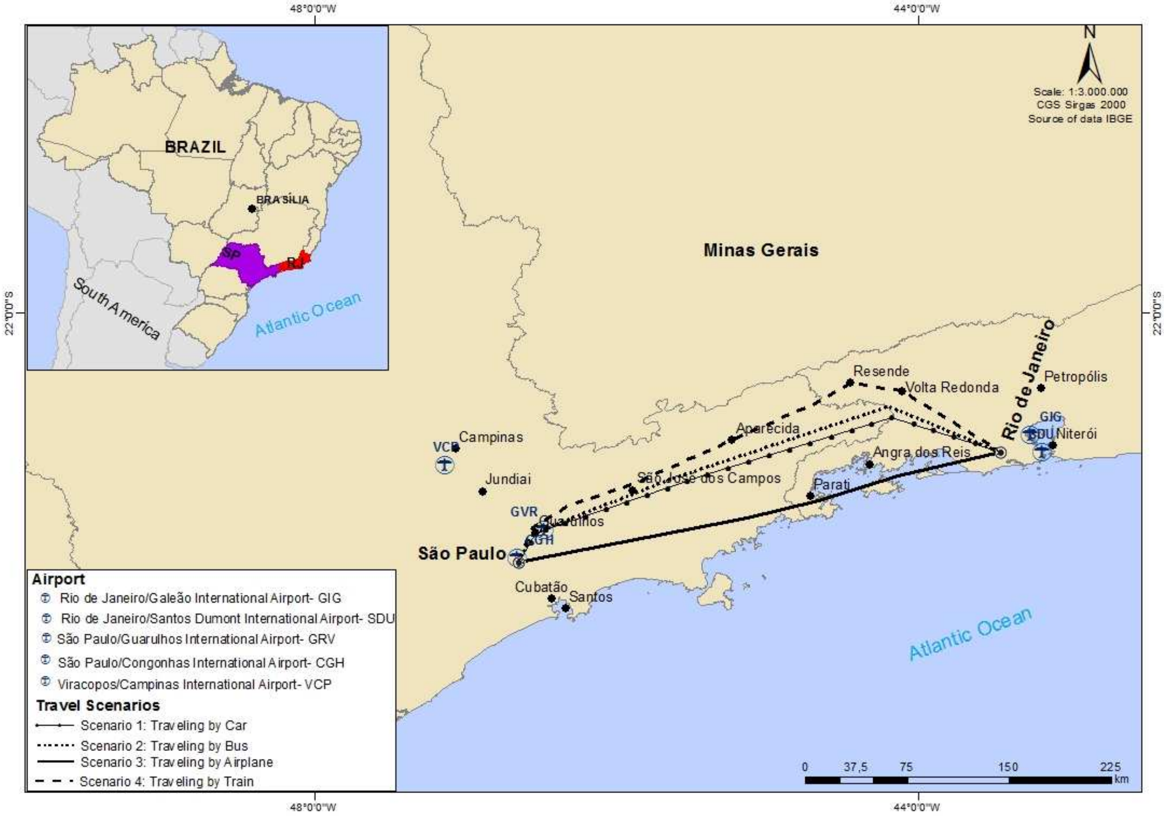

Figure 1: Visual representation of the travel scenarios considered in this study.

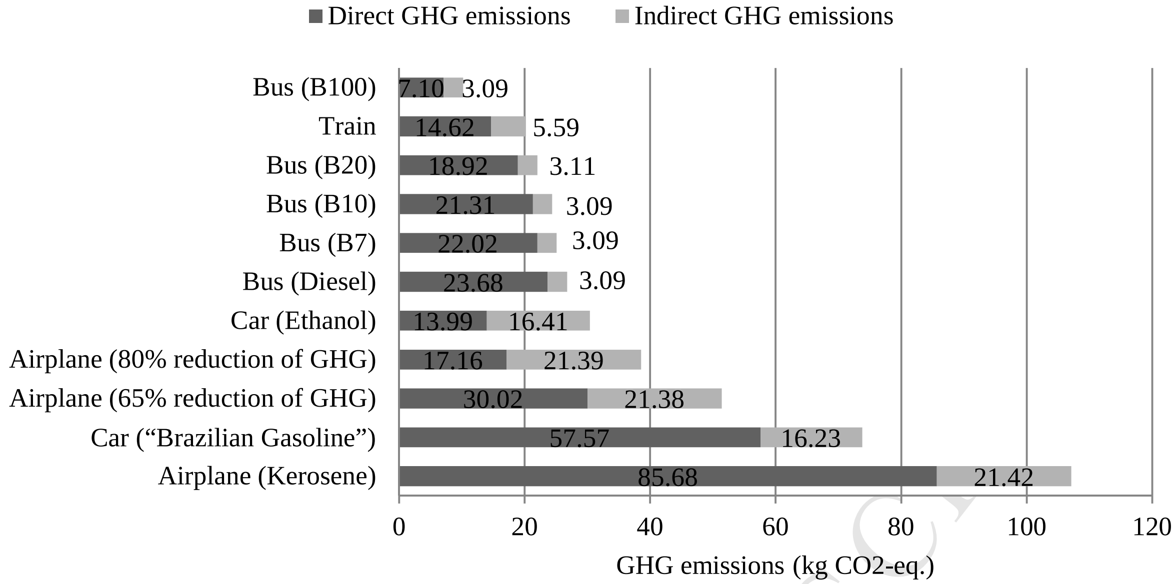

Figure 2: Direct and "indirect" carbon footprints from different transport scenarios.