Health impacts related to urban and transport planning: A burden of disease assessment

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ABBREVIATIONS

CVD	Cardiovascular disease
DALYs	Disability-adjusted life-years
dB(A)	A-weighted decibel
EBD	Environmental Burden of Disease
ERF	Exposure response function
ESCAPE LUR	European Study of Cohorts for Air Pollution Effects Land Use Regression model
GBD	Global Burden of Disease
HIA	Health impact assessment
ICD-10	International classification of disease, version 2010
$L_{Aeq,16hr}$	Day time (7:00-23:00 hr) equivalent sound pressure level
L_{den}	Day-evening-night EU indicator with 5 and 10 dB weights for the evening and the night time
L_{dn}	Day-night indicator with a 10 dB weight for the night time only
L_{night}	Night time (7:00-23:00 hr) equivalent sound pressure level
METs	Metabolic equivalents of task
NDVI	Normalized Differenced Vegetation Index
NO_2	Nitrogen dioxides
OECD	Organization for Economic Cooperation and Development
OLI	Operational Land Imager
O_3	Ozone
PA	Physical activity
PAF	Population attributable fraction
$PM_{2.5}$	Particulate matter with a diameter ≤2.5 μm
RR	Relative risk
SDGs	Sustainable Development Goals
TIRS	Thermal Infrared Sensor
TRAP	Traffic-related air pollution
UHI	Urban heat island

UTOPHIA	Urban and TranspOrt Planning Health Impact Assessment tool
WHO	World Health Organization
YLDs	Years lived with disability
YLLs	Years of life lost
%HA	Percentage of population highly annoyed
%HSD	Percentage of population highly sleep disturbed

ABSTRACT

Introduction: Until now, estimates of the Global Burden of Disease (GBD) have mainly been produced on national or regional levels. These general estimates, however, are less useful for city governments who have to take decisions on local scales. To address this gap, we focused on the city-level burden of disease (BD) due to exposures affected by urban and transport planning. We conducted a BD assessment using the Urban and Transport Planning Health Impact Assessment (UTOPHIA) tool to estimate annual preventable morbidity and disability-adjusted life-years (DALYs) under compliance with international exposure recommendations for physical activity (PA), exposure to air pollution, noise, heat, and access to green spaces in Barcelona, Spain.

Methods: Exposure estimates and morbidity data were available for 1357361 Barcelona residents ≥20 years (2012). We compared recommended with current exposure levels to estimate the associated BD. We quantified associations between exposures and morbidities and calculated population attributable fractions to estimate the number of attributable cases. We calculated DALYs using GBD Study 2015 background DALY estimates for Spain, which were scaled to Barcelona considering differences in population size, age and sex structures. We also estimated annual health costs that could be avoided under compliance with exposure recommendations.

Results: Not complying with recommended levels for PA, air pollution, noise, heat and access to green spaces was estimated to generate a large morbidity burden and resulted in 52001 DALYs (95% CI: 42866-61136) in Barcelona each year (13% of all annual DALYs). From this BD 36% (i.e. 18951 DALYs) was due to traffic noise with sleep disturbance and annoyance contributing largely (i.e. 10548 DALYs). Non-compliance was estimated to result in direct health costs of 20.10 million € (95% CI: 15.36-24.83) annually.

Conclusions: Non-compliance of international exposure recommendations was estimated to result in a considerable BD and in substantial economic expenditure each year in Barcelona. Our findings suggest that (1) the reduction of motor traffic together with the promotion of active transport and (2) the provision of green infrastructure would result in a considerable BD avoided and substantial savings to the public health care system, as these measures can provide mitigation of noise, air pollution and heat as well as opportunities for PA promotion.

KEYWORDS

Burden of disease, disability-adjusted life-years, health impact assessment, morbidity, transport planning, urban planning

1. INTRODUCTION

With continuing urbanization it is predicted that by 2050 70% of the world's population will be living in cities (United Nations, 2014). Urban life conveys great potential to improve our well-being, as it provides us with employment, access to essential goods and services and the opportunity for social interaction (United Nations, 2014).

At the same time, urban life and urban design also have detrimental effects on our well-being. Over the decades of urbanization processes, levels of physically-intensive labor and mobility activities have decreased, while convenience has increased and resulted in sedentary lifestyles (Sallis et al., 2015). Typically, our urban fabrics are made up of dense construction, with large amounts of public space being assigned to accommodating motor traffic. As a consequence, little space is available for green or blue infrastructure that could provide urban resilience, would beautify our cities and could be used for recreational purposes and to promote physical activity (PA) (Eakin et al., 2017; Nieuwenhuijsen and Khreis, 2016). With expansion of a city, scarcity of space and increases in housing prices, migration processes take place which force people to relocate to urban peripheries that often are low density neighborhoods that in return imply high motor vehicle dependency and long commuting times (Litman and Steele, 2017; Shoag and Muehlegger, 2015). Motor traffic exposes us not only to physical hazards, but also to hazardous emissions of air pollution, noise and anthropogenic heat (Mueller et al., 2017; Nieuwenhuijsen, 2016). Together with the effects of climate change, these emissions can contribute to increasing temperatures in cities.

The ‘city’, nowadays the primary settlement form, is increasingly becoming the unit of analysis and is gaining in importance in policy decision-making (WHO, 2015). Cities have direct local accountability and may be more agile to act in terms of governance structures compared to national governments. Cities can identify local problems and therefore develop specific policies that can target actions more effectively. The importance of local accountability on how urban spaces are managed has been recognized recently in the Sustainable Development Goals (SDGs) and the aligned adoption of the New Urban Agenda that make sustainable cities and communities a pressing issue for sustainable urban renewal (United Nations, 2017, 2015). The New Urban Agenda proposes how urban spaces should best be planned to provide sustainable urbanization processes and specifically allocates power to cities and towns by committing to “support local governments in determining their own administrative and management structures, in line with national legislation and policies, as appropriate, in order to adapt to local needs” (United Nations, 2017).

Until now, estimates of the Global Burden of Disease (GBD) have mainly been produced on national or regional levels (Forouzanfar et al., 2015). These estimates, however, are less useful for city governments that have to allocate resources and take decisions on the local scale with direct impacts on residents’ daily lives. To address this gap, we aimed to evaluate the city-level burden of disease (BD) impact and direct economic implications of current urban and transport planning practices. We therefore, estimated annual preventable BD and direct economic health gains under compliance with international exposure recommendations for PA, exposure to air pollution, noise and heat, and access to green spaces.

2. MATERIAL AND METHODS

2.1 Study setting

We further developed and applied the Urban and Transport Planning Health Impact Assessment (UTOPHIA) tool (Mueller et al., 2017) (Supplementary Material A, Fig. A.1) to the city of Barcelona, Spain. Barcelona has one of the highest population densities in Europe with 1.6 million people living on 100 km^2. Its urban design is made-up of dense, semi-tall construction, streaked by narrow street canyons. Only 10% of the city area is assigned as green space (Barcelona City Council, 2012). As typical for the Mediterranean region, Barcelona's climate (classified as dry-summer subtropical) is comprised of warm summers and mild winters with an annual mean temperature of 18 ºC and low precipitation (Barcelona City Council, 2012; Brines et al., 2015). Despite a well-connected public transport system with frequent service (i.e. metro, bus, trams, trains) within the municipality area, which in 2013 carried almost 900 million passengers (Barcelona City Council, 2013a), the provision of public transport for the wider metropolitan area is less well-developed. Of the almost two million daily commuter trips from the metropolitan area, over 40% are made in private motor vehicle (Barcelona City Council, 2013a). Barcelona's internal motor vehicle fleet of over 500000 cars and 300000 motorcycles plus the large daily motorized metropolitan commuter fleet result in a large traffic volume and one of the highest emission levels in Europe (Barcelona City Council, 2013b; Nieuwenhuijsen et al., 2014). During the summer months urban heat islands (i.e. UHI; urban areas being hotter than surrounding areas) can form and the UHI effect for Barcelona has been observed to be as high as 8 ºC (Moreno-Garcia, 1994).

2.2 Burden of disease assessment – Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) tool

We conducted a BD assessment for Barcelona residents ≥20 years (N=1357361) at the census tract level (N=1061) using data from 2012. The census tracts have a mean area of 9.6 ha with an average population of 1528 residents. Using the UTOPHIA tool (Mueller et al., 2017), we estimated (1) preventable morbidity (Supplementary Material B), (2) disability-adjusted life-years (DALYs) and its components of years of life lost (YLLs) and years lived with disability (YLDs) (Supplementary Material C), and (3) economic health gains if Barcelona complied with international exposure recommendations for PA, exposure to air pollution, noise and heat, and access to green spaces (Table 1).

We obtained incidence rates, stratified by sex if available, for selected morbidities from the Catalan Information System for Research in Primary Care (SIDIAP) (SIDIAP, 2016) or the literature (Table 2). Background YLLs [(1) natural-causes: communicable, maternal, neonatal, and nutritional disorders; non-communicable diseases; (2) road injury], and cause-specific YLDs for Spain were available through the GBD Study 2015 (Institute for Health Metrics and Evaluation (IHME), 2017). YLLs and YLDs for Spain were scaled to Barcelona considering differences in population size, age and sex structures (Table C.1) (Instituto Nacional de Estadística, 2011). We obtained recommended exposure levels and compared them to current levels (Table 1). We obtained exposure response functions (ERFs) from the literature to quantify the associations between exposures and morbidities (Tables 3-7). We used ERFs preferably assessing long-term effects and coming from meta-analyses, large longitudinal studies or having a particular exposure-risk gradient for Barcelona. We calculated the relative risk (RR) and population attributable fraction (PAF) for each exposure difference between recommended and current levels.

YLLs and YLDs corresponding to non-compliance were calculated based on the Environmental Burden of Disease (EBD) approach (Hänninen and Knol, 2011) (Tables 3-7) (Fig. C.1-C.2, Tables C.1-C.3). YLLs and YLDs were calculated for the age groups the selected RRs correspond to. To capture the attributable BD more broadly than would be possible by relying on the selected cause-specific RRs only (Tainio, 2015), we calculated natural-cause YLLs by using all-cause mortality RRs for PA (Woodcock et al., 2011), air pollution (WHO. Regional Office for Europe, 2014a), noise (Halonen et al., 2015), heat (Guo et al., 2014) and green space (Gascon et al., 2016b). YLDs (and YLLs for road injury) were calculated using cause-specific RRs. Estimated YLLs and YLDs were summed to obtain DALYs. As a sensitivity analysis, we calculated cause-specific YLLs and YLDs by applying directly the selected cause-specific RRs following the approach of previous studies (Ding et al., 2016; Stevenson et al., 2016) (Tables 3-7). To estimate health cost savings, we performed a literature review to identify direct health care costs associated with each morbidity (Table 8). We estimated direct savings per prevented case of morbidity under compliance of exposure recommendations. We also estimated the willingness to pay to avoid annoyance and sleep disturbance related to traffic noise (Istamto et al., 2014) (Table 9).

2.3 Internationally recommended exposure levels

1. Physical activity: The WHO recommends adults (≥18 years) to achieve 150 minutes of moderate-intensity PA or 75 minutes of vigorous-intensity PA weekly (WHO, 2010) (Table 1).

2. Air pollution: Particulate matter with a diameter ≤2.5 µm ($PM_{2.5}$) is widely used as an indicator of fossil fuel combustion sources and thus air pollution from motor traffic (Mueller et al., 2015). The WHO recommends annual mean $PM_{2.5}$ concentrations to not exceed 10 µg/m^3 (WHO, 2006).

3. Noise: The WHO recommends day time (7:00-23:00 hr) outdoor noise levels to not exceed equivalent sound pressure levels above 55 dB(A) (WHO, 1999) and night time (23:00-7:00 hr) levels to not exceed 40 dB(A) (WHO. Regional Office for Europe, 2009).

4. Heat: Although there are no official guidelines, reducing traffic and impermeable surfaces in urban areas, while at the same time increasing greenery and urban albedo may provide cooling by up to 4 ºC (Doick et al., 2014; Zhao et al., 2014).

5. Green spaces: A European Commission working group as well as the WHO recommend universal access to a green space, defined as living within 300 m linear distance to a green space ≥0.5 ha (European Commission, 2001; WHO. Regional Office for Europe, 2016).

2.4 Current exposure levels

2.4.1 Physical activity

PA data were available for 3279 Barcelona residents (20-64 years: N=2486; ≥65 years: N=793) through the 2011 Barcelona Health Survey, a population-based randomized sample studying the health status of Barcelonians (Bartoll et al., 2013) (Supplementary Material D). PA data were extrapolated to all Barcelona residents ≥20 years. WHO guidelines were translated into metabolic equivalent of task (MET) minutes/ week: adults 18-64 years, 600 MET minutes/ week; adults ≥65 years, 450 MET minutes/ week (IPAQ Webpage, 2005) (Tables D1.-D.2). The exposure difference between current

MET minutes and recommended 600/ 450 MET minutes/ week was estimated. We used the following morbidity outcomes (Table 3): cardiovascular disease (CVD) (Kyu et al., 2016), stroke (Kyu et al., 2016), type 2 diabetes (Kyu et al., 2016), colon cancer (Kyu et al., 2016), breast cancer (Kyu et al., 2016), and dementia (Hamer and Chida, 2009).

2.4.2 Air pollution

Annual mean $PM_{2.5}$ data (2012) were available on the census tract level through the European Study of Cohorts for Air Pollution Effects Land Use Regression (ESCAPE LUR) model (Eeftens et al., 2012). The exposure difference between current $PM_{2.5}$ concentrations and recommended 10 $\mu g/m^3$ was estimated for each census tract. We used the following health outcomes (Table 4): CVD (Cesaroni et al., 2014), stroke (Stafoggia et al., 2014), type 2 diabetes (Eze et al., 2015), preterm birth (Sapkota et al., 2010), and low birth weight (Pedersen et al., 2013).

2.4.3 Noise

Road traffic noise levels were available on census tract level through Barcelona's strategic noise map (Generalitat de Catalunya, 2006). Different indicators were calculated based on the noise exposure units corresponding to the selected morbidities (Table 5), namely day time ($L_{Aeq,16hr}$) and night time (L_{night}) equivalent sound pressure levels, day-evening-night EU indicator L_{den} with 5 and 10 dB weights for the evening and night time, and day-night indicator L_{dn} with a 10 dB weight for the night time (Supplementary Material E). We used following morbidity outcomes (Table 5): CVD (Babisch, 2014), hypertension (van Kempen and Babisch, 2012) and stroke (Sørensen et al., 2011). Additionally, we calculated the percentage of residents being highly annoyed (%HA) (Fidell et al., 1991; Schultz, 1978) and highly sleep disturbed (%HSD)

(Miedema and Vos, 2007; Miedema et al., 2003) by road traffic noise as well as estimated alterations thereof under compliance with noise exposure recommendations.

2.4.4 Heat

We used data on daily maximum temperatures (2012) available from a central monitor in Barcelona (Klein Tank, 2002). Drawing on a temperature raster map (2007, resolution 1 km) (Grupo de Investigación Kraken. Universidad Extremadura, 2007) and using QGIS (v2.6.1), monthly maximum temperatures on the census tract level were available. Monitor and raster map data were combined to estimate daily maximum temperatures on the census tract level for 2012.

We used morbidity outcomes with strong local evidence of an association with heat (Table 6): traffic incidents with injury (including fatal injuries) (Basagaña et al., 2015), respiratory hospital admissions (Michelozzi et al., 2009) and preterm birth (Schifano et al., 2016). According to the time frames and temperature thresholds provided in the studies, indicating when health effects occur, local temperature thresholds were calculated (i.e. traffic incidents, mean maximum temperature from May 15^{th,} 2012 to October 15th, 2012 = 26.6 ºC; respiratory hospital admissions; 90th percentile of maximum temperature from April 1st, 2012 to September 30th, 2012 = 30.5 ºC; preterm birth, mean maximum temperature from April 1st, 2012 to October 31st, 2012 = 25.3 ºC) (Supplementary Material F). For days exceeding the local threshold in maximum temperature, the exposure difference between daily maximum temperature and the threshold level was calculated on census tract level. The corresponding RRs and PAFs were calculated. Attributable cases were estimated on a daily level. We subtracted 4 ºC (i.e. presumed impact of reduced impermeable surfaces and increased urban albedo), from daily maximum temperature for days above the threshold. The exposure difference between the 4 ºC reduced daily maximum temperature and the threshold was calculated. The corresponding RR and PAF were calculated. The number of cases (i.e. traffic injuries, respiratory hospital admissions, preterm birth) attributable to 4 ºC reduced temperatures was subtracted from the number of cases attributable to estimated temperatures in 2012 (Table F.1).

2.4.5 Green space

In order to provide universal access to a green space ≥0.5 ha within 300 m linear distance, we estimated how much 'greenness' each census tract would need to have (Supplementary Material G). We defined 'greenness' by using the mean Normalized Differenced Vegetation Index (NDVI) within a 300 m buffer of each census tract (excluding large water bodies). NDVI is a satellite-based indicator of the density of photosynthetically-active vegetation (Gascon et al., 2016a). NDVI values range from -1 to +1 with higher values indicating higher vegetation density. NDVI was available through Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images (resolution 30 m × 30 m) (US Geology Survey, 2015). Using ArcGIS (v10.0), NDVI levels on census tract level were calculated as well as quintiles of the NDVI distribution. Data on green spaces in Barcelona were available through Urban Atlas (2007, resolution 1:10000) (European Environment Agency, 2007). Using ArcGIS, we abstracted the residential distance of Barcelona Health Survey respondents (N=3417) to the nearest green space ≥0.5 ha. For each NDVI quintile, the proportion of Health Survey respondents living within 300 m of a green space ≥0.5 ha was determined by matching census tract numbers (Table G.1). Estimates for the Health Survey respondents were extrapolated to all Barcelonians. A logarithmic function was fitted to predict the ‘greenness’ (NDVI level) needed to provide universal access to a green space ≥0.5 ha within 300 m (Fig. G.1). A mean NDVI level of 0.18 was predicted to provide universal access. The exposure difference between the current NDVI level of each quintile and the necessary 0.18 NDVI was determined (Table G.2). Depression was used as the morbidity outcome associated with green space exposure, with local Barcelona risk gradient (Triguero-Mas et al., 2015) (Table 7). The corresponding RR and PAF were calculated.

3. RESULTS

Barcelona currently does not comply with international exposure recommendations to protect health (Table 1) (Mueller et al., 2017). We estimated that more than 70% of residents were insufficiently physically active. The annual mean $PM_{2.5}$ level of 16.6 $\mu g/m^3$ exceeded the WHO guideline of 10 $\mu g/m^3$. Mean day time noise levels of 65.1 dB(A) and a night time levels of 57.6 dB(A) exceeded recommended levels of ≤55dB(A) and ≤40 dB(A), respectively. Barcelona’s summer months were too hot for favorable health outcomes and one third of the population did not live within 300 m linear distance to a green space ≥0.5 ha.

A large reduction in BD was estimated with compliance of exposure recommendations for PA, air pollution, noise, heat, and access to green spaces. Overall, we estimated to be preventable annually: 1699 cases of CVD (95% CI: 724-2674); 1340 cases of hypertension (95% CI: 743-1937); 849 cases of stroke (95% CI: 539-1159); 740 cases of depression (95% CI: 295-1199); 648 cases of type 2 diabetes (95% CI: 356-942); 210 cases of dementia (95% CI: 122-298); 198 cases of low birth weight (95% CI: 75-315); 126 cases of preterm birth (95% CI: 106-146); 48 traffic incidents with injury (potentially fatal) (95% CI: 0-97); 20 cases of respiratory hospital admissions (95% CI: 12-28); 15 cases of colon cancer (95% CI: 0-30); and 9 cases of breast cancer (95% CI: 0-21) (Tables 3-7, Fig. 1). In addition, the prevalence of %HA and %HSD due to traffic noise were estimated to be decreasing from 19% to 6% and from 10% to 3%, respectively (Table 5).

In Barcelona, a background BD of 401347 DALYs due to natural-causes is expected annually (i.e. 200757 YLLs, 200591 YLDs) (Table C.1). Exposure level recommendation compliance was estimated to result in a health gain of 52001 DALYs (95% CI: 42866-61136) avoidable each year (13% of all expected DALYs), with noise contributing 18951 DALYs (95% CI: 11786-26117), PA contributing 16053 DALYs (95% CI:11584-20523), air pollution contributing 9901 DALYs (95% CI: 6877-12923), heat contributing 4876 DALYs (95% CI: 4101-5648), and green spaces contributing 2220 DALYs (95% CI: 674-3766) (Fig. 2). Traffic noise-related %HSD and %HA were especially prevalent and contributed alone 10548 DALYs to the noise-related BD. Results of the sensitivity analysis, estimating YLLs with the cause-specific RRs, showed a lower health gain, namely the avoidance of 25967 DALYs (95% CI: 15029-36904), with noise contributing most, followed by air pollution, PA, green spaces and heat (Tables 3-7). Compliance of recommendations was estimated to result in direct health care savings of 20.10 million € (95% CI: 15.36-24.83) annually (Table 8). Willingness to pay to avoid health risks from excess traffic noise (i.e. annoyance and sleep disturbance) was estimated to amount to 7.35 million € (95% CI: 3.26-11.45) annually (Table 9).

4. DISCUSSION

Our results show that a considerable morbidity burden, 52000 DALYs and 20 million € in direct health care costs could be prevented annually in Barcelona if urban and transport planning related exposures of PA, air pollution, noise, heat and access to green spaces were improved according to internationally-recommended levels. The largest share in BD was attributable to traffic noise (over 18000 DALYs), with especially sleep disturbance and annoyance being highly prevalent and contributing largely. Results of the sensitivity analysis showed a remarkably lower impact, namely the avoidance of only 26000 DALYs. Therefore, results are highly sensitive to the DALY estimation method.

Until now, the scarce evidence that exists in this area has primarily focused on the BD associated with transport. A study for Warsaw, one of the most congested cities in Europe, estimated annually 58000 DALYs attributable to noise, air pollution and traffic injuries (with noise contributing the largest), and a health gain of 17000 DALYs avoided due to transport-related PA (Tainio, 2015). A recent study for sparsely populated New Zealand, found 25000 DALYs attributable to traffic incidents, air pollution and noise (Briggs et al., 2016). Another recent study estimated 400 to 800 DALYs per 100000 persons avoided due to changes in PA, air pollution and traffic incidents in Boston, Copenhagen, Delhi, London, Melbourne and São Paulo under a compact city scenario (Stevenson et al., 2016). Moreover, similar to our study, a study for the region of Flanders, Belgium found 11% of the population HA and 7% HSD from environmental noise (Stassen et al., 2008).

Exposures modifiable through urban and transport planning have different impacts in terms of burdens related to premature mortality and morbidity. Whilst noise is associated with a large morbidity burden (i.e. large YLD burden), Barcelonians die more prematurely from physical inactivity and air pollution exposure (i.e. large YLL burden) (Fig. 2). A recent health risk assessment for Switzerland concluded that air pollution and noise exposure have similar external cost impacts, with air pollution contributing particularly with mortality and noise with impaired quality of life (Vienneau et al., 2015). Despite different YLL and YLD contributions of the different exposures, using the summary health measure of DALYs allows to compare disparate health effects with different disability severities, by translating them into a single comparable unit (National Research Council Of The National Academies, 2011).

As shown, exposures related to current urban and transport planning practices result in a considerable BD and substantial health care costs. Spain has the second highest life expectancy worldwide (after Japan) of 83.2 years at birth (OECD, 2015). However, a better measure of quality of life might be how much time people actually spend in good health and how this time can be prolonged. In 2011, Spanish health care expenditure accounted for 9.4% of the national gross domestic product [GDP of 1477 billion US$ in 2011 (OECD, 2012a)], which is slightly above the Organization for Economic Cooperation and Development (OECD) average (OECD, 2014). Considering that more than 70% of health care expenditure in Spain is funded by public sources (OECD, 2014), containing these costs (by for example promoting the compliance of exposure recommendations) should be of great interest to public administrations. In Barcelona, exposure level compliance was estimated to translate into savings of over 20 million € of direct health care costs annually. Moreover, willingness to pay estimates to avoid health risks from traffic noise amounted to over 7 million € annually, which emphasizes the severity of noise being perceived as a serious health threat. Other implied indirect and intangible costs such as restricted-activity, productivity loss, or emotional suffering were not considered. Thus, the total economic impact, also affecting other policy sectors, is most likely underestimated in our study.

4.1 Uncertainties

As common in health impact assessment (HIA), this study implies uncertainties about causal inferences. The morbidity and BD estimations have to be interpreted with caution, especially when putting them into the wider context and comparing them with estimates from other settings. Differences in estimations are due to varying assessment methodologies, counterfactuals scenarios, exposure quantity and quality considered, ERFs applied, outcomes considered, their incidence rates and underlying population parameters. Where gaps in knowledge on the true properties of parameters exist, HIA draws on assumptions and extrapolations, which add to further uncertainty.

In HIA studies, DALYs have previously been estimated in different ways according to authors' judgment. DALY estimations can yield different results as seen by the two different methods applied (i.e. depending on background YLLs and RR gradients considered). When using all-cause mortality RRs to calculate natural-cause YLLs, the mortality burden of other outcomes associated with the exposures, which we could not quantify, is also captured. Thus, we believe that our approach better reflects the overall BD associated with the exposures. When applying the cause-specific RRs to YLLs and YLDs directly, as in the sensitivity analysis, solely the BD of the included health outcomes is reflected and underestimates the total BD attributable to the exposures.

Our estimated DALYs are exclusively attributable to the five exposures studied (i.e. noise, PA, air pollution, heat and green spaces). Other risk factors, such as socio-economic and lifestyle factors, or genetic predispositions, keep contributing steadily to the BD (Stevenson et al., 2016). The more comprehensively an exposure is assessed, the larger will be the contribution of this exposure to the overall BD (Stansfeld, 2015). For instance, other noise sources, such as air and rail traffic or industrial sites were not considered, but are suggested to have an independent BD (WHO. Regional Office for Europe, 2011). Also, other traffic-related air pollution (TRAP) such as nitrogen dioxides (NO_2) or ozone (O_3) potentially have an independent BD (Faustini et al., 2014; Héroux et al., 2015; Walton et al., 2015) that was disregarded in the present study. As mutual confounding effects by different TRAPs cannot be ruled-out completely, we only assessed the BD of $PM_{2.5}$ as commonly done in transport HIAs (Mueller et al., 2015). Nonetheless, if health effects of TRAPs are truly independent, then the true BD has been underestimated. Many of the considered exposures affect multiple health outcomes, although not all associations are well quantified with continuous ERFs in the literature. By excluding these outcomes, the attributable BD will most likely be underestimated. For example, PA is suggested to be associated with hypertension (Huai et al., 2013), while noise is suggested to be associated with type 2 diabetes (Dzhambov, 2015) and obesity (Dzhambov and Dimitrova, 2016).

PA, air pollution and noise are all associated with CVD. The largest burden of CVD, however, is suggested to be attributable to air pollution as it shows to have the strongest exposure-risk gradient (i.e. largest RR). Nevertheless, there may be the risk of double-counting of cases and DALYs if multiple exposures are correlated. This raises the issues of mutual confounding and effect modification, and highlights the necessity for more research on the independence of health effects and their physiological mechanisms. Independence of health effects has so far only been demonstrated for noise and air pollution exposure (Stansfeld, 2015; Tétreault et al., 2013). New research evidence suggests modification of health effects of air pollution by temperature (Li et al., 2017). Health effects of green spaces may indeed result from increases in PA levels or mitigation effects of air pollution, noise and heat and thus may not be independent (Gascon et al., 2016b). Therefore, our results should be interpreted with caution as synergetic effects between the exposures cannot be ruled out.

For noise, most of the estimated DALYs were due to annoyance and sleep disturbance. However, to estimate the BD associated with these two outcomes it is recommended to use prevalence instead of incidence, as a steady-state situation is assumed (Hänninen and Knol, 2011), which limits comparability. Despite the small disability weights for annoyance and sleep disturbance [i.e. 0.02 and 0.07, respectively (WHO. Regional Office for Europe, 2011)], the large prevalence of both outcomes results in a substantial BD. Thus, results can be controversial when comparing BD of less severe but common health outcomes to severe but rare outcomes (Hänninen and Knol, 2011; Tainio, 2015). Albeit, it has been suggested that those people being noise-annoyed are probably also the ones being sleep disturbed (Tainio, 2015); therefore, the noise associated BD (and willingness to pay to avoid noise exposure) may have been overestimated. The contribution of noise, insufficient PA and air pollution is much larger than the contribution of heat and green spaces to the estimated BD. On the one hand, this might imply that these three exposures are the most concerning in the urban context. On the other hand, this finding might partially be due to the simple fact that more research has been performed on PA, air pollution and recently noise and stronger evidence exists for these exposures. For some exposure-health outcome combinations, measuring and quantifying the exposure or the outcome has been challenging and epidemiological studies did not provide enough evidence for causality yet, even if causal relations are suspected (Ezzati et al., 2004).

Despite the utility of using DALYs to make different health effects comparable, the scaling of DALYs from the national to the city level can be limited by omission to consider variability in baseline health status between the different populations (e.g. possible differences in health status between city and rural populations). Furthermore, the estimated BD refers to one point in time only. The relative contribution of each exposure might change in the future: in times of climate change and increasing population densities (i.e. more people moving into cities where space is limited), considering the exposures of heat and green spaces and their health effects gains in importance; potential advancements in motor vehicle design might improve air quality and noise levels; while community-level interventions may help increase PA levels. More evidence is needed on the multiple exposures in the urban context, their relation with health and their potentially interactive effects in order to estimate the attributable BD more holistically.

4.2 Possible solutions

As far as we are aware, the present study is the first to look comprehensively into the BD associated with not just transport but also with urban planning related exposures, estimating a substantial BD and economic expenditure for Barcelona. As we estimated noise, PA and air pollution to contribute the most, we suggest that, in terms of urban and transport planning, healthy living could best be promoted by reducing Barcelona’s burdensome motor traffic volume (i.e. a common source of noise, physical inactivity, and air pollution) and promoting walking and cycling for transport in combination with improvements in public transport (i.e. active transport, a common mitigator of noise, physical inactivity and air pollution).

Implementing these transport measures concurrently, i.e. reducing motor traffic through, for example, traffic calming (e.g. ‘superblocks’), congestion charging or parking pricing and promoting active transport through, for example, expansions of the cycling and public transport network (also improving access for the metropolitan area), can help overcome the motor transport-associated noise and air pollution burden while at the same time increase PA levels (Macmillan et al., 2014; Rojas-Rueda et al., 2011; Woodcock et al., 2014). The urban planning sector can support by creating more attractive environments in which people like to live and be physically active in (Nieuwenhuijsen, 2016; Nieuwenhuijsen et al., 2016). Urban planning related features that promote an active lifestyle have been identified, besides others, as proximity to green spaces and surrounding greenness (i.e. trees, greenways, etc.) (Sallis et al., 2015). Despite the weaker direct associations with health, green spaces are an important urban and transport management tool (Mueller et al., 2017). Not only do green spaces provide a place for PA (either for leisure or as a pleasant active transport route diversion), but urban greenery can also be a natural noise barrier, can help offset greenhouse gas emissions and other air pollutants (Lee et al., 2015) and provides shading and cooling in the summer months (Doick et al., 2014). Moreover, in the urban context where space is limited, the more space that is assigned to parks and green belts, the less space there is available for roadways and the hazardous traffic it accommodates (i.e. replacement effect).

5. CONCLUSIONS

Non-compliance of recommended levels for PA, air pollution, noise, heat and green spaces were estimated to result in a considerable BD and substantial direct health care costs each year in Barcelona. Improvements are expected with changes to urban and transport planning related practices. Our findings suggest that (1) the reduction of motor traffic together with the promotion of active transport and (2) the provision of green infrastructure would result in a considerable BD avoided and substantial savings to the public health care system, as these measures can provide mitigation of noise, air pollution and heat as well as opportunities for PA promotion.

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CONFLICT OF INTEREST

There is no conflict of interest to declare.

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Table 1. International exposure recommendations and current exposure levels in Barcelona

Exposure	Recommendation	Current exposure
Physical activity		
Adults 18-64 years	600 MET minutes/ week	78 MET minutes/ week
Adults ≥65 years	450 MET minutes/ week	39 MET minutes/ week
Air pollution		
Annual mean $PM_{2.5}$	10 μg/ m^3	16.6 μg/ m^3
Noise		
Day time (7:00-23:00 hr) outdoor activity noise ($L_{Aeq,16hr}$) level	55 dB(A)	65.1dB(A)
Night time (23:00-7:00 hr) outdoor activity noise (L_{night}) level	40 dB(A)	57.6 dB(A)
Heat	Changes to urban plan may provide cooling of 4 ºC	Traffic accidents with injury[a]: >26.6 ºC on 98 days (mean exceedance by 2.3 ºC) Respiratory hospital admissions[b]: >30.5 ºC on 21 days (mean exceedance by 1.1 ºC) Preterm birth[c]: >25.3 ºC on 132 days (mean exceedance by 2.8 ºC)
Green spaces	Access to green space ≥0.5 ha within 300 m linear distance	31% of residents without access to green space ≥0.5 ha within 300 m linear distance

[a]mean maximum temperature from May 15th, 2012 to October 15th, 2012
[b]90th percentile of maximum temperature from April 1st, 2012 to September 30th, 2012
[c]mean maximum temperature from April 1st, 2012 to October 31st, 2012

Table 2. Morbidity incidence rates

Health outcome	Sex	Incidence rate (per 100000 persons)	Population (Location)	Age	Year	Reference
CVD (Ischemic heart disease ICD-10 codes: I20-I25	M	642	Barcelona	≥35 years	2015	(SIDIAP, 2016)
	F	278	Barcelona	≥35 years	2015	
Hypertension (ICD-10 codes: I10-I15)	M	1595	Barcelona	≥35 years	2015	(SIDIAP, 2016)
	F	1602	Barcelona	≥35 years	2015	
Stroke	M	690	Spain	≥65 years	2010	(Martínez-Salio et al., 2010)
	F	370	Spain	≥65 years	2010	
Type 2 diabetes mellitus (ICD-10 codes: E11)	M	774	Barcelona	≥35 years	2015	(SIDIAP, 2016)
	F	560	Barcelona	≥35 years	2015	
Colon cancer (ICD-10 codes: C18, except C18.1 and C18.8)	M	102	Barcelona	≥35 years	2015	(SIDIAP, 2016)
	F	76	Barcelona	≥20 years	2015	
Breast cancer (ICD-10 codes: C50)	F	210	Barcelona	≥20 years	2015	(SIDIAP, 2016)
Dementia	M	1110	Spain	≥65 years	2008	(Bermejo-Pareja et al., 2008)
	F	960	Spain	≥65 years	2008	
Depression	Both	895	Catalonia	≥18 years	2014	(Vilagut and Alonso, 2014)
Traffic incidents with injuries (fatal or non-fatal)	Both	583	Barcelona	≥20 years	2012	(Barcelona City Council, 2013b)
Respiratory hospital admissions	M	4964	Catalonia	≥75 years	2014	(Generalitat de Catalunya, 2015)
	F	3530				
Fecundity	F	3662	Barcelona	15-49 years	2014	(Agència de Salut Pública de Barcelona, 2014)
Preterm birth	Both	7400[a]	Spain	-	2010	(WHO, 2012)
Low birth weight	Both	7700[a]	Spain	-	2012	(OECD, 2012b)

CVD=cardiovascular disease; F=female; ICD-10=international classification of disease (2010); M=male
[a]per 100000 births

Table 3. Preventable cases and DALYs for physical activity under compliance of exposure recommendation in Barcelona

								Attributable burden of disease			Sensitivity analysis Attributable burden of disease		
Physical activity	**Risk estimate**	**Exposure**	**Age group**	**Study design**	**Reference**	**Sex**	**Preventable cases (95% CI)**	**YLLs**	**YLDs**	**DALYs**	**YLLs**	**YLDs**	**DALYs**
Natural-cause mortality	RR = 0.81 (95% CI: 0.76-0.85)	per 660 MET min/ week	≥ 20 years	Meta-analysis	(Woodcock et al., 2011)	Both	NA	15493 (11729-20666)	0	15493 (11729-20666)			
CVD	RR = 0.909 (95% CI: 0.857-0.964)	per 600 MET min/ week	≥ 20 years	Meta-analysis	(Kyu et al., 2016)	M	223 (84-372)		59 (22-104)	59 (22-104)	837 (317-1372)	59 (22-104)	896 (340-1475)
						F	111 (42-185)		63 (24-104)	63 (24-104)	566 (215-929)	63 (24-104)	629 (239-1032)
Stroke	RR = 0.910 (95% CI: 0.831-1.000)	per 600 MET min/ week	≥ 65 years	Meta-analysis	(Kyu et al., 2016)	M	51 (0-104)		16 (0-33)	16 (0-33)	119 (0-238)	16 (0-33)	135 (0-271)
						F	42 (0-86)		22 (0-44)	22 (0-44)	178 (0-357)	22 (0-44)	200 (0-401)
Type 2 diabetes mellitus	RR = 0.980 (95% CI: 0.967-0.996)	per 600 MET min/ week	≥ 20 years	Meta-analysis	(Kyu et al., 2016)	M	55 (11-92)		41 (8-69)	41 (8-69)	19 (4-32)	41 (8-69)	61 (12-101)
						F	46 (9-77)		44 (9-74)	44 (9-74)	23 (4-38)	44 (9-74)	67 (13-111)
Colon cancer	RR = 0.978 (95% CI: 0.940-1.016)	per 600 MET min/ week	≥ 20 years	Meta-analysis	(Kyu et al., 2016)	M	8 (0-23)		5 (0-14)	5 (0-14)	64 (0-181)	5 (0-14)	69 (0-195)
						F	7 (0-19)		4 (0-11)	4 (0-11)	51 (0-143)	4 (0-11)	55 (0-154)
Breast cancer	RR = 0.987 (95% CI: 0.971-1.003)	per 600 MET min/ week	≥ 20 years	Meta-analysis	(Kyu et al., 2016)	F	9 (0-21)		9 (0-20)	9 (0-20)	42 (0-96)	9 (0-20)	51 (0-116)
Dementia	RR = 0.72 (95% CI: 0.60-0.86)	per 1980 MET min/ week	≥ 65 years	Meta-analysis	(Hamer and Chida, 2009)	M	75 (34-119)		83 (38-131)	83 (38-131)	256 (116-402)	83 (38-131)	339 (154-533)
						F	135 (61-214)		214 (97-336)	214 (97-336)	489 (222-771)	214 (97-336)	703 (319-1107)
Total								**15493 (11729-20666)**	**560 (409-710)**	**16053 (11584-20523)**	**2645 (1895-3396)**	**560 (409-710)**	**3205 (2337-4073)**

CVD=cardiovascular disease; DALYs=disability-adjusted life-years; F=female; M=male; MET=metabolic equivalent of task; RR=relative risk; YLD=years lived with disability; YLL=years of life lost; 95% CI=95% confidence interval

Table 4. Preventable cases and DALYs for air pollution under compliance of exposure recommendation in Barcelona

								Attributable burden of disease			Sensitivity analysis Attributable burden of disease		
Air pollution	**Risk estimate**	**Exposure**	**Age group**	**Study Design**	**Reference**	**Sex**	**Preventable cases (95% CI)**	**YLLs**	**YLDs**	**DALYs**	**YLLs**	**YLDs**	**DALYs**
Natural-cause mortality	RR = 1.07 (95% CI:1.04-1.09)	per 10 μg/m^3 $PM_{2.5}$	≥ 20 years	Meta-analysis	(WHO. Regional Office for Europe, 2014b)	Both		8806 (5152-11149)	0	8806 (5152-11149)	-	-	-
CVD	HR=1.13 (95% CI: 0.98-1.30)	per 5 μg/m^3 $PM_{2.5}$	≥25 years	Meta-analysis	(Cesaroni et al., 2014)	M	565 (0-1101)		176 (0-346)	176 (0-346)	2483 (0-4880)	176 (0-346)	2659 (0-5226)
						F	284 (0-553)		188 (0-370)	188 (0-370)	1699 (0-3338)	188 (0-370)	1887 (0-3708)
Stroke	HR=1.19 (95% CI: 0.88-1.62)	per 5 μg/m^3 $PM_{2.5}$	≥65 years	Meta-analysis	(Stafoggia et al., 2014)	M	188 (0-425)		70 (0-161)	70 (0-161)	511 (0-1175)	70 (0-161)	582 (0-1336)
						F	156 (0-352)		92 (0-212)	92 (0-212)	754 (0-1731)	92 (0-212)	846 (0-1942)
Type 2 diabetes mellitus	RR=1.10 (95% CI: 1.02-1.18)	per 10 μg/m^3 $PM_{2.5}$	≥20 years	Meta-analysis	(Eze et al., 2015)	M	299 (64-506)		238 (51-404)	238 (51-404)	115 (24-194)	238 (51-404)	352 (75-598)
						F	249 (53-421)		256 (54-434)	256 (54-434)	128 (27-218)	256 (54-434)	384 (82-652)
Preterm birth (complications)[a]	RR=1.15 (95% CI: 1.14–1.16)	per 10 μg/m^3 $PM_{2.5}$	≥20 years	Meta-analysis	(Sapkota et al., 2010)	Both	86 (81-91)		75 (70-79)	97 (92-103)	49 (46-52)	75 (70-79)	146 (138-155)
Low birth weight	OR=1.18 (95% CI: 1.06-1.33)	per 5 μg/m^3 $PM_{2.5}$	20-49 years	Pooled effect estimate analysis	(Pedersen et al., 2013)	Both	198 (75-315)		NA	NA	NA	NA	NA
Total								**8806 (5152-11149)**	**1095 (709-1481)**	**9901 (6877-12923)**	**5739 (2600-8877)**	**1095 (709-1481)**	**6834 (3397-10269)**

CVD=cardiovascular disease; DALYs=disability-adjusted life-years; F=female; HR=hazard rate; M=male; RR=relative risk; YLD=years lived with disability; YLL=years of life lost; 95% CI=95% confidence interval

[a]YLLs and YLDs of preterm birth complications were calculated for the population ≥20 years.

Table 5. Preventable cases and DALYs for noise under compliance of exposure recommendations in Barcelona

								Attributable burden of disease			Sensitivity analysis Attributable burden of disease		
Noise	**Risk estimate**	**Exposure**	**Age group**	**Study design**	**Reference**	**Sex**	**Preventable cases (95% CI)**	**YLLs**	**YLDs**	**DALYs**	**YLLs**	**YLDs**	**DALYs**
Natural-cause mortality	RR =1.04 (95% CI: 1.00-1.07)	Daytime traffic noise LAeq,16hr > 60 dB(A) versus < 55 dB(A	≥25 years	Ecological study	(Halonen et al., 2015)	Both		7981 (0-13025)	0	7981 (0-13025	-	-	-
CVD	OR=1.08 (95% CI 1.04 – 1.13)	per weighted day-night noise level L_{dn} of 10 dB(A) (range 52-77 dB(A))	≥25 years	Meta-analysis	(Babisch, 2014)	M	343 (179-529)		106 (55-164)	106 (55-164)	1499 (782-2317)	106 (55-164)	1605 (837-2481)
						F	173 (90-266)		114 (59-176)	114 (59-176)	1025 (534-1584)	114 (59-176)	1138 (593-1759)
Hyper-tension	OR=1.034 (95% CI 1.011 – 1.056)	per 5 dB(A) increase of the 16 hour average ($L_{Aeq,16hr}$) road traffic noise level (range 45-75 dB(A))	≥25 years	Meta-analysis	(van Kempen and Babisch, 2012)	M	617 (207-983)		3 (1-5)	3 (1-5)	37 (13-60)	3 (1-5)	40 (13-64)
						F	723 (243-1150)		6 (2-10)	6 (2-10)	77 (26-123)	6 (2-10)	83 (28-133)
Stroke	IRR=1.27 (95% CI 1.13 – 1.43)	per 10 dB higher level of road traffic noise (L_{den}).	≥65 years	Prospective cohort study	(Sørensen et al., 2011)	M	225 (124-313)		84 (46-117)	84 (46-117)	610 (334-855)	84 (46-117)	694 (379-973)
						F	187 (103-260)		110 (60-154)	110 (60-154)	899 (491-1260)	110 (60-154)	1009 (551-1414)
% HA	$0.5118 * (L_{den} - 42) - 1.436*10^{-2} * (L_{den} - 42)^2 + 9.868*10^{-4} *(L_{den} - 42)^3$	within traffic noise range 45 - 75dB(A) (L_{den})	≥20 years	Recommended by (WHO. Regional Office for Europe, 2011)	(Fidell et al., 1991; Schultz, 1978)	Both	Current: 19.4% HA		6972 (3984-21453)	6972 (3984-21453)	0	6972 (3984-21453)	6972 (3984-21453)
							Compliance: 6.3% HA[a]						
% HSD	$20.8 - 1.05 (L_{night}) + 0.01486 (L_{night})^2$	traffic noise 45 - 65 dB(A) L_{night}; outside, maximally exposed facade	≥20 years	Recommended by (WHO. Regional Office for Europe, 2011)	(Miedema and Vos, 2007; Miedema et al., 2003)	Both	Current: 9.9% HSD		3575 (1788-9960)	3575 (1788-9960)	0	3575 (1788-9960)	3575 (1788-9960)
							Compliance: 2.6% HSD[b]						
Total								**7981 (0-13025)**	**10970 (693-21247)**	**18951 (11786-26117)**	**4148 (3107-5189)**	**10970 (693-21247)**	**15118 (4779-25457)**

CVD=cardiovascular disease; DALYs=disability-adjusted life-years; dB(A)=decibel a-weighted; F=female; IRR=incidence risk ratio; M=males; OR=odds ratio; RR=relative risk; YLD=years lived with disability; YLL=years of life lost; %HA=proportion of people highly annoyed; %HSD=proportion of people highly sleep disturbed; 95% CI=95% confidence interval

[a] 178773 persons are highly noise-annoyed because of exceedance of the recommended day time noise level.

[b] 99603 persons are highly sleep disturbed because of exceedance of the recommended night time noise level.

Table 6. Preventable cases and DALYs for heat under compliance of exposure recommendation in Barcelona

								Attributable burden of disease			Sensitivity analysis Attributable burden of disease		
Heat	**Risk estimate**	**Exposure**	**Age group**	**Study design**	**Reference**	**Sex**	**Preventable cases (95% CI)**	**YLLs**	**YLDs**	**DALYs**	**YLLs**	**YLDs**	**DALYs**
Natural-cause mortality	RR= 1.19 (95% CI: 1.16-1.23)	99th versus 74th temperature percentile	NA	Time-series study	(Guo et al., 2014)	Both		4818 (4139-5683)	0	4818 (4139-5683)	-	-	-
Traffic incident with injury (fatal or non-fatal)	RR=1.011 (95% CI 1.01-1.021)	per 1ºC increase in mean maximum temperature[a]	≥20 years	Time-series analysis	(Basagaña et al., 2015)	Both	48 (0-97)	21[b] (19-42)	14 (13-29)	35 (32-72)	21 (19-42)	14 (13-29)	35 (32-72)
Respiratory hospital admissions	RR=1.045 (95% CI 1.019-1.073)	per 1ºC increase in maximum temperature above threshold[c]	≥75 years	Time-series analysis	(Michelozzi et al., 2009)	M	9 (4-13)		NA	NA	NA	NA	NA
						F	11 (5-17)						
Preterm birth (complications)[d]	RR=1.053 (95% CI:1.028-1.078)	per 1ºC increase in mean maximum temperature[e]	≥20 years	Survival analysis of pregnancy cohorts in Rome and Barcelona	(Schifano et al., 2016)	Both	40 (22-55)		23 (13-33)	23 (13-33)	15 (8-22)	23 (13-33)	38 (21-55)
Total								**4839 (4499-5178)**	**38 (25-50)**	**4876 (4101-5648)**	**36 (20-52)**	**38 (25-50)**	**73 (47-99)**

DALYs=disability-adjusted life-years; F=female; M=male; RR=relative risk, YLD=years lived with disability; YLL=years of life lost; 95% CI= 95% confidence interval

[a]mean maximum temperature (15.05.2012-15.10.2012) was used as a threshold defined at 26.6 ºC.

[b]YLLs for road injury were added because fatal injuries are external causes of death.

[c]90th percentile maximum temperature (01.04-2012-30.09.2012) was used as a threshold defined at 30.5 ºC.

[d]YLLs and YLDs of preterm birth complications were calculated for the population ≥20 years.

[e]mean maximum temperature (1.04.2012-31.10.2012) was used as a threshold, defined at 25.3 ºC.

Table 7. Preventable cases and DALYs for green space under compliance of exposure recommendation in Barcelona

Green space	Risk estimate	Exposure	Age group	Study design	Reference	Sex	Preventable cases (95% CI)	Attributable burden of disease: YLLs	Attributable burden of disease: YLDs	Attributable burden of disease: DALYs	Sensitivity analysis Attributable burden of disease: YLLs	Sensitivity analysis Attributable burden of disease: YLDs	Sensitivity analysis Attributable burden of disease: DALYs
Natural-cause mortality	RR = 0.99 (95% CI: 0.98-1.01)	Per 10% increase in greenness	≥ 20 years	Meta-analysis	(Gascon et al., 2016b)	Both		1483 (0-2982)	0	1483 (0-2982)	-	-	-
Depression	RR = 0.80 (95% CI; 0.71 – 0.91)	per 0.08 NDVI	≥20 years	Cross-sectional	(Triguero-Mas et al., 2015)	Both	740 (295-1199)	0	737 (311-1131)	737 (311-1131)	0	737 (311-1131)	737 (311-1131)
Total								**1483 (0-2982)**	**737 (311-1131)**	**2220 (674-3766)**	**0**	**737 (311-1131)**	**737 (311-1131)**

DALYs=disability-adjusted life-years; NDVI= normalized difference vegetation index; RR=relative risk; YLD=years lived with disability; YLL=years of life lost; 95% CI= 95% confidence interval

Table 8. Estimated direct health care costs by health outcome

Health outcome	Description	€/ incident case	Reference	Avoidable € in million/ year (95% CI)
CVD (Coronary heart disease)	Estimated health care costs per case of coronary heart disease in Spain	1267[a]	(Ding et al., 2016)	2.15 (0.50-3.81)
Hypertension	Mean total costs of arterial hypertension according to level of co-morbidity in a Catalan cohort	1312	(Sicras-Mainar and Navarro-Artieda, 2009)	1.76 (0.59-2.80)
Type 2 diabetes	Estimated health care costs per case of type 2 diabetes in Spain	2652[b]	(Ding et al., 2016)	1.72 (0.36-2.91)
Stroke	Estimated health care costs per case of stroke in Spain	2497[c]	(Ding et al., 2016)	2.12 (0.57-3.85)
Breast cancer	Estimated health care costs per case of breast cancer in Spain	1234[d]	(Ding et al., 2016)	0.01 (0-0.03)
Colon cancer	Estimated health care costs per case of colorectal cancer in Spain	3418[e]	(Ding et al., 2016)	0.05 (0-0.14)
Dementia	Mean yearly care costs of dementia in the home setting in a Spanish cohort	23474	(Farré et al., 2016)	4.93 (2.23-7.82)
Depression	Mean direct annual health costs according to response to the treatment of major depressive disorder in a Catalan cohort	639[f]	(Sicras-Mainar et al., 2012)	0.47 (0.19-0.77)
Low birth weight	Mean total costs of hospitalization of very low birth weight infants in Italy (≈60 days of hospitalization)	20502	(Cavallo et al., 2015)	4.06 (1.54-6.46)
Preterm birth	Mean first year hospitalization costs of infants born with a gestational age of <37 weeks in a Swedish cohort	20263	(Ringborg et al., 2006)	2.55 (2.09-2.96)
Respiratory hospital admissions	Mean direct costs for hospital admissions from acute exacerbations of chronic obstructive pulmonary disease in Spain.	4129	(De Miguel-Díez et al., 2013)	0.08 (0.04-0.12)
Traffic injuries	Mean direct healthcare costs per injured person in Catalonia	3855	(García-Altés and Puig-Junoy, 2011)	0.19 (0.04-0.35)
Total				**20.10 (15.36-24.83)**

CI=confidence interval; CVD=cardiovascular disease

[a]Original value of 1735 $ in 2013. Dollar to Euro exchange rate (2013)=0.73.

[b]Original value of 3633 $ in 2013. Dollar to Euro exchange rate (2013)=0.73.

[c]Original value of 3421 $ in 2013. Dollar to Euro exchange rate (2013)=0.73.

[d]Original value of 1691 $ in 2013. Dollar to Euro exchange rate (2013)=0.73.

[e]Original value of 4682 $ in 2013. Dollar to Euro exchange rate (2013)=0.73.

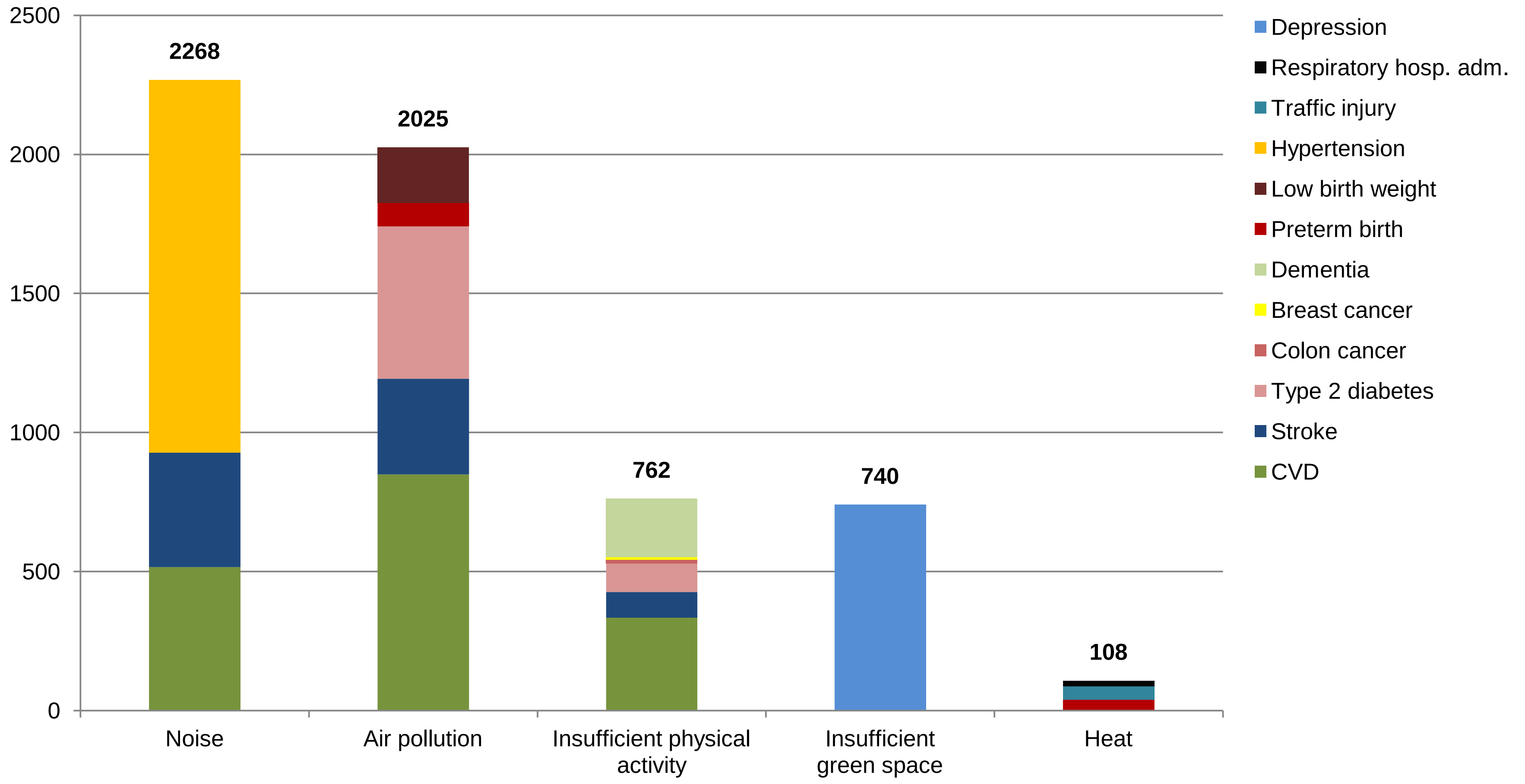
[f]The estimates costs were 451-826 €. The mean value of 639 € was used.

Table 9. Willingness-to-pay to avoid risks related to road-traffic noise

Health outcome	Affected population	Description	€/ incident case (95% CI)	Reference	Avoidable € in million/ year (95% CI)
Noise –related annoyance	178773	Median willingness to pay to avoid severe annoyance related to road-traffic noise per person/ year in Spain	30 (10-50)[a]	(Istamto et al., 2014)	5.36 (1.79-8.94)
Noise-related sleep disturbance	99603	Median willingness to pay to avoid general risks related to road traffic noise per person/ year in Spain	20 (10-50)[a]	(Istamto et al., 2014)	1.99 (1.00-4.98)
Total	**278376**				**7.35 (3.26-11.45)**

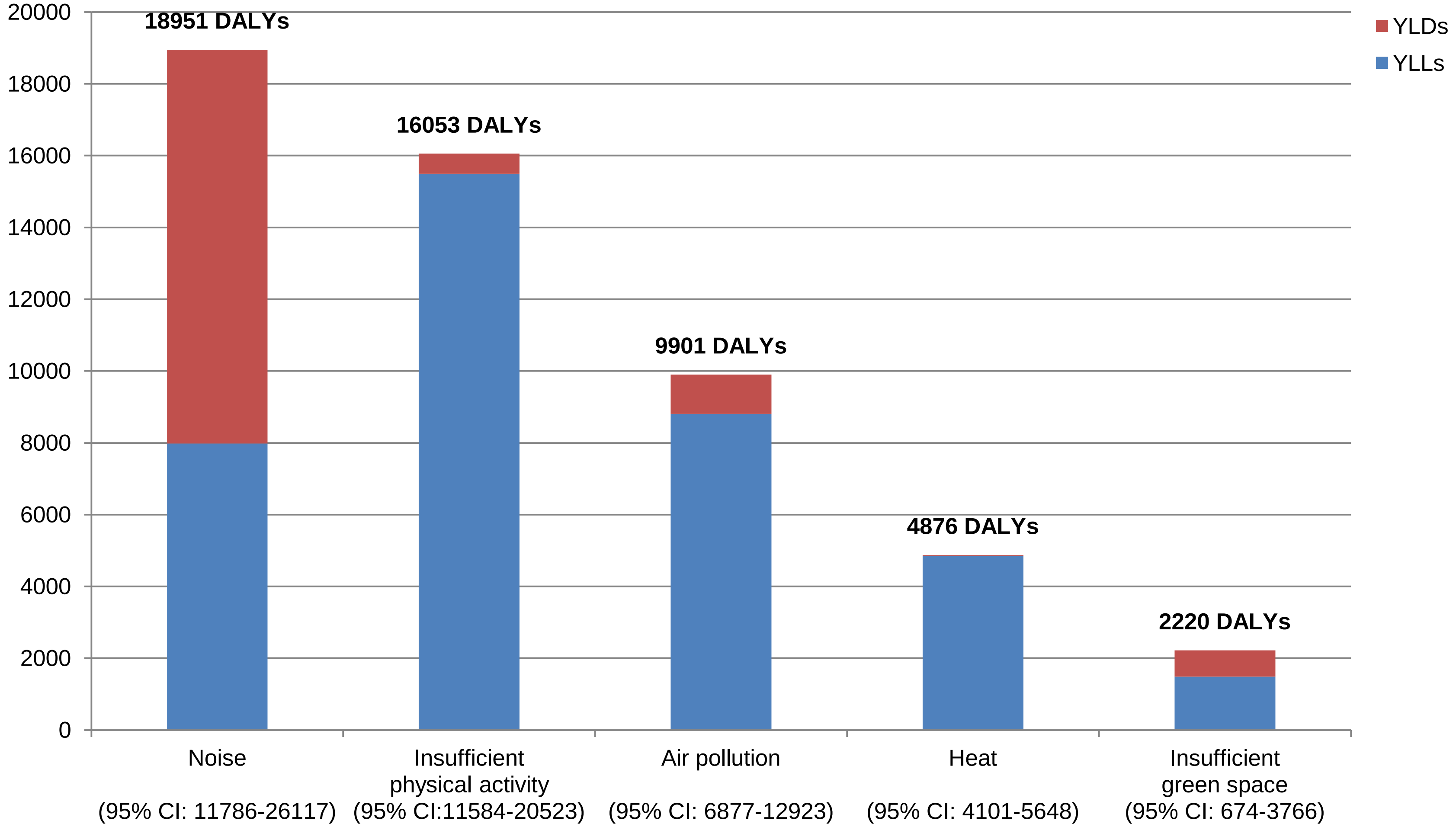
95% CI=95% confidence interval
[a]Confidence interval are the lowest and highest median values estimated in the cross-European study by (Istamto et al., 2014).

Figure 1. Morbidity cases attributable to non-compliance of international exposure recommendations of physical activity, air pollution, noise, heat and access to green spaces in Barcelona



CVD=cardiovascular disease; hosp.adm=hospital admissions
Noise-related annoyance and sleep disturbance (i.e. 178773 persons and 99603 persons, respectively) are not considered.

Figure 2. YLLs, YLDs and DALYs attributable to non-compliance of international exposure recommendations of physical activity, air pollution, noise, heat and access to green spaces in Barcelona



DALY=disability-adjusted life-years; YLDs =years lived with disability; YLLs=years of life lost; 95% CI=95% confidence interval