MANAGEMENT OF URBAN MOBILITY TO CONTROL CLIMATE CHANGE IN CITIES

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Abstract

The need of decarbonization of urban mobility is one of the main priorities for all countries to achieve greenhouse gas (GHG) emissions reduction targets. In general, the transport modes which have experienced the most growth in recent years tend to be the most polluting. Most efforts have been focused on the vehicle efficiency improvements and vehicle fleet renewal; nevertheless more emphasis should be placed on strategies related to the management of urban mobility and modal share. Research of individual travel which analyzes CO_2 emissions and car and public transport share in daily mobility will enable better assessments of the potential of urban mobility measures introduced to limit GHG emissions produced by transport in cities. This paper explores the climate change impacts of daily mobility in Spain using data from two National Travel Surveys (NTSs) (2000 and 2006) and includes a method by which to estimate the CO_2 emissions associated with each journey and each surveyed individual. The results demonstrate that in the 2000 to 2006 period, there has been an increase in daily mobility which has led to a 17% increase in CO_2 emissions. When separated by transport mode, cars prove to be the main contributor to that increase, followed by public transport. More focus should be directed toward modal shift strategies which not only take the number of journeys into account but also consider distance. The contributions of this paper have potential applications in the assessment of current and future urban transport policies related to low-carbon urban transportation.

INTRODUCTION

Transport is widely recognized to be one of the most significant sources of GHG emissions, in particular CO_2 emissions, which is directly related to the consumption of carbon-based fuel, and the greenhouse effect is regarded as one of the most serious threats to the environment today. In 1997, the Kyoto Protocol highlighted the transport sector as key to achieving its target (*1*). Global CO_2 emissions from transport represented 22.5% of global CO_2 emissions in 2008 in OECD countries and they have increased by 44% from 1990 to 2008 (*2*). Car dependence has been identified as the main reason for this increase in transport emissions. Crucially, many countries are currently experiencing an economic recession which has had an impact on transport activity, most noticeably freight activity (*2*). Consequently, a slight decrease in transport emissions is occurring in a timely manner. More specifically, in the case of Spain, transport emissions have increased 70% between 1990 and 2009, reaching a total of 94.5 million tons of CO_2 (*3*). As motorized modes are favored over other forms of transport, road transportation is the main energy consumption mode in Spain, and consequently the main transportation pollutant source, making up 80% of the total transport energy demand (*4*). Passenger emissions are rising more rapidly than freight transport emissions, caused by an overall increase in daily mobility. These numbers put into perspective the need to set specific emissions targets for passenger mobility and to develop policies aiming at cohesive and concrete emissions reductions in passenger transport (*5*).

Local mobility is important, as 40% of all transport-related CO_2 emissions is produced in cities. The need for decarbonization of urban mobility is a main priority if countries are to achieve GHG emissions reduction targets. Moreover, the car is the main mode: 75% of all kilometers traveled (passenger-km) in European urban areas are produced by car journeys (*6*). Presently, public transport mode share is decreasing almost everywhere and now accounts for only 16% of journeys (*6*). In order to achieve GHG emissions reduction targets, more emphasis must be placed on modal split policies that highlight public transport and non-motorized transport as viable options. For instance Lapillone et al. (*7*) obtained that public transport is four times more energy-efficient than cars. Moreover, where rail infrastructures and bus lanes are available, public transport is able to compete with cars because of its efficiency and the fact that travel times during peak periods tend to favor public transport users. Overall, public transport offers a better level of service, mainly due to its regularity and reduced travel times.

Thus, a shift is required, both in travel behavior as well as in the perception of public transport as unsafe, time-consuming and inconvenient among populations accustomed to traveling by car (*8*). The EU Transport White Paper 2011 (*9*) sets challenging targets for a shift to more sustainable modes in urban transportation in European countries. EU White Paper encourages cities to increase the modal share of non-motorized modes. Modal shift policies are consistently among the best practices in urban areas for reducing the environmental effects of urban transport. Rail modes are seen as an ecological form of transportation (*10*). Buses offer flexibility, can be employed quickly in response to changing demand and do not need specialized infrastructure as in the case of trains (*11*). Walking and cycling are carbonless and environmentally-friendly solutions for individual urban transport (*12*). In Europe, cycling and walking account for approximately 13% of urban passenger-kilometers (*13*). In Spain, motorized modes are favored over other forms of transport and much investment is made in new road infrastructure in dense urban areas. Moreover, Spanish daily commute patterns have indicated that the population is slowly reverting from public transport to carbon-intensive automobile transport (*5*). The difference, however, in the use of public transport in large and small urban areas is significant. In dense cities, travelers are more likely to use public transport; in Madrid, Barcelona and Bizkaia, 20-30% of trips are public transport-based, as compared with smaller urban areas where the share of public transport is 5-11%. It is also important to highlight that in Spain a significant percentage (30-45%) of daily journeys are made on foot (*14*).

The targets of this paper are to investigate if mobility patterns are evolving towards a low-carbon urban transport. For this end the study aims to explore the influence of modal share on climate change impacts by providing an overview of Spanish daily mobility trends from 2000 to 2006. The research focuses on passenger trips and considers daily travel time, distance, and CO_2 emissions. The analysis will enable better assessment of the potential of future urban mobility measures to limit GHG emissions produced by transport in cities. This research has potential applications in the evaluation of current and future urban transport policies to promote better mobility management in cities.

The paper is structured as follows: the next section presents the dataset and the methodology used to estimate CO_2 emissions linked to passenger transport using the Spanish NTS. Then, a general analysis of car and public transport share in daily mobility and the evolution of this indicator over time are provided. The average daily emissions per passenger are presented and car and public transport use are analyzed with a view toward climate change impacts. Lastly, an analysis of modal share will be used to show that measures must be taken at a local level, related to low-carbon urban transport, in order to reach climate change targets.

DATA AND METHODOLOGY TO DETERMINE THE CLIMATE CHANGE IMPACTS OF URBAN MOBILITY

Household travel survey data

Urban transportation management needs to become familiar with urban mobility patterns. At a national level, National Travel Surveys (NTS) have become key tools for analyzing mobility patterns in order to propose policy recommendations. Some studies have been conducted that make use of this resource. Stead (*15*) analyzed transport emissions, their impact and trends in Britain using the 1989/91 NTS to recommend certain transport policies. It was determined that measures to increase occupancy and manage transport capacity were required to attain maximum reductions in vehicle emissions. Nicolas and Damien (*16*) highlighted the relevance of using NTSs to analyze individual trip behavior and to better consider environmental transport policies. French daily mobility remains car-based, and in order to combat the climate change impacts that occur as a consequence, policies that affect car fleet mix and its technology have been suggested (*16*). Recently, travel behavior and transport fuel use in the Netherlands and the United Kingdom were studied (*17*). In recent decades, travel patterns in both countries have more or less remained the same while individual CO_2 emissions per capita have increased. Fewer than half of all journeys in the Netherlands and less than two-thirds of all journeys in the UK are made by car. The results showed that car availability is consistently the most significant predictor of individual CO_2 emissions, and its influence on emissions has only increased over time.

The Spanish household travel survey provides an overall view of mobility in Spain and its main patterns. The Spanish Ministry of Transport and Public Works (MOTPW) developed the Spanish Residents Mobility Survey (*MOVILIA*) in 2000 and 2006 (*18, 19*). The Mobility Survey requests information regarding trip origin and destination, travel mode, departure and arrival time, and trip purpose for one working day and one weekend day. In addition, information about individuals within households is gathered and includes location of residence, gender, age, income, car ownership, occupation, etc. Two daily mobility surveys have been conducted: *MOVILIA* 2000 and *MOVILIA* 2006. Both surveys employed the same trip definition, sampling method and survey mode**.** The 2006 data contains data some 230,000 trips made by over 49,000 people.

TABLE 1 Technical Characteristics of the Spanish NTS (*MOVILIA*) 2000 and 2006

	***MOVILIA* 2000**	***MOVILIA* 2006**
Main bodies involved	Ministry of Transport	Ministry of Transport
Statistical unit	Household	Household
Household members	All HH members (up to four people)	1 individual
Individual excluded from survey	No age limit	No age limit
Trip definition	Movement from origin to destination for a main purpose	Movement from origin to destination for a main purpose
Main mode definition	The main mode is either a stated main mode or determined following a mode	The main mode is either a stated main mode or determined following a mode

	MOVILIA 2000	*MOVILIA* 2006
	hierarchy where public transport (train>metropolitan bus>metro>urban bus)> car passenger> car driver> bicycle> on foot	hierarchy where public transport (train>metropolitan bus>metro>urban bus)> car passenger> car driver> bicycle> on foot
Trips excluded	Walking trips less than 10 min	Walking trips less than 5min
Geographical scope	Autonomous Region	Province
Sampling method	Random sampling stratified by geographic region and household structure	Random sampling stratified by geographic region and household structure
Type of questionnaire	One working day and one weekend day; by memory	One working day and one weekend day; by memory
Choice of the day/period	Randomly predefined day	Randomly predefined day
Survey period	2 months	1 month
Survey mode	Daily mobility and HH characteristics: face to face survey	Daily mobility and HH characteristics: face to face survey
Contact before survey	Official letter before survey	Official letter before survey
Computer aid-interview	Daily mobility: CAPI	Daily mobility: No
Number of reminders	130,000 reminders.	-
Response rate	70%	55%

There are some differences between the two surveys. In 2000, the geographic scope only allows for data to be separated at a regional level, while the second survey is broken down by province. As for individuals surveyed, in 2006 only one individual per household was surveyed as compared to 2000 when up to four members of each household were surveyed. This change was introduced because, despite the increased number of individuals in the sample, the number of trips was not clearly defined in 2000. Finally, walking trips of less than 10 minutes were excluded in 2000, while only walking trips of less than 5 minutes were excluded in 2006.

Estimating CO_2 emissions for urban trips

The carbon dioxide emissions per passenger and trip are calculated by multiplying the trip distance by the emissions factor for each aggregated transport mode (*15, 16, 17, 20*), as follows:

$$CO_2\ emissions\ per\ passenger\ (gCO_2/(passenger\text{-}trip)) = EF_i\ (gCO_2/(passenger\text{-}km)) \times Dt\ (km) \quad (1)$$

Where, *EF* is the average emission factors of the transport mode *i* (aggregation of all emission factors of vehicle types considered in the mode of transport *i*) and *Dt* is the trip distance. The first step is the estimation of CO_2 emissions factor for each mode of transport considered in the survey.

The *MOVILIA* survey data serves as a source of information with which to estimate the CO_2 emissions per passenger trip, by applying the emission factors of each transport mode. Each trip recorded by the survey (from the available information) contains characteristics about the individual, travel time, transport mode, and more. The main indicators which could be obtained from *MOVILIA* are: number of trips and total travel time per passenger per day which are broken down by: day of the week (working or weekend day), transport mode, purpose, and age class. One of the issues with the *MOVILIA* data is the lack of information about trip distance and transport modes are aggregated in groups according to: (a) walking and cycling (or soft modes), (b) car and motorcycle, (c) urban bus and metro, (d) interurban bus, (e) train and (f) other (taxis, collective company transport, etc.). In Figure 1 the proposed methodology for estimating the CO_2 emissions per passenger trip has been charted.

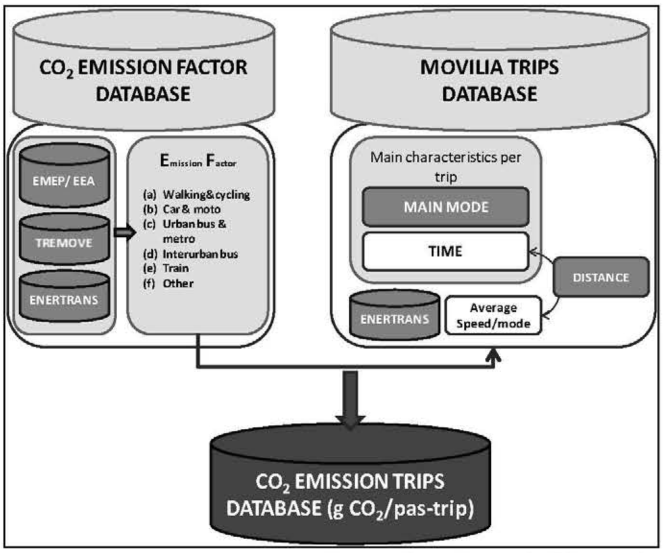

FIGURE 1 Methodology for estimation of CO_2 emissions per passenger-trip in *MOVILIA* survey.

For cars and motorcycles, the vehicle emission factors from *EMEP/EEA* – the European emissions guidebook used to estimate the emission factor and relevant activity data in order to calculate the exhaust emissions for different vehicles types (*21*) – are applied. Each vehicle type has its own equation based on its age, fuel type and operating speed. According to *Enertrans* results for Spain (*22*), the average speed of 40km/h and 35km/h for cars and motorcycles respectively has been used. The average emission factor per passenger for cars and motorcycles for each year (2000 and 2006) was estimated by introducing the occupancy rate and activity demand by vehicle type from the *TREMOVE* database (*23*). For urban and interurban buses, the same approach based on *EMEP/EEA* methodology is applied, taking into account the urban driving mode for urban buses. In the case of rail-based modes, the emissions factors were obtained using previous studies which estimate the emissions factor data for rail modes in Spain (*24*). As different transport modes are aggregated in the survey, i.e. urban bus/metro, in these cases an aggregation factor for each mode of transport is applied based on their demand (passenger per kilometer by each mode of transport from *TREMOVE* database). Finally, the Other category (f) in the survey is defined as the aggregation of various other modes of transport, such as taxis, collective company transport, etc. The emissions factor in this case is calculated based on an aggregation of the average emissions factor of the different modes of transport.

The second step is focused on the indirect calculation of trip distance. The project *Enertrans* (*22*) provides real average speed data for the different transport modes in Spain. These data, together with trip time from *MOVILIA* (*18, 19*) are used to calculate the trip distance. Finally, by using Equation 1, the carbon dioxide emissions per passenger and trip are calculated.

Figure 2 shows the average CO_2 emissions obtained in passenger-kilometer for each mode. Private cars and motorcycles represent the highest producer of CO_2 emissions. The evolution of vehicle fleet composition toward more efficient vehicles accounts for the slight decrease in average emissions when comparing 2000 to 2006.

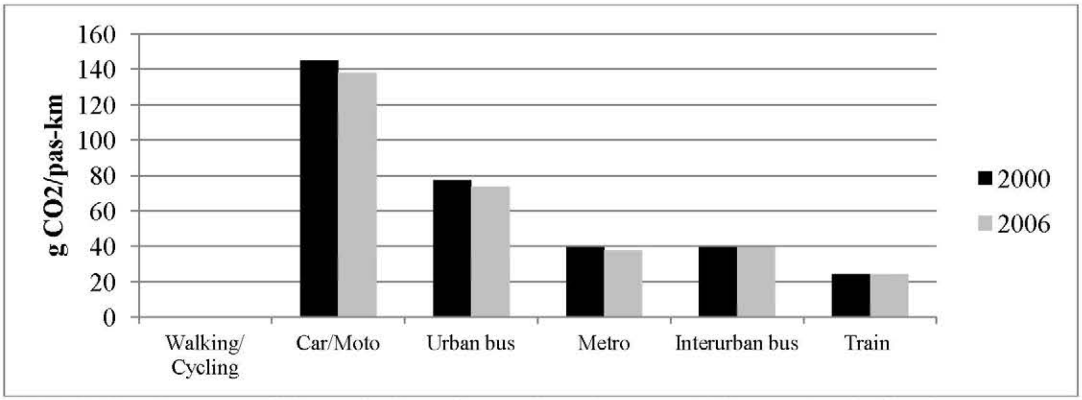

FIGURE 2 Average CO_2 emissions for main urban mobility modes in Spain.

TRENDS IN SPANISH PASSENGER URBAN MOBILITY: ANALYSIS OF CARS AND PUBLIC TRANSPORT USE 2000-2006

Before applying the methodology, this section will present an analysis of the mobility patterns by focusing on transport mode. The environmental impact of transport is strongly determined by overall transport activity and modal split. A comparison of the 2000 and 2006 *MOVILIA* surveys is discussed and will provide information to aid in understanding the results of the following section.

One of the important variables that influence the modal split is household car availability (*17*). In 2006, 31.6% of Spanish households had more than one vehicle with which to make journeys, while in 2000 this figure was only 27.6% – a difference of four points (see Figure 3). This shift has likely contributed to the increase in journeys by car and consequently to the rise in CO_2 emissions in urban mobility in Spain.

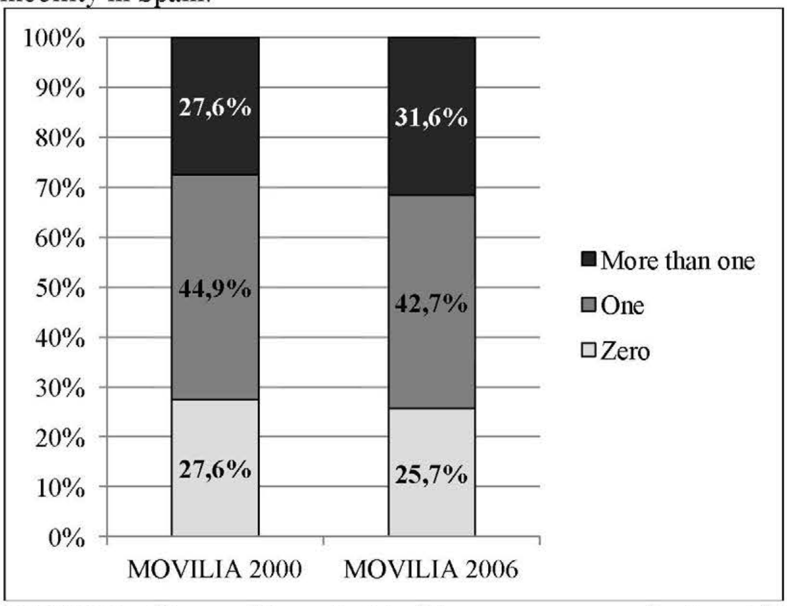

FIGURE 3 Share of household with one or more private vehicle.

The average number of trips per passenger per day on a working day is higher in 2006 – 3.3 trips/day – as compared with 2.9 trips/day in 2000 (see Table 2). With regard to travel time, considering only people traveling on working days, there is a slight increase in the average travel time from 71 minutes in 2000 to 73 minutes in 2006.

TABLE 2 Main Results per Individual on Working and Weekend Days

	MOVILIA 2000	MOVILIA 2006
SAMPLE SIZE Household	23,635	49,027
SAMPLE SIZE Individuals	62,473	49,027
WORKING DAY		
% INDIVIDUAL WHO TRAVEL	65.5%	83.5%
No. TRIPS (average of individual who travel)	2.9	3.3
AVERAGE TRAVEL TIME	71min	73 min
WEEKEND DAY		
% INDIVIDUAL WHO TRAVEL	51.1%	72.0%
No. TRIPS (average of individual who travel)	2.5	2.9
AVERAGE TRAVEL TIME	76 min	80 min
USE OF MECHANICAL MODES		
CAR/MOTO	79.4%	81.3%
PUBLIC TRANSPORT	20.6%	18.7%

Finally, as was expected, the car is the main motorized mode used by Spanish travelers in their daily mobility. Moreover, in 2006 the use of the car is higher than in 2000, to the detriment of public transport use. It is worth to have in mind that the share of walking trips in Spanish cities is rather high, accounting more than 40% of the trips while public transport patronage is about 10%. These figures influence the transfer potential of trips among transport modes. In addition, a recent study in Spain that measured mobility patterns in areas with investment in new public transport infrastructure points out that in many such cases a positive effect on the modal shift from the private- to public-based modes has been observed (*25*).

In conclusion, from 2000 to 2006, Spanish daily mobility is increasing and moving toward a more car-dependent lifestyle. People make more and longer journeys and the use of public transport is clearly decreasing. This issue makes it clear that more research into the climate change impacts of daily mobility and more strategies focused on managing daily mobility will be needed to achieve sustainable mobility targets in cities.

TRENDS IN MODAL SPLIT AND CLIMATE CHANGE IMPACTS IN SPANISH URBAN MOBILITY

The level of CO_2 emissions per individual journey is dependent on transport mode and on the distances traveled in each mode or the total trip time. According to the calculation of individual CO_2 emissions based on the Spanish NTS data for 2000 and 2006, private vehicles (cars or motorcycles) represent the highest contributor of CO_2 emissions in Spain in both years. Figure 4 displays the share of private vehicles and public transport in the number of trips, travel time and CO_2 emissions for 2000 and 2006.

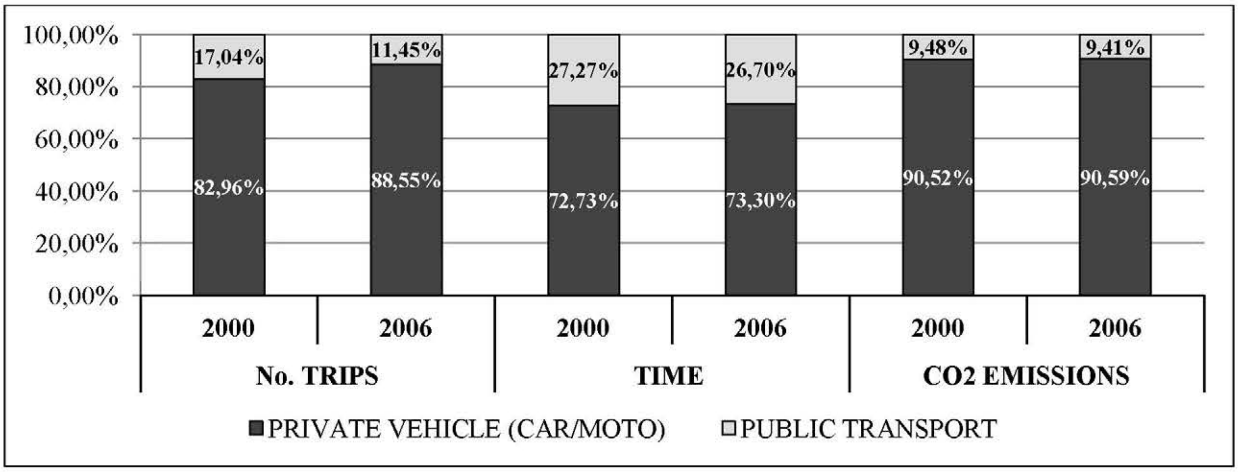

FIGURE 4 Share by private vehicle and public transport in the number of trips, time and CO_2 emissions: 2000 and 2006.

A comparison of the data for private vehicles and public transport provided the following results. The slight increase in the number of trips made by private vehicle has produced a decrease in public transport use (about 6 points) from 2000 to 2006. On the other hand, the time spent traveling each day in private vehicles and public transport remains constant in that period of time. This indicates that unless the number of trips by public transport has decreased, the time spent on each trip has increased and consequently the CO_2 emissions impact has not been significantly reduced. There has been a rise in the number of trips made by private vehicles and a slight increase in spent time traveling; thus, the travel time per journey made by private vehicle in 2006 is shorter than in 2000. Nevertheless, the increase in the number of private vehicle trips signifies an overall increase in CO_2 emissions in that period of time.

Soft modes have not been included in this analysis because of the differences between the two Spanish NTSs. In 2000, walking trips of less than 10 minutes were excluded, while only those of less than 5 minutes were excluded in 2006. However, it should be mentioned that the number of trips by soft modes represents an important share in Spanish urban mobility, around 40% of trips made by all transport modes.

Table 3 includes the results of the application of the proposed methodology and the comparison of the evolution from 2000 to 2006 (calculated as the percentage increase with respect to 2000). The comparison of soft modes has not been made because of the different definitions of soft modes journeys used in the two surveys. In the final section of the table, an impact assessment of each of the indicators is included. The (+) means that there was a slight increase in 2006 with respect 2000 levels and the (++) signifies a moderate increase. On the other hand, the (-) signifies a lightweight decrease and the (--) means that there was a measured decrease. The results were obtained for an average day (taking into account working and weekend days).

TABLE 3 Trends in Modal Split and CO_2 Emissions per Traveler on an Average Day

Traveler - average day		SOFT MODES	CAR/MOTO	PUBLIC TRANSPORT	OTHER	TOTAL
No. TRIPS	2000	0.83	1.09	0.22	0.08	**2.22**
	2006	1.44	1.19	0.15	0.06	**2.84**
	Δ%		9.2%	-31.8%	-25.0%	
TIME (min)	2000	15.30	19.59	7.34	1.91	**44.14**
	2006	24.84	24.51	8.93	1.89	**60.16**

Traveler - average day		SOFT MODES	CAR/MOTO	PUBLIC TRANSPORT	OTHER	TOTAL
	Δ%		25.1%	21.7%	-1.0%	
CO_2 EMISSIONS (g CO_2)/ day?	2000	0.00	1,797.45	188.32	180.42	**2,166**
	2006	0.00	2,142.75	222.52	170.95	**2,536**
	Δ%		19.2%	18.2%	-5.2%	**17.1%**
IMPACT ASSESSMENT	TRIPS		(+)	(--)	(--)	
	TIME		(++)	(+)	(-)	
	CO_2 EMISSIONS		(+)	(+)	(-)	(+)

Generally, the increase in Spanish daily travel has led to an increase in GHG emissions in cities: there is a noticeable rise of the total CO_2 emissions of 17.08%. The results show that unless there has been a decrease in the total number of daily journeys, public transport journeys have gotten longer, which negatively impacts CO_2 emissions. Private vehicle share in daily mobility has increased by 9.2% in number of trips and by 25.1% in travel time with respect to 2000 levels. The main consequence is that private vehicles are the main contributor to the growth of total CO_2 emissions associated with daily mobility in Spain. Soft modes have attracted a high rate of trips over the same period; nevertheless, this has not been enough to stop the increase in CO_2 emissions.

In conclusion, there is a need to improve the public transport share by making it more competitive with respect to private vehicles in cities. For example in the case of Madrid, Monzón et al. (*26*) found that although Madrid has a good supply of public transport, car is still an attractive option in urban areas and the time spent. Improved management of public transport infrastructure is key to reducing the use of private vehicles and consequently the climate change impacts in cities.

CONCLUSIONS AND URBAN SUSTAINABILITY POLICIES

In Spain, emissions per passenger are rising rapidly due to an increase in daily mobility. More efforts must be made to prevent the climate change impacts associated with this rise. This paper has analyzed modal split trends and their relationship to climate change impacts. In order to assess the global contribution of daily mobility to climate change, a relevant evaluation based on NTSs has been applied to the case of Spanish daily mobility in 2000 and 2006. The changes of that period in car versus transit use have been analyzed. The findings could be useful for transport planners to make an effective design of policies to change mobility trends for meeting CO_2 emissions reduction targets.

The Spanish NTS data served as a source of information with which to estimate the CO_2 emissions per passenger trip, by applying the emissions factors of each transport mode. The carbon dioxide emissions per passenger and trip are calculated by multiplying the trip distance by the emissions factor for each aggregated transport mode. The evolution of vehicle fleet composition toward more efficient vehicles accounts for the slight decrease in passenger–km emissions in 2006 as compared to 2000; even so, current efforts toward improvements in vehicle technology and fuel efficiency are not enough to achieve the emissions reduction targets in cities.

The results of this analysis reveal that from 2000 to 2006 there has been an increase in daily mobility which has produced a 17% increase in CO_2 emissions and car use is the main cause of that increase. More focus must be directed toward public transport, which is key to moving towards a decarbonization of urban mobility. Nevertheless, this strategy is somewhat limited; some studies of the city of Madrid, Spain have suggested that only 18% of trips currently made by car could be made by other modes, respecting trip time conditions, and without affecting their characteristics (*27*). In addition, it has been shown that distance is an important issue to be taken into account (*15*). However, sustainable mobility in cities begins with better integration of policies which aim to coordinate environmental, economical and social considerations. Based on this study, it can be concluded that modal shift in cities may form part of the process of stabilizing the carbon footprint of urban mobility. Furthermore, this study suggests that low-carbon and energy efficiency strategies should focus not only in long distance trips, but also in urban movements, which account for 40% of emissions and are increasing along the years.

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