Preventive Medicine 57 (2013) 573–579

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach

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ARTICLE INFO

Available online 9 August 2013

Keywords:
Physical activity
Air pollution
Traffic injuries
Public transport
Bicycling
Health impact assessment

ABSTRACT

Objective. Quantify the health impacts on morbidity of reduced car trips and increased public transport and cycling trips.

Methods. A health impact assessment study of morbidity outcomes related to replacing car trips in Barcelona metropolitan (3,231,458 inhabitants). Through 8 different transport scenarios, the number of cases of disease or injuries related to physical activity, particulate matter air pollution <2.5 μm ($PM_{2.5}$) and traffic incidents in travelers was estimated. We also estimate $PM_{2.5}$ exposure and cases of disease in the general population.

Results. A 40% reduction in long-duration car trips substituted by public transport and cycling trips resulted in annual reductions of 127 cases of diabetes, 44 of cardiovascular diseases, 30 of dementia, 16 minor injuries, 0.14 major injuries, 11 of breast cancer and 3 of colon-cancer, amounting to a total reduction of 302 Disability Adjusted Life Years per year in travelers. The reduction in $PM_{2.5}$ exposure in the general population resulted in annual reductions of 7 cases of low birth weight, 6 of preterm birth, 1 of cardiovascular disease and 1 of lower respiratory tract infection.

Conclusions. Transport policies to reduce car trips could produce important health benefits in terms of reduced morbidity, particularly for those who take up active transportation.

Introduction

Transportation is a key sector for the economy and social development. But transportation is also a major source of air pollutant emissions, representing for example 23% of greenhouse gas emissions globally (OECD, 2010b). Furthermore car use promotes physical inactivity and sedentary lifestyle which are associated with obesity, cardiovascular disease, diabetes, cancer, and other diseases. Both physical inactivity and air pollution have been classified as two of the 10 leading risk factors of burden of disease worldwide in 2010 (Douglas et al., 2011; Lim et al., 2013). Multiple international agencies have called for the implementation of public policies to increase the use of active transportation (walking and cycling) and public transport to reduce the car dependency in urban areas, to reduce greenhouse gas emissions, mitigate climate change and encourage physical activity (UNEP, 2010; WHO Europe, 2000).

Various studies estimating impacts of transport interventions or policies on health have been published recently. Some quantified the impact of implementing transport interventions on all cause mortality, such as public bicycle system in Barcelona (Rojas-Rueda et al., 2011). Others quantified the possible impacts on morbidity and mortality of future transport interventions, such as increasing the number of walking or cycling trips in different urban areas around the world (De Hartog et al., 2010; Grabow et al., 2011; Holm et al., 2012; Lindsay et al., 2011; Olabarria et al., 2012; Rabl and de Nazelle, 2012; Woodcock et al., 2009, 2013).

The present study aims to quantify the morbidity impacts of transport policies through a health impact assessment (HIA) approach, selecting the best available evidence based on a review of the literature. It takes into account different types of trips (short and long duration),

Abbreviations: BAU, Business as usual; DALYs, Disability Adjusted Life Years; HEI, Health Effects Institute; HIA, Health Impact Assessment; MeSH, Medical Subject Headings; METs, Metabolic Equivalent of Task; NO2, Nitrogen Dioxide; NOx, nitrogen oxides; OECD, Organization for Economic Co-operation and Development; OR, Odds ratio; PM_{10}, Particulate matter less than 10 μm; $PM_{2.5}$, Fine particles (less than 2.5 μm); RR, Relative Risk; UFP, Ultra-fine Particles; WHO, World Health Organization; YLD, Years Lived with Disability; YLL, Years of Life Lost.

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http://dx.doi.org/10.1016/j.ypmed.2013.07.021

different modes of transport (bicycle, bus, tram, metro and train), different exposure populations (travelers and the general population) and different types of exposures (air pollution, physical activity and traffic incidents).

Methods

Scenarios

The HIA (Joffe and Mindell, 2002) was based on eight different scenarios of car trip replacement by public transport and bicycle trips used in a previous study conducted in the metropolitan area of Barcelona (Rojas-Rueda et al., 2012) (see Table 1).

Two populations were included in the analysis: 1) "Travelers", defined as those who performed a modal shift due to the intervention (new cyclist or new public transport user). In our assessment, the travelers were exposed to the three health determinants included in the model (air pollution, physical activity and traffic incidents). And 2) the "General population", defined as those who live in Barcelona city (all age groups). In our assessment the general population was exposed to changes in air pollution concentrations related to traffic reduction associated with the transport policy intervention (the 8 scenarios) in comparison with the concentrations of air pollution in the business as usual (BAU) scenario.

Transport data

The information needed on travel mode share and trip distances by mode of transport (car, bike, and public transport) was obtained from surveys and records conducted by the city and Metropolitan area of Barcelona (DSM, 2010). We estimated the average car trip length of "inside" (3.1 km) and "outside" (6.4 km) Barcelona and developed different scenarios of mode shifts to alternative modes (Table 1).

Morbidity outcomes

To select the health outcomes we identified the dose–response functions published in the scientific literature that associate health determinants (air pollution and physical activity) with morbidity outcomes (Fig. 1). The selection of dose–response functions was based on proposals derived from a series of expert meetings held in Barcelona between 2010 and 2012, a systematic review of the scientific literature, and expert judgment. For traffic incidents, another approach was used, focusing on the data available for traffic incidents in Barcelona city. In this case we used the injury records for 2002–2009 for each mode of transport, which reported minor and major injuries within the city (ASPB, 2011).

Physical activity

To assess the physical activity in travelers it was assumed that for each public transport trip the traveler walked for 10 min and for cycling trips, trip duration depended on the distance traveled in each scenario (inside 3.1 km and outside 6.4 km). The relative risks (RR) obtained for physical activity and each morbidity outcome were used to estimate the number of cases of disease expected in each scenario (see Table 2).

Air pollution

Particulate matter less than 2.5 μm ($PM_{2.5}$) was selected as the main air pollutant in this model because it has shown strong associations with health outcomes (Lim et al., 2013; HEI, 2010). For travelers, we estimated and compared the exposure concentration and inhaled dose for travel by car, bicycle, walking, bus/tram and metro/train. Concentration levels for car, bike, walk and bus were obtained from a measurement study conducted in Barcelona (de Nazelle et al., 2011). For air pollution exposure in the general population we used the Barcelona Air-Dispersion Model (Lao and Teixido, 2011) to estimate the reduction in the concentrations in $PM_{2.5}$ in Barcelona city for each scenario.

Traffic incidents

Traffic injuries in Barcelona were estimated based on the injury records from 2002 to 2009 reported by the Barcelona Public Health Agency (ASPB, 2011). For each mode of transport, the risk of suffering a minor or major injury per billion of kilometers traveled was estimated using the average number of injuries (minor or major) per year and the kilometers traveled per year in each mode of transport. The kilometers traveled per year were calculated based on the number of trips per mode of transport and the average trip duration reported by the Barcelona Transport Department (DSM, 2010; RMB, 2006) (Tables 3 and 4).

Morbidity rates

We estimated population-attributable number of cases for each scenario based on dose–response function and morbidity rates for each disease (Perez and Kunzli, 2009; WHO, 2008). The relevant morbidity rates for the different diseases were obtained from different epidemiological studies and public records published for the local population (Bermejo-Pareja et al., 2008; Chacon et al., 2010; INE, 2006, 2010; Lopez-Abente et al., 2010; Martinez-Salio et al., 2010; Mata-Cases et al., 2006; Medrano et al., 2006; OECD, 2010a; Pollan et al., 2010). Each morbidity rate was obtained for age and sex specific groups (see Table 5).

Burden of disease

A Disability Adjusted Life Years (DALYs) approach was used to synthesize and compare the health impacts of different morbidity outcomes of the three main exposures (air pollution, physical activity and traffic injuries) and the two populations (travelers and general population) in each scenario, following the WHO approach (WHO, 2004).

Results

Physical activity impacts in travelers

In all scenarios there was a reduction in the number of cases with disease per year related to physical activity exposure in travelers (see Table 6). For cardiovascular disease the maximum change of cases per year was −44.33, for diabetes mellitus type 2 −127.90, for breast cancer in women −11.35, for colon cancer −3.66 and for dementia −30.54, all in scenario 8. The DALYs per year estimated change ranged from −103.33 (scenario 3) to −259.16 (scenarios 8) (see Table 7).

Table 1
Scenarios description, number of car trips replaced and percentages.

	Inside Barcelona scenarios[a]				Outside Barcelona scenarios[b]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Car trips reduction	20%	40%	20%[c]	40%[c]	20%[d]	40%[d]	20%[e]	40%[e]
Trips/day replaced by Bike (%)	94,460 (100)	188,920 (100)	47,230 (50)	94,460 (50)	0	0	34,065 (20)	68,130 (20)
Trips/day replaced by public transport (%)[f]	0	0	47,230 (50)	94,460 (50)	170,324 (100)	340,648 (100)	136,259 (80)	272,518 (80)

[a] Inside Barcelona scenarios refers to the trips that start and end in Barcelona city.
[b] Outside Barcelona scenarios refers to the trips that start or end in Barcelona city and start or end in Barcelona metropolitan area.
[c] Here we assumed that the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train.
[d] Here we assumed that the 26% of the trips is replaced by bus/tram and 74% are by metro/train.
[e] Here we assumed that the 20% of the trips is replaced by bike, the 21% by bus/tram and 59% are by metro/train.
[f] Public transport includes: bus, tram, train and metro.

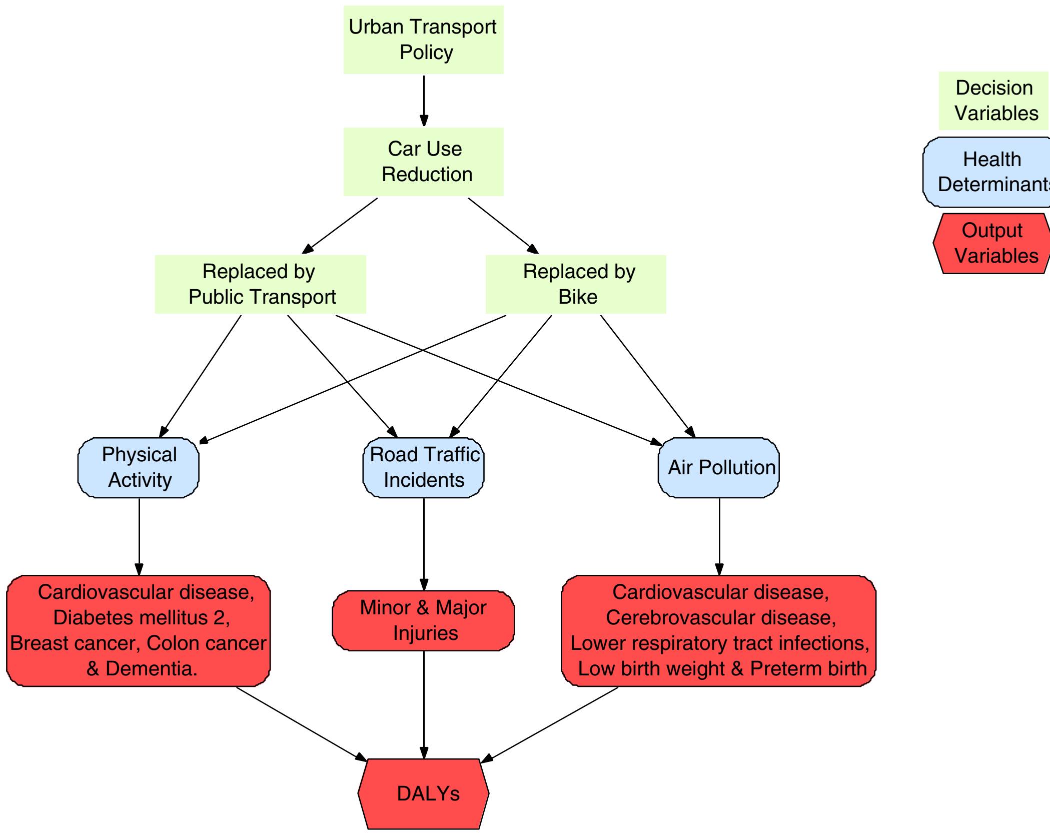

Fig. 1. Health impact assessment model of transport policies and morbidity. DALYs: Disability Adjusted Life Years.

Air pollution impacts in travelers

In all scenarios there was an increase in the number of cases of disease per year related to $PM_{2.5}$ exposure in travelers (see Table 6). In cerebrovascular disease the maximum increment of cases per year was 0.03, for lower respiratory tract infections 0.31, for preterm birth 1.55, for low birth weight 0.36, and for cardiovascular disease 0.35, all in scenario 8. The DALYs estimates for scenarios 1 to 8 ranged from 0.4 DALYs per year (scenario 5) to 2.01 DALYs per year (scenario 8) (see Table 7).

Traffic injuries impacts in travelers

In the traffic injuries a reduction in cases of minor was estimated. The maximum reduction of minor injuries per year was −16.60 (scenario 8) (see Table 6). For major injuries we estimated a reduction in cases, except for scenarios 1 and 2, where we found an increase of the number of major injuries (0.007 and 0.014, respectively). For DALYs estimated change, increases in DALYs per year for scenarios 1 (2.53) and 2 (5.37) were estimated, and reductions in DALYs per year for scenarios 3 to 8 were estimated ranging from −0.32 (scenario 3) to −61.61 (scenario 6) (see Table 7).

Air pollution impacts in the general population

For Barcelona scenarios (scenarios 1 to 8) the maximum estimated change in the number of cases per year of cerebrovascular disease was −0.50, for lower respiratory tract infections −1.09, for preterm birth −6.62, for low birth weight −7.40 and for cardiovascular disease −1.24, all in the scenarios with 40% of car trips reduction (scenarios 6 and 8) (see Table 6). The estimated reduction in

Table 2
Dose–response functions and 95% confidence intervals derived for the systematic review.

Health determinant	Outcome	Dose–response model and 95% confidence interval	Unit	Reference
Physical activity				
	Cardiovascular diseases	0.84 (0.79–0.9)	3 h per week at 3 km/h: 7.5 METs	Hamer and Chida (2008)
	Dementia	0.72 (0.6–0.86)	33 METs per week (>1657 kcal per week)	Hamer and Chida (2009)
	Type 2 diabetes incidence	0.83 (0.75–0.91)	Per 10 METs per week	Jeon et al. (2007)
	Breast cancer women	0.94 (0.92–0.97)	For each additional hour per week	Monninkhof et al. (2007)
	Colon cancer men	0.8 (0.67–0.96)	Per 30,1 METs per week	Harriss et al. (2009)
	Colon cancer women	0.86 (0.76–0.98)	Per 30,9 METs per week	Harriss et al. (2009)
Air pollution ($PM_{2.5}$)				
	Cerebrovascular disease	1.0081 (1.003–1.0132)	10 μg/m^3	Dominici et al. (2006)
	Lower respiratory tract infections	1.0092 (1.0041–1.0143)	10 μg/m^3	Dominici et al. (2006)
	Preterm birth	1.15 (1.14–1.16)	10 μg/m^3	Sapkota et al. (2010)
	Low birth weight	1.1 (1.03–1.18)	10 μg/m^3	Dadvand et al. (2013)
	Cardiovascular diseases	1.025 (1.015–1.036)	10 μg/m^3	Mustafic (2012)

METs: Metabolic Equivalent of Task; $PM_{2.5}$: Particulate matter less than 2.5 μm.

Table 3
Injuries per billion of km traveled, by mode in Barcelona.

	Injuries/billion of km traveled
Minor injury	
Bike	1469
Bus	339
Walk	783
Car	2489
Major injury	
Bike	51
Bus	4
Walk	69
Car	26

Km: kilometers.

DALYs for Barcelona scenarios ranged from −0.19 (scenarios 1 and 3) to −0.75 (scenarios 6 and 8) (see Table 7).

Discussion

Our results show that in the Barcelona metropolitan area, a region of 3.2 million inhabitants, a 40% reduction of short and long car trips could prevent a large number of cases of disease (60–248) each year in travelers and general population. The estimated reduction in disease was much larger in those changing modes compared to the general population (travelers:general population ratio 1:3). The greatest benefit came from the increase in physical activity, and the largest reduction in number of cases was estimated for cardiovascular disease and type 2 diabetes.

These results follow the same trends shown in previous studies, suggesting that increasing active transport and reducing car trips can bring health benefits in terms of morbidity (Grabow et al., 2011; Holm et al., 2012; Woodcock et al., 2013). Compared to previous publications our study adds new health outcomes (e.g. preterm birth, low birth weight) to the assessment of impacts of transport interventions. Furthermore this study accounted for different trip distances (short and long trips), different populations (travelers and general population), different modes of transport (bike, metro, train, tram and bus), different exposures (air pollution, physical activity and traffic injuries) and different health outcomes for each exposure.

When comparing the DALYs between different exposures and both populations (travelers and the general population), it is obvious that physical activity is the main predictor variable of the model (see Fig. 2). When comparing DALYs in different scenarios, the scenarios with more health benefits were the scenarios with a higher number of bike trips (such as scenario 2 and scenario 8), which were the scenarios with higher levels of physical activity. For traffic incidents, when comparing different scenarios, the scenarios with a higher reduction of DALYs associated with traffic incidents are the scenarios with a higher rate of substitution of car trips by public transport (scenarios 5 to 8). When comparing the DALYs associated with air pollution in travelers and in the general population, the increase in DALYs in travelers is higher than the reduction in DALYs estimated in the general population, resulting in an increase in the overall DALYs estimate for air pollution in all scenarios; however, this increase in DALYs by air pollution is always smaller than the DALYs reductions resulting from physical activity in all scenarios.

Comparing the mortality impacts from our previous study (Rojas-Rueda et al., 2012) with morbidity impacts in this current study, we see the same trends across the scenarios between all-cause mortality and each analyzed disease (see Appendix). Appendix-Figs. 12 to 15 shows the different scenarios sorted in ascending order according to the number of deaths avoided (dotted line). They show trends for all-cause mortality (Rojas-Rueda et al., 2012) and morbidity outcomes, which are mostly consistent for the different scenarios, the three health determinants and in the two populations.

This study has limitations similar to all risk assessment studies due to the lack of availability of data requiring assumptions to be made to model the different scenarios. For this reason, sensitivity analyses were performed to assess the robustness of our results and to test the effects of deviations from the main assumptions and data choices, and in all the sensitivity analyses we consistently found net health benefits for all of our car replacement scenarios (see Appendix).

Another limitation could be the absence of the effect of safety in numbers in our model (Jacobsen, 2003). Although some authors suggest that this effect may not be due simply to the number of cyclists but also to the change in traffic management when increasing the number of cyclists (Bhatia and Wier, 2011).

Some studies also suggested a correlation between active transport and reduction of body weight in adults (Gordon-Larsen et al., 2005; Pucher et al., 2010), but a recently published systematic review, has been unable to define a quantitative summary measure, given the large heterogeneity between studies (Wanner et al., 2012), therefore the impact on body weight was not included in our model.

One strength of this study was the selection of different health outcomes for physical activity and air pollution (see Fig. 1), based on a systematic review and consultation with experts, prioritizing dose–response functions published in high quality studies with high methodologically robustness.

Another strength of the study was the use of local measurements of $PM_{2.5}$ concentration in the different microenvironments (bike, walk, car and bus) in the city of Barcelona (de Nazelle et al., 2011). In addition, for estimating the impacts of air pollution in the general population, we ran an Air-Dispersion model (Lao and Teixido, 2011) which took into account different parameters (weather, different emission sources, type of motor vehicle and street canyon effect) (see Appendix-Figs. 10 and 11 and Appendix-Table-4).

In this study we found the need for studies which report dose–response functions for air pollution and physical activity and health outcomes. We also found a lack of information related to traffic incidents, especially the under-reporting of rates in our population and the description of accidents diagnosis. Furthermore there is a need for future studies comparing cities, showing the possible variability in potential health impacts for similar interventions or transport policies in different populations.

In terms of public policy implications, our study shows that there is a need to redirect transport policies and public investment, to encourage

Table 4
Relative risk for traffic injuries, between cars and other modes of transport.

	Inside Barcelona Scenarios				Outside Barcelona Scenarios			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Minor injuries								
Car to bike	0.9993	0.9993	0.9982	0.9982	NA	NA	0.9944	0.9944
Car to PT	NA	NA	0.9979	0.9979	0.9944	0.9944	0.9948	0.9948
Major injuries								
Car to bike	1.0005	1.0005	0.9998	0.9998	NA	NA	0.9987	0.9987
Car to PT	NA	NA	0.9996	0.9996	0.9987	0.9987	0.9988	0.9988

NA: not applicable.

Table 5
Morbidity rates.

Disease	Cases/100,000	Population	Age	Year	Reference
Cerebrovascular disease (women)	370	Spain	>65 years	2010	Martínes-Salio et al. (2010)
Cerebrovascular disease (men)	690	Spain	>65 years	2010	Martínes-Salio et al. (2010)
Lower respiratory tract infection (women)	229	Spain	20–79	2007	Chacon et al. (2010)
Lower respiratory tract infection (men)	316	Spain	20–79	2007	Chacon et al. (2010)
Cardiovascular disease (women)	56	Barcelona	25–74	2005	Medrano et al. (2006)
Cardiovascular disease (men)	209	Barcelona	25–74	2005	Medrano et al. (2006)
Diabetes mellitus 2 (women)	381	Barcelona	>14 years	2000	Mata-Cases et al. (2006)
Diabetes mellitus 2 (men)	376	Barcelona	>14 years	2000	Mata-Cases et al. (2006)
Breast cancer (women)	83	Spain	>25 years	2004	Pollan et al. (2010)
Colon cancer (women)	33	Spain	Age adjusted	2004	Lopes-Abente et al. (2010)
Colon cancer (men)	60	Spain	Age adjusted	2004	Lopes-Abente et al. (2010)
Dementia (women)	1110	Spain	>65 years	2008	Bermejo-Pareja et al. (2008)
Dementia (men)	960	Spain	>65 years	2008	Bermejo-Pareja et al. (2008)
Preterm birth	6800	Spain	15–49	2006	INE, 2006
Low birth weight	7600	Spain	15–49	2008	OECD, 2010a
Woman fecundity	6800	Spain	15–49	2010	INE, 2010

INE: National Institute of Statistics of Spain; OCDE: Organization for Economic Co-operation and Development.

public transport, pedestrians and cyclists over cars. It also emphasizes the need for joint work between health practitioners, transport specialists and urban planners.

Conclusions

This study shows that transport policies directed to reduce car use and increase public transport and cycling trips have health benefits in terms of diseases. These health benefits result principally from the effects of the increase in physical activity in travelers, secondly from the reduction in traffic injuries (when car trips were substituted by public transport) and finally from the reduction in the exposure to air pollution in the general population. These findings also show that an estimation of all-cause mortality can be a reasonable indicator for the disease impacts in health impact assessment models of transportation.

Contributors

AdeN and MJN conceived and designed the study. DR-R and AdeN collected the data. DR-R, AdeN and MJN analyzed and interpreted the data and wrote the manuscript. DR-R, AdeN, and MJN edited and approved the final version for submission. AdeN and MJN are guarantors.

Table 6
Morbidity results (cases/year) for each scenario, in travelers and general population.

	Inside Barcelona scenarios[a]				Outside Barcelona scenarios[b]			
	Scenario 1	Scenario 2	Scenario 3[c]	Scenario 4[c]	Scenario 5[d]	Scenario 6[d]	Scenario 7[e]	Scenario 8[e]
Travelers								
Physical activity (cases/year)								
Cardiovascular disease	−15.17	−30.33	−10.92	−21.84	−12.04	−24.08	−22.17	−44.33
Diabetes mellitus 2	−44.59	−89.19	−32.35	−64.71	−36.26	−72.53	−63.95	−127.9
Breast cancer	−3.95	−7.91	−2.87	−5.74	−3.21	−6.43	−5.67	−11.35
Colon cancer	−1.32	−2.63	−0.97	−1.94	−1.13	−2.26	−1.83	−3.66
Dementia	−10.92	−21.84	−8.03	−16.06	−9.27	−18.55	−15.27	−30.54
Air pollution ($PM_{2.5}$) (cases/year)								
Cerebrovascular disease	0.04	0.08	0.02	0.04	0.01	0.02	0.01	0.03
Lower respiratory tract infection	0.16	0.31	0.09	0.18	0.04	0.08	0.15	0.31
Preterm birth	0.95	1.9	0.55	1.1	0.28	0.56	0.94	1.55
Low birth weight	0.22	0.43	0.13	0.27	0.02	0.05	0.19	0.36
Cardiovascular disease	0.13	0.26	0.07	0.15	0.05	0.1	0.18	0.35
Traffic injuries (cases/year)								
Minor injuries	−0.299	−0.598	−1.676	−3.353	−4.346	−8.691	−8.327	−16.653
Major injuries	0.007	0.014	−0.01	−0.02	−0.036	−0.071	−0.072	−0.144
General population								
Air pollution ($PM_{2.5}$) (cases/year)								
Cerebrovascular disease	−0.12	−0.25	−0.12	−0.25	−0.24	−0.5	−0.24	−0.5
Lower respiratory tract infection	−0.27	−0.55	−0.27	−0.55	−0.53	−1.09	−0.53	−1.09
Preterm birth	−1.64	−3.31	−1.64	−3.31	−3.23	−6.62	−3.23	−6.62
Low birth weight	−1.83	−3.7	−1.83	−3.7	−3.61	−7.4	−3.61	−7.4
Cardiovascular disease	−0.31	−0.62	−0.31	−0.62	−0.6	−1.24	−0.6	−1.24

$PM_{2.5}$: Particulate matter < 2.5 μm;
[a] Inside Barcelona scenarios refers to the trips that start and end in Barcelona city.
[b] Outside Barcelona scenarios refers to the trips that start or end in Barcelona city and start or end in Barcelona metropolitan area.
[c] Here we assumed that the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train.
[d] Here we assumed that the 26% of the trips is replaced by bus/tram and 74% are by metro/train.
[e] Here we assumed that the 20% of the trips is replaced by bike, the 21% by bus/tram and 59% are by metro/train.

Table 7
Results in Disability Adjusted Life Years (DALY) per year, in each scenario.

	Inside Barcelona Scenarios [a]				Outside Barcelona Scenarios [b]			
	Scenario 1	Scenario 2	Scenario 3[c]	Scenario 4[c]	Scenario 5[d]	Scenario 6[d]	Scenario 7[e]	Scenario 8[e]
Travelers (DALY/year)								
Physical activity	−141.87	−283.74	−103.33	−206.66	−117.18	−234.36	−161.93	−259.16
Air pollution ($PM_{2.5}$)	1.59	3.17	0.9	1.79	0.41	0.83	1	2.01
Traffic injuries	2.53	5.37	−0.32	−0.65	−30.96	−61.61	−22.46	−45.23
Travelers-Total	−137.76	−275.19	−102.76	−205.51	−147.73	−295.14	−183.39	−302.39
General population (DALY/year)								
Air pollution ($PM_{2.5}$)	−0.19	−0.38	−0.19	−0.38	−0.38	−0.75	−0.38	−0.75
Total (DALY/year)	−137.95	−275.58	−102.95	−205.9	−148.1	−295.89	−183.76	−303.14

$PM_{2.5}$: Particulate matter < 2.5 μm;
Public transport includes: bus, tram, train and metro.
[a] Inside Barcelona scenarios refers to the trips that start and end in Barcelona city.
[b] Outside Barcelona scenarios refers to the trips that start or end in Barcelona city and start or end in Barcelona metropolitan area.
[c] Here we assumed that the 50% of the trips was replaced by bike, the 22% by bus/tram and 28% are by metro/train.
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[e] Here we assumed that the 20% of the trips is replaced by bike, the 21% by bus/tram and 59% are by metro/train.

Funding

This work is part of the European-wide project Transportation Air pollution and Physical ActivitieS: an integrated health risk assessment programme of climate change and urban policies (TAPAS), which has partners in Barcelona, Basel, Copenhagen, Paris, Prague, and Warsaw. TAPAS is a four year project funded by the Coca-Cola Foundation, AGAUR, and CREAL. http://www.tapas-program.org/.

Conflict of interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work; no financial relationships with any organizations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

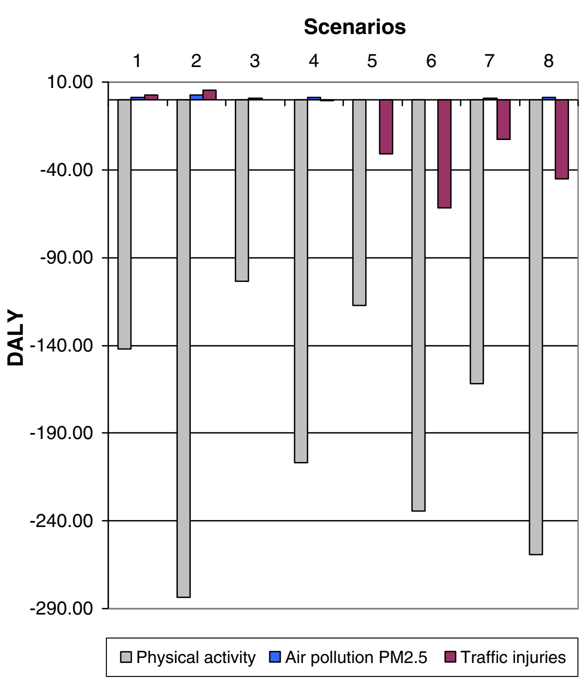

Fig. 2. Disability Adjusted Life Years by scenario and exposure, in travelers and general population (see Table 1 for details on the eight scenarios). DALYs: Disability Adjusted Life Years; $PM_{2.5}$: Particulate matter < 2.5 μm.

Ethical approval

Not required.

Acknowledgments

The selection of the dose–response functions was advised by participants of a series of workshops of the TAPAS project conducted in Barcelona between 2010 and 2012. We are particularly grateful to James Woodcock, Mike Jerrett, Gerard Hoek, Zorana Jovanovic and Marko Tainio who provided scientific guidance to the selection of the dose–response function and provided important ideas for the development of this article. The dispersion model was built by the Energy and Air Quality department of Barcelona Regional, and we want to thank especially the contribution of José Lao, who also helped to develop the emission inventories and the air quality analysis in this model. Furthermore we would like to thank Marko Tainio who helped define the sensitivity scenarios and his advice for DALYs estimation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2013.07.021.

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