Sustainable transportation strategies for decoupling road vehicle transport and carbon dioxide emissions

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Abstract

Purpose – The purpose of this paper is to identify research priorities to guide transportation stakeholders in their practice, education, and research.

Design/methodology/approach – A literature review of published, conference proceedings, agency reports, books, and web site documents was conducted, aiming at the identification of the diverging strategies and practices undertaken by transportation stakeholders in order to be able to generate initial meaningful insights about a sustainable transportation system.

Findings – Sustainable transportation systems are in certain way a new paradigm where a business-as-usual approach is not possible. Vehicle makers produce more energy efficient vehicles. Nevertheless, fossil fuel is still the predominant source of energy. Regarding the level of carbon dioxide (CO_2) emissions, non-motorized transport modes are preferable over motorized transport modes, and public transportation modes preferable to private transportation modes. It is also import to include environmental consideration along the design, construction, maintenance, and operation of the transportation infrastructure. While vehicles powered by alternate fuel such as biofuel, electricity, and/or fuel cell are becoming more popular, shifting to more sustainable transport modes would also require changes on commuter behaviors and individual preferences.

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Practical implications – The paper discusses the efforts that are underway for decoupling transport and CO_2 emissions, being useful for transportation stakeholders to implement or improve the effectiveness of their potential or current sustainability transport initiatives through the identification of strategies, opportunities, and barriers.
Originality/value – Although there is plenty of good information about sustainability and transportation modes in literature, most of the articles analyzed focus on specific factors of the whole transportation system. The originality/value of this paper is found in the holistic perspective, here presented, of the state of the art issues that a sustainable transport system would encompass.
Keywords Climate change, CO_2 emissions, Sustainable transport, Sustainable vehicles
Paper type Literature review

1. Introduction

Transportation plays a key role in promoting the livability of communities (Miller *et al.*, 2013) due to its interaction with all three areas of sustainable development (Souza and Kahn, 2013). Under this circumstance, stakeholder involvement is essential in order to incorporate diverse perspectives and preferences (Rangarajan *et al.*, 2013). Bearing this in mind, this paper shows a comprehensive and extensive literature review on sustainable transportation with the purpose of identifying research priorities to guide transportation stakeholders in their practice, education, and research. This literature framework focusses on good practices that contribute in making more sustainable transportation systems, but leave out the magnitudes of each contribution. Although there is plenty of good information about sustainability and transportation modes in the literature, most of the articles focus on specific factors of the whole transportation system; therefore, the originality/value of this paper is found in its holistic perspective used to review the state of the art issues that a sustainable transport system would encompass.

The transportation sector includes the movement of people and goods by cars, trucks, trains, ships, airplanes, and other vehicles. The high growth rates of transportation activity has generated negative effects on the environment and on populations (Eppel, 1999) who are experiencing numerous traffic problems such as severe traffic congestion and road accidents coupled with air and noise pollution (Sarkar and Tagore, 2011).

The transportation sector is the second largest contributor to carbon dioxide (CO_2) emissions due to fossil fuel combustion. This sector makes up 28 percent of the total greenhouse gas (GHG) emissions in the USA (United States Department of State, 2010) and 25 percent of GHG emissions in the European Union (European Commission, 2014). Every other sector contributes in reducing emissions, except for the transportation sector (Heinrichs *et al.*, 2014). Thus, special attention must be paid to the need for decoupling transportation and CO_2. It is obvious that under this context, transportation contributes little to sustainable development; therefore, urgent interventions are required to make the transportation sector more sustainable.

One of the key challenges for any sustainable system is to balance the environmental, economic, and social dimensions within decision-making processes. This usually involves trade-offs between the chance of occurrence of events that are being considered and the "impact of the outcome of the decision-making" (She *et al.*, 2012). These trade-offs are the result of complex technological and cultural relationships that require systematic thinking in order to be better understood. This thinking attempts to understand the larger context in which the system operates, and explain the behavior of the system based on that role (Atwater *et al.*, 2008).

Either by car, by train, by airplane, or by boat; each mean of transportation has its own constraints related to sustainability; and more particularly to climate change

(Janic, 2004; Forsyth, 2011; Miola *et al.*, 2011; Rangarajan *et al.*, 2013; Dedes *et al.*, 2012). For that reason, characterizing a sustainable transportation system taking into account all transportation modes and their negative externalities on society could be complex and to some extend impractical.

2. Methodology

This paper shows a body of knowledge built from a rigorous literature review of 105 sources, of which 93 were scientific articles. All of the articles were peer-reviewed, and about 70 percent of those were published from 2011 to 2014. Basically, the latest literature published in scientific journals concerning sustainable transportation was covered. This information was complemented with information in books, international organization reports, and articles in electronic sources. Keywords related to sustainable transportation were used to search in electronic research databases. The validity and relevance of the literature reviewed was appraised under the following criteria: impact factor of the journal, international prestige of the journal or organization, updated scientific literature, the sustainable transportation practices in the information, the sustainable theories in the information source, and the strategies for a sustainable transportation system.

The authors have limited the scope of this paper to an environmentally sustainable road vehicle transportation system. However, the sustainability transportation principles discussed here would be applied to any transportation mode.

3. Conceptualizing a sustainable transportation system

Any concept that includes the adjective sustainable stems from the root concept of sustainable development. Understanding it has been one of the major challenges for sustainability researchers and practitioners from the time when sustainable development was first coined as a development that meets the needs of the present without compromising the ability of future generation to meet their own needs (The World Commission on Environment and Development, 1987). This definition has distinct meanings to people in different settings that conceive sustainability and act towards it depending on their knowledge, background, experience, perception, values, and context (Leal, 2000). Although this complication has been debated extensively (Ayres, 1993), the minimum technical requirements are often unknown (Prugh *et al.*, 2000). Despite discrepancies about the meaning, people agree that the concept involves, at least, environmental, social, and economic considerations (Dragun and Jakobsson, 1997) what is called the triple bottom-line (Hacking and Guthie, 2008).

The concept of sustainable transportation involves the same debate about meaning and uncertainty, according to Black (2010), there is still no political or scientific agreement on a sustainable transportation definition. It can mean the cheapest point to point transport available, or reliable and predictable journeys, or the quickest means to move perishable freight, or journeys that use the least amount of energy or resources to fulfill the task (Sweeting and Winfield, 2012). At the end, there is also an emerging consensus that transportation system sustainability should capture attributes of system effectiveness and system impacts on economic development, environmental integrity, and social quality of life (Jeon *et al.*, 2013). A definition fitting in the general definition of sustainable development is given by the Organization for Economic Cooperation and Development (OECD) (2002), defining a sustainable transportation system as "one that does not endanger public health or ecosystems and meets mobility needs consistent with (a) use of renewable resources at below their rates of regeneration and (b) use of non-renewable resources at below the rates of development of renewable substitutes".

4. Decoupling transport and CO_2 emissions

CO_2 emissions are now accepted as the biggest contributor to climate change; which, in turn, is acknowledged as one of the most serious current environmental problems (Morrison and Hatfield-Dodds, 2011). The more people allow CO_2 levels to increase, the more people allow temperatures to rise, with consequently greater knock-on effects (Moolna, 2012). Internalizing the cost of environmental externalities in the road transportation sector has not been possible (Santos *et al.*, 2010); even though it is known that CO_2 emissions from the transportation sector are growing faster than total CO_2 emissions (Saboori *et al.*, 2014). The problem is to such a degree that the Intergovernmental Panel on Climate Change recently claimed that without aggressive and sustained mitigation policies being implemented, transportation emissions could increase at faster rate than emissions from the other energy end-use sector by 2050 (Intergovernmental Panel on Climate Change, 2014).

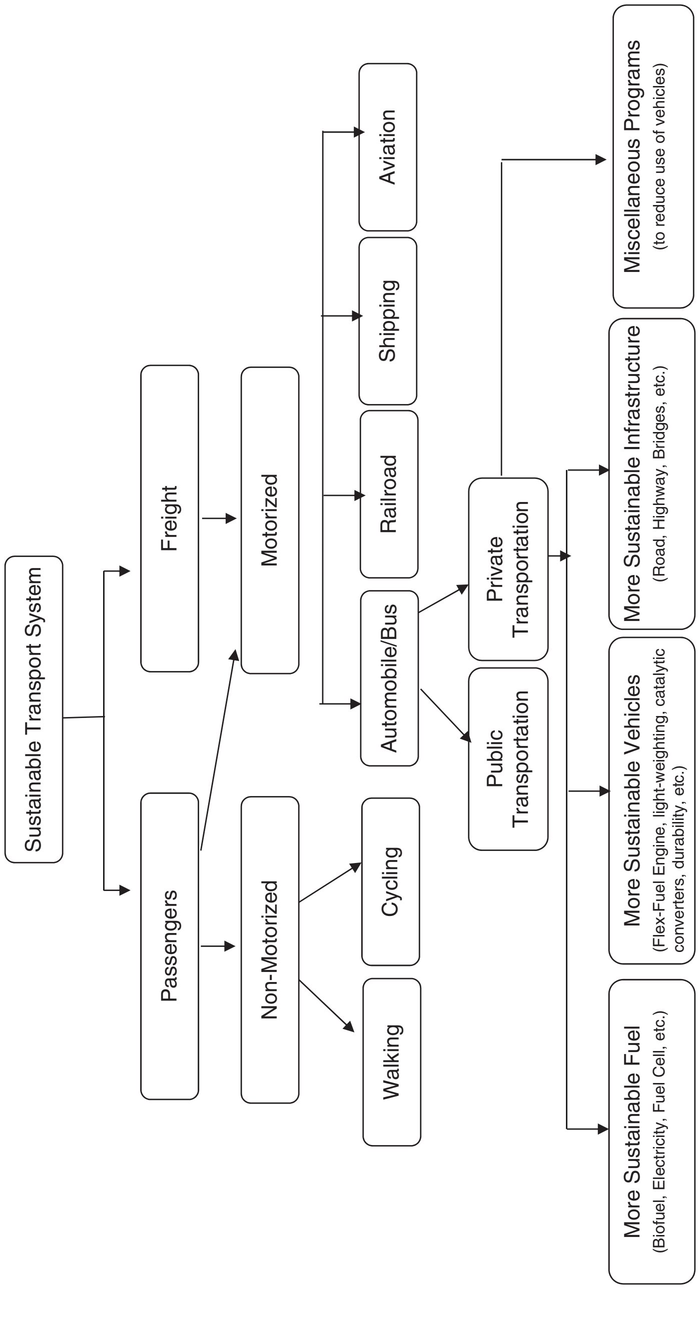
The Scientific and Technical Advisory Panel of the Global Environment Facility by the United Nations Environment Programme claims that a sustainable future relies on the decoupling of economic growth and CO_2 emissions in the transportation sector. It also suggests the use of sustainable, low-carbon transportation, which is defined as a strategy to provide economically viable infrastructure and operation that offers safe and secure access for both people and goods whilst reducing short and long term negative impact on the local and global environment (Dalkmann and Huizenga, 2010).

Doing transportation business as usual may lead to worsening the climate change situation; Zanni and Bristow (2010) claim that if the actual growth in freight traffic continues and if there are no new policy interventions, the CO_2 emissions may increase by an additional 109 percent by 2050. However, this forecast, as almost all forecasts, should be taken with some caution due to uncertainties around transportation. This is particularly true with regards to the economic development in different branches of economy that considerably affect the development of energy efficiency and CO_2 emissions of road freight transport (Liimatainen and Pöllänen, 2013). For instance, the economic growth is indeed a major cause of rapid development of China's transport infrastructure (Yu *et al.*, 2012).

Climate change and CO_2 emissions are clearly becoming the significant factor in logistical decision making (Piecyk and McKinnon, 2010). The European Union has set the target to increase the competitiveness of transport while reducing GHG emissions caused by transportation by at least 60 percent from the 1990 levels by the year 2050 (European Commission, 2011). However, not all decisions concerning transportation systems are made at continental or national level; many of them are made at a local level where the planning style does not appear to be hugely significant for the development of transportation (Hrelja, 2011).

5. Sustainable transport strategies

A wide variety of strategies are being used to reduce the GHG emissions caused by the transportation system; yet, it is very likely that climate change mitigation solutions would require a differentiated strategy for passenger and freight transport (Mattila and Antikainen, 2011). The diverging sustainable transportation strategies and practices undertaken by stakeholder around the world are discussed below (see Figure 1).



Source: Authors' own elaboration

Figure 1.
Conceptual framework for decoupling road vehicle transport and carbon dioxide emissions

a. Non-motorized modes of transportation

For passenger transport it is obvious that public and non-motorized transport have better environmental and social impacts, such as lower emissions and resources consumption as well as a greater variety and accessibility (Haghshenas and Vaziri, 2012). Actually, in Latin American cities there exists a combination of public and non-motorized transport (Hidalgo and Huizenga, 2013).

There is no doubt that walking is the most environmentally friendly alternative for commuting; however, this is an option often left out in numerous cities where many places are not within walking distance. Instead, bicycling is an active and affordable mode of transportation that brings significant benefits beyond climate change mitigation; yet, these benefits are difficult to estimate (Krizek *et al.*, 2007). On the other hand, commuting by bicycle is a risky activity that requires a bicycle-friendly infrastructure (Macmillan *et al.*, 2014); nevertheless, this alone does not guarantee traffic safety on bicycle paths. For instance, in the Netherlands less than a quarter of all hospitalized bicyclists are directly related to a crash with motorized traffic (Van der Horst *et al.*, 2014). For that reason, this mode transportation also requires bicyclists to have road safety knowledge and obey laws (Connaughton *et al.*, 2012).

b. Motorized modes of transportation

Motorized transportation is used for passengers and freight mobility; hence, their ideal situation would be to keep motorized mobility levels at their maximum while keeping inequitable influences at their minimum, taking into account environmental capacity constraints (Feng and Timmermans, 2014).

Biofuel vehicles. The first aim of decoupling transportation and CO_2 emissions is at the vehicle itself where efficiency improvements made by car assemblers are clear (Wells and Orsato, 2005). Technology has been a key factor in the success; at least in terms of reliability and cost (Costa and Fernandes, 2012). Probably in the near future, CO_2 emissions from new cars are going to be lower than present day levels (Zachariadis, 2013). There are many areas where the automobile has improved its sustainability performance; for instance, the introduction of better catalytic converters (Farago *et al.*, 2005), light-weighting vehicles (Kim *et al.*, 2011), and longer lasting cars (Nieuwenhuis, 2008). However, producing alternative fuels is among the most impressive advances (Richardson, 2005). Determining the appropriate fuel mode depends on various factors including efficiency, price, and capability among others (Vahdani *et al.*, 2011).

Since the beginning of the environmental concerns, attempts have been made to substitute gasoline vehicles with diesel vehicles; the latter having a higher fuel economy and generate lower CO_2 emissions (Wallington *et al.*, 2013). On the other hand, diesel cars generate more conventional air pollutants than gasoline cars (Mayeres and Proost, 2013). Compressed natural gas (CNG) is a popular alternative to replace conventional diesel on buses because its purification process eliminates several pollutants that are contained in other fossil fuels (Park and Tak, 2012) and also because this has the potential to reduce health risks (Cohen, 2005). In addition to the benefits mentioned above, it is also more cost effective than diesel (Rose *et al.*, 2013). Reduction of pollutants has also been observed after switching from medium and light diesel and gasoline vehicle engines to CNG (Yasar *et al.*, 2013).

Biofuels are obtained from renewable and biomass resources using a wide range of technologies (Rangel *et al.*, 2010). Nowadays, they are regarded as potential substitute to fossil fuel mainly because of their contribution to reduce GHG emissions (Florin *et al.*, 2014). Yet competitive production costs compared to conventional fuels are imperative for biofuels to gain market shares (Festel *et al.*, 2014). There are several kinds of biofuels; for instance, biodiesel has been approved as an environmentally sound fuel based on chemistry approaches (Shandilya and Kumar, 2014). Life cycle assessment studies show that buses running on biogas are an optimal environmental alternative for replacing buses running with diesel and CNG (Kliucininkas *et al.*, 2012).

As biofuels appear to substitute fossil fuel, new technologies are being developed to substitute gasoline cars. In 2003, a car that could be fueled with ethanol or gasoline was built in Brazil; although its performance in kilometers per liter is inferior to cars fueled by gasoline, the proportion of flex cars, as these cars are called, is almost 100 percent of the total sales of new cars (Ferreira *et al.*, 2009; Du and Carriquiry, 2013). Although in Brazil the preferences for ethanol are high, this situation differs in Sweden where consumers require government incentive to change behavior. This indicates that consumer behavior differs among established and new markets for ethanol (Pacini and Silveira, 2011).

Electricity/fuel cell vehicles. The use of electricity is another strategy for greening transportation, electric cars are an efficient means of transportation in the short-term because the current power transmission and distribution network, but in a long-term this could not be the most affordable alternative (Van der Zwaan *et al.*, 2013). Therefore, a mid-point option is driving hybrid electric vehicles (Van Mierlo *et al.*, 2006); mainly at congested and large city urban transit (De Almeida *et al.*, 2013).

A hybrid electric vehicle is defined as a vehicle with the conventional internal combustion engine and an electric motor as its major sources of power (Tzeng *et al.*, 2005). Although, they are not still a commercially viable alternative, they can contribute to the reduction of CO_2 emissions not only in the transportation sector but also in the energy sector by enhancing the generation of cheap and clean electricity (Mejia *et al.*, 2012). Having hydrogen as the main power source, fuel cell can replace batteries in electric motor making this alternative more attractive (Regattier *et al.*, 2007). Projections indicate that the future generations of fuel cell vehicles might achieve important reductions of GHG emissions (Ally and Pryor, 2007); yet, the high production cost is still preventing it from mass commercialization (Liew *et al.*, 2014). Additionally, emissions savings from alternative fuel can increase capital costs (Croft and Durango, 2012).

Despite of the potential environmental advantages the automobiles running on alternative fuels have, especially electric and hydrogen, they are still not preferred by users due to their limited driving range and considerable refueling times (Hoen and Koetse, 2014). On the other hand, national transportation policies can encourage a shift to low-carbon fuel such as electricity, fuel cell, hydrogen, and biofuels (International Energy Agency, 2010).

Private and public transportation. The sustainability of the holistic automobile system is in a certain way related to individual preferences about traveling in private vehicles or in public transportation fleets. Therefore, the challenge to transportation stakeholders is capitalizing the benefits of a multimodal mobility system (Spickermann *et al.*, 2013). Automobile ownership and use are generally accepted as the key determinants of the travel behavior of individuals (Kim and Kim, 2004). In 2009, there were about 168.5 vehicles per 1,000 persons circulating back and forth every single day in the world (The World Bank, 2009). This amount of vehicles has worsened the traffic causing congestion in many cities at both developing and developed countries.

Congestion refers to the delay imposed on all vehicles sharing a road by the presence of other vehicles (De Rus and Romero, 2004).

This phenomenon has potentially increased the degradation of air quality (Zhang and Batterman, 2013). Nonetheless, the environment is not the only one being affected, there are other marginal external costs caused by additional congestion (Bigazzi and Figliozzi, 2013). Bilbao (2008) has shown several costs and welfare losses arising from congestion such as the price of the time lost, the cost of additional fuel consumption, and noise pollution.

In better-organized societies, the vehicle ownership is being reduced through increasing the quality of public transportation by fostering the renewal of their older vehicles to newer vehicles powered with several types of fuel modes. Often, investment in public transportation has been one of the environmentally preferred alternatives by urban planners. Private and public partnerships have invested in rapid bus transit and associated access networks (Mitric, 2013), but this has tended to be accidental and chaotic rather than planned (Gwilliam, 2013). In the USA these kinds of partnerships have been very popular for building public transit systems to revitalize their urban core and grow in a sustainable manner (Mathur and Smith, 2013). However, although their impact at the short-term was effective, over the longer term, they have proven to be problematic (Siemiatycki, 2010).

Miscellaneous practices. From a holistic perspective, the most significant environmental impacts of the automobile technology system arise from the infrastructure required when using the car and the social structure behind the vehicles (Allenby, 1999). Therefore, beyond the sustainability of the automobile itself, it is also necessary to address the sustainability efforts not only toward the reduction of the infrastructure required for using the motorized vehicles, but also to reduce the travel distance by optimizing the routes for a fleet of vehicles (MirHassani and Mohammadyari, 2014).

In order to discourage the use of private vehicles, several planning and management initiatives have been implemented around the world aimed at reducing traffic and its negative consequences (Tsekeris and Geroliminis, 2013). The design, construction, maintenance, and operation of transportation infrastructure must include studies associated with environmental impact analyses in order to reduce its impact on climate change (Meyer and Weigel, 2011). Beyond this provision, design efforts to reduce traffic congestion should also be taken in account because the increased provision of interstate highways and major urban roads are unlikely to relieve congestion (Duranton and Turner, 2011).

Transportation systems are socio-technical systems characterized by their complexity and ambiguity; usually, they rely immensely on user behavior and patterns such as the commuting distance (Clark *et al.*, 2003). Even the number of workers in households are likely to play an increasingly important role in determining future transportation demand (Surprenant-Legault *et al.*, 2013).

Shifting to more sustainable transportation modes would require changes on travel behaviors, attitudes, and lifestyles that determine the mobility mode preferences of persons (Klinger *et al.*, 2013). With this purpose, countries have implemented soft policies to promote behavioral change in favor of using sustainable transportation by informing the public about the consequences of and alternatives to their transport choices (Santos *et al.*, 2010). Individual preferences with the available transport options depend on factors related to modal and demographic characteristics (Jou and Chen, 2014). It is more likely that commuters would be willing to shift to public transportation if services are considered efficient enough (Jain *et al.*, 2014). As with alternative fuel, individual preferences determine the use of private or public transportation. For example, Germans are five times more likely to use public transportation than Americans; moreover, public transportation in Germany attracts a much broader cross-section of society and for a greater diversity of trip purposes (Buehler and Pucher, 2012).

Parking restrictions in many cities have been established in order to reduce reliance on cars and promote sustainable transportation development (Al-Fouzan, 2012; Barter, 2012; Qian *et al.*, 2012). In very organized neighborhoods, a system called Carsharing has allowed associates to use a fleet of vehicles on a short-term basis; as a consequence, the automobile ownership has decreased (Engel-Yan and Passmore, 2013). Another method to reduce the environmental pollution due to traffic congestion is Carpooling, this method involves two or more users that travel together in the same direction into the same private vehicle along a semi common route (Yan *et al.*, 2014). Finally, a new tendency has emerged recently in the United States, the number of people getting rid of their cars exceeded new car sales in 2009 for the first time since Second World War; it seems that this tendency could continue through at least 2020 (Brown, 2010).

6. Summary of literature review and conclusions

Vehicle manufacturers have made an excellent job at producing more energy saving vehicles and increasing sustainability efforts along the supply chain (Vanalle and Blancos, 2014); nevertheless, fossil fuels are still the predominant source of energy within the current transportation system. Fortunately, over the last decade, alternative fuels have emerged as potential substitutes to fossil fuels in order to contribute to reducing GHG emissions from transportation.

Due to lower CO_2 emissions, non-motorized, and public transportation modes are preferable over motorized transportation modes; this implies that transportation stakeholders must capitalize the benefits of a multimodal mobility system. In regard to the CO_2 reduction target, it is also important to include environmental consideration along the design, construction, maintenance, and operation of the transportation infrastructure. For this purpose, an increasing number of transportation governmental agencies have made alliances with private capitals to fund investment in transportation infrastructure.

Vehicles powered by alternate fuels such as biofuel, electricity, and /or fuel cell are now in the market. However, shifting to more sustainable modes of transportation would also require changes on commuter behaviors and individual preferences that are determined by factors related to modal and demographic characteristics. Therefore, increasing the quality of public transportation may result in a reduction of the vehicle ownership. A number of ancillary strategies, like carsharing and parking restrictions programs, are also necessary in order to discourage the use of private vehicles. This has resulted in the reduction of negative traffic consequences such as severe traffic congestion that increases the CO_2 emissions.

Findings in this literature review have made clear that sustainable transportation systems are in a certain way a new paradigm where a business-as-usual approach is no longer possible. Transportation stakeholders perform diverse strategies and practices in order to decouple transportation and CO_2 emissions. Transportation systems are socio-technical systems characterized by their complexity and ambiguity. Taking decisions can be difficult due to the many trade-offs involved. However, these constrains must be overcome because the success of the transportation system consists on reaching the balance among the environmental, economic, and social dimensions of sustainability. The diverse sustainable transportation strategies discussed here may serve as a guide to transportation stakeholders in their practice, education, and research.

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