HEALTH IMPACT ASSESSMENT OF URBAN AND TRANSPORT PLANNING POLICIES

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... To my family and Joan who wanted nothing else but my happiness and who supported me through all my adventures, especially this one ...

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"The only thing standing between you and your goal is the bullshit story you keep telling yourself as to why you can't achieve it"

Jordan Belfort

CREAL Retreat 2013, © Payam Dadvand

Abstract

Urbanization processes are ongoing. Some aspects of urban life such as a sedentary lifestyle, the risk of traffic incidents, high levels of air pollution, noise and heat, and a lack of green spaces can have detrimental effects on our health and well-being. Despite consensus that these exposures related to urban and transport planning affect our health, there is little quantification of these health risk factors in the urban context. Quantitative health impact assessment (HIA) can provide numeric indices of health risk factors and can inform the health benefit-risk tradeoff of public policies. The present thesis sheds light on the utility of quantitative HIA in urban and transport planning policies. Almost 3,000 premature deaths, over 50,000 disability-adjusted life-years (DALYs) and over 20 million € in direct health care spending were estimated to be attributable to current urban and transport planning practices in Barcelona, Spain annually. The present thesis suggests that overwhelming motor transport volumes in cities need to be reduced through (1) the promotion of active transport (i.e. walking and cycling for transport in combination with public transport), facilitated by for instance the expansion of cycling networks and (2) the reinforcement of green spaces. Active transport together with green spaces, were assessed to provide considerable net health benefits through increases in physical activity levels and mitigation of motor transport-associated emissions of air pollution, noise and heat. The present thesis concludes that HIA is a useful tool for quantification of anticipated health impacts of public policies and more extensive application of HIA is encouraged.

Resumen

Algunas de las características de la vida urbana como el estilo de vida sedentario, el riesgo de sufrir accidentes de tráfico, los altos niveles de contaminación atmosférica, el ruido, el calor y la falta de espacios verdes pueden tener efectos perjudiciales en nuestra salud y bienestar. Aunque se sabe que estas exposiciones afectan nuestra salud, existe poca cuantificación de estos factores de riesgo en el contexto urbano. Las evaluaciones del impacto sobre la salud cuantitativas (HIA por sus siglas en inglés) proporcionan datos sobre los factores de riesgo en la salud e información del equilibrio entre beneficio y riesgo de las políticas públicas. Se estima que cada año casi 3,000 muertes prematuras, más de 50,000 años de vida ajustados por discapacidad (DALYs por sus siglas en inglés) y más de 20 millones de € de gastos directos en el sistema de salud que son atribuibles a las actuales políticas urbanas y de transporte en Barcelona, España. Esta tesis sugiere que el tráfico rodado en las ciudades necesita ser reducido mediante (1) la promoción del transporte activo (caminar, ir en bicicleta, transporte público), facilitada p.ej. por la expansión de la red de carril de bicicleta, y (2) con el aumento de los espacios verdes. Se estimó que el transporte activo y los espacios verdes proporcionan considerables beneficios netos para la salud a través del aumento de la actividad física y de la mitigación de las emisiones de contaminantes atmosféricos, ruido y calor asociadas al transporte motorizado. La presente tesis concluye que la HIA es una herramienta útil para la cuantificación anticipada de los impactos en la salud de las políticas públicas y se recomienda una aplicación extensiva de esta metodología.

Resum

Algunes de les característiques de la vida urbana com l'estil de vida sedentari, el risc de patir accidents de trànsit, els alts nivells de contaminació atmosfèrica, soroll i calor i la manca d'espais verds poden tenir efectes perjudicials en la nostra salut i benestar. Malgrat el consens que aquestes exposicions afecten la nostra salut, existeix poca quantificació d'aquests factors de risc en el context urbà. Les avaluacions quantitatives d'impacte en salut (HIA per les seves sigles anglès) poden proporcionar dades dels factors de risc en la salut i informar de l'equilibri entre benefici i risc de les polítiques públiques. Cada any quasi 3,000 morts prematures, més de 50,000 anys de vida ajustats per discapacitat (DALYs per les seves sigles en anglès) i més de 20 milions d'euros de despesa directa en el sistema de salut s'estimen atribuïbles a les actuals pràctiques polítiques urbanes i de transport a Barcelona, Espanya. La present tesi suggereix que el trànsit rodat en les ciutats necessita ser reduït mitjançant: (1) la promoció del transport actiu (caminar, anar en bicicleta, transport públic), facilitada, per exemple, per l'expansió de la xarxa de carril de bicicleta i (2) l'augment d'espais verds. L'avaluació mostra que el transport actiu i els espais verds proporcionen considerables beneficis nets per la salut a través de l'augment en l'activitat física i la mitigació de les emissions de contaminació atmosfèrica, soroll i calor associades al transport motoritzat. La present tesi conclou que la HIA es una eina útil per la quantificació anticipada dels impactes en salut de les polítiques per la qual cosa recomana una aplicació extensiva d'aquesta metodologia.

Preface

The present thesis was written at the Barcelona Institute for Global Health (ISGlobal)/ Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain between November 2013 and June 2017 and was supervised by Prof. Mark Nieuwenhuijsen and Dr. David Rojas-Rueda. The present thesis consists of a compilation of four scientific articles first-authored by the PhD candidate according to the procedures of the Biomedicine PhD program of the Department of Experimental and Health Sciences of the Universitat Pompeu Fabra, Barcelona, Spain.

The present thesis contributes to (1) the identification and understanding of exposures related to urban and transport planning practices in the urban context, (2) the quantification of health impacts associated with urban and transport planning practices, (3) the interpretation of these health impacts, and finally (4) the presentation of possible policy solutions for a more sustainable and healthier urban living.

Apart from one systematic review and three original research papers included in the present thesis, of which the PhD candidate is first author and was responsible for the data collection, data preparation, statistical analyses, interpretation of findings, writing of the articles and submissions for publication, the PhD candidate co-authored five further publications related to health impact assessment (HIA) of urban and transport planning related exposures, identifying driving forces, and giving outlooks for possible future directions (see Annex).

Moreover, the PhD candidate has collaborated in the European multi-centered Physical Activity through Sustainable Transport Approaches (PASTA) project, which has partners in Antwerp, Barcelona, London, Örebro, Rome, Vienna and Zurich. PASTA is a multi-faceted, cross-disciplinary research project that studies the interrelationship between transport behavior and health (Gerike et al. 2016). In the PASTA project the PhD candidate was primarily involved in Work-Package (WP) 4 with the aim of improving the HIA methodology for transport-related health impacts. WP4 aimed to derive parameters for quantitative HIA of active transport policies (i.e. walking and cycling for transport in combination with public transport) as there is still uncertainty about methodologies, relevant health exposure pathways, exposure response relationships and other important HIA model input parameters (Gerike et al. 2016).

Within the PASTA project, the PhD candidate also contributed to WP3 and WP2. In WP3, the PhD candidate supported actively the recruitment of almost 2,000 persons to the Barcelona PASTA online survey in order to longitudinally study active transport behavior. In WP2, with the aim of studying active transport determinants, the PhD candidate contributed to the identification of Barcelona-specific active transport enabling factors and determinants.

Abbreviations

AB	Attributable burden
BC	Black carbon
CAFE	Clean Air for Europe Study
CI	Confidence interval
CO_2	Carbon dioxide
CVD	Cardiovascular disease
DALYs	Disability-adjusted life-years
dB(A)	Decibel A-weighted
EEA	European Environment Agency
EBD	Environmental Burden of Disease
EC	European Commission
EPOMM	European Platform on Mobility Management
ERF	Exposure response function
ESCAPE	European Study of Cohorts for Air Pollution Effects
EU	European Union
GBD	Global Burden of Disease
GIS	Geographic information system
HEAT	Health Economic Assessment Tool
HIA	Health impact assessment
ICD-10	International classification of disease, version 2010
ITHIM	Integrated Transport and Health Impact Modelling Tool
LUR	Land use regression

$L_{Aeq,16hr}$	Day time (7:00-23:00 h) equivalent sound pressure level
L_{den}	Day-evening-night EU noise indicator with 5 and 10 dB weights for the evening and the night time
L_{dn}	Day-night noise indicator with a 10 dB weight for the night time only
L_{night}	Night time (23:00-7:00 h) equivalent sound pressure level
MET	Metabolic equivalent of task
NDVI	Normalized Differenced Vegetation Index
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
OECD	Organization for Economic Cooperation and Development
OLI	Operational Land Imager
OSM	OpenStreetMap
O_3	Ozone
P	Proportion
PA	Physical activity
PAF	Population attributable fraction
PASTA	Physical Activity through Sustainable Transport Approaches Project
$PM_{2.5}$	Particulate matter with aerodynamic diameters less than 2.5 µm
RR	Relative risk
S	Scenario

SD	Standard deviation
SDGs	Sustainable Development Goals
SO_2	Sulfur dioxides
TAPAS	Transportation, Air pollution and Physical ActivitieS Model
TB	Total burden
TEMS	European Platform on Mobility Management Modal Split Tool
TIRS	Thermal Infrared Sensor
TRAP	Traffic-related air pollution
UHI	Urban heat island
UN	United Nations
UTOPHIA	Urban and TranspOrt Planning Health Impact Assessment Model
VoSL	Value of Statistical Life
WHO	World Health Organization
YLD	Years lived with disability
YLL	Years of life lost
%GS	Percentage green space surface
%HA	Percentage of population highly annoyed
%HSD	Percentage of population highly sleep disturbed

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1. INTRODUCTION

With continuing urbanization processes it is predicted that by 2050 70% of the world's population will live in cities (United Nations 2014). As the environments we inhabit affect our health, urban designs that support healthy living are urgently needed.

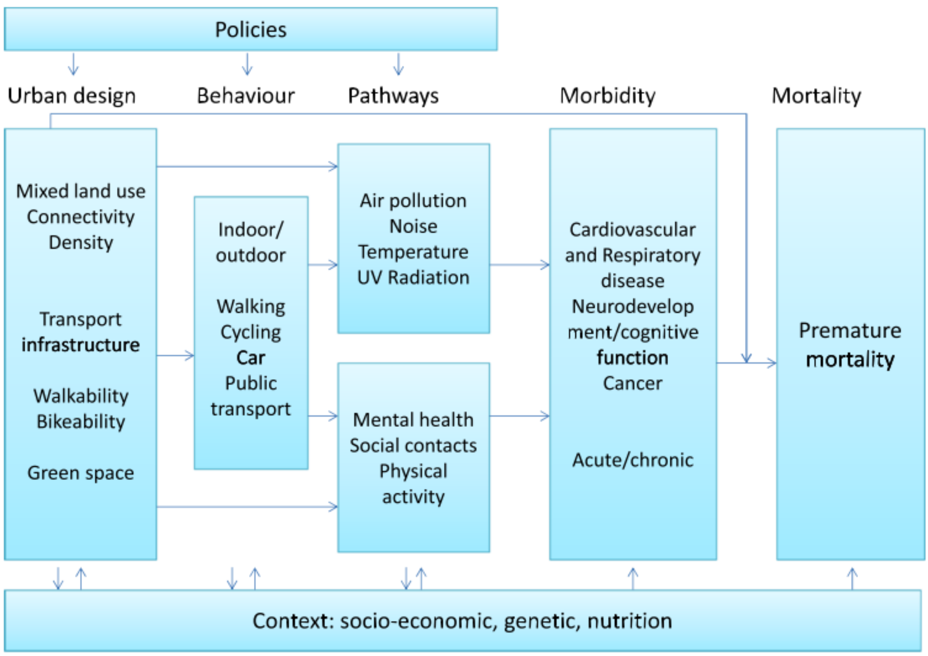
On the one hand, urban life conveys great potential to improve and sustain our health and well-being, as it provides us with employment, access to essential goods and services (including health care), and the opportunity to socially interact with each other (United Nations 2014). Living in cities is associated with higher levels of literacy and education as well as enhanced opportunities for cultural and political engagement (United Nations 2014). On the other hand, despite these comparative advantages of city-living, city design and it´s supportive systems, such as the transport system, can also have detrimental effects on our health and well-being.

Over the decades of urbanization processes, levels of physically-intensive labor and mobility activities have decreased, while convenience and comfort have increased, resulting in sedentary lifestyles and an ever-growing obesity epidemic (Sallis et al. 2015). At the same time, continuing expansions of road and highway infrastructure as well as increases in motor vehicle sales and ownership are contributing factors to overwhelming motor vehicle volumes that congest our cities. Motor traffic exposes us not only to physical hazards (i.e. traffic incidents), 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 contribute to increasing temperatures in our cities and put environmental quality and human health and well-being at risk. The urban fabrics we live in are typically 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 infrastructure that could provide urban resilience, would beautify our cities and could be used for recreational purposes and promote physical activity (PA) (Nieuwenhuijsen & Khreis 2016; Eakin et al. 2017). All of these exposures that are associated with urban and transport planning practices (i.e. physical inactivity, traffic incidents, air pollution, noise, heat and a lack of green spaces), have been linked with premature mortality and morbidity and affect our quality of life and well-being (Woodcock et al. 2011; WHO. Regional Office for Europe 2014b; Guo et al. 2014; Bhalla et al. 2014; Halonen et al. 2015; Gascon et al. 2016).

Environmental factors are greatly modifiable and interventions on the community level, such as urban and transport planning, were shown to be more effective than interventions at the individual level (Nieuwenhuijsen 2016). In contrast to behavior change interventions, where new behaviors are often dismissed over time, effects of strategic built-environment changes are long-lasting and plan for 20-40 years into the future (Saelens et al. 2003; Litman 2014).

Consequently, built-environment interventions require special mindfulness in the planning process. In fact, policy-makers need to have a good understanding of the magnitude and strength of linkages between urban and transport planning practices, environmental exposures and human health in order to dispose policy actions that can target effectively (Figure 1.1) (Nieuwenhuijsen 2016).

Figure 1.1 Conceptual framework on the relation between urban and transport planning, environmental exposures and health.



From Nieuwenhuijsen 2016

Therefore, a quantification of urban and transport planning related exposures and their interactive effects in the urban context is urgently needed and important in order to understand the real magnitude of the risk these exposures pose for environmental quality and human health and well-being (Nieuwenhuijsen 2016). Numerical indices of expected environmental and health impacts are important for planning purposes and resource allocation as decision-makers may give more weight to outcomes that are measurable (Joffe & Mindell 2005). Especially in times of continuing urbanization processes and city growth, urban and transport planning policies that consider the impacts on the environment and human health are becoming pressing issues that are recognized in the United Nations' (UN) Sustainable Development Goals (SDGs) and the aligned adoption of the New Urban Agenda soliciting for sustainable city and community development (United Nations 2015; United Nations 2017).

Health impact assessment (HIA) has been proposed as a tool that can help policy-makers foresee how different urban and transport policy options might affect related exposures and associated health outcomes (Ståhl et al. 2006). HIA can support the planning process by informing objectively on expected health impacts of a proposed policy. HIA systematically identifies and judges exposure pathways and associated health outcomes and their distribution among the population under study (WHO. Regional Office for Europe 1999; Mindell et al. 2003). This way, policy-makers can take informed decisions when adopting a certain policy option, warranting that benefits to population health are maximized and risks are mitigated.

1.1 Urban and transport planning related exposures

1.1.1 Physical activity

Ever since the industrial revolution, the development of new technologies and the availability of new devices has led to decreased physical hardship during labor and mobility activities (Hallal et al. 2012). However, the human body and its systems (e.g. skeletal, metabolic, cardiovascular, etc.) need to be stimulated regularly by physical activity (PA) in order to develop and function optimally (Booth et al. 2008). The World Health Organization (WHO) recommends adults to perform at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity aerobic PA throughout the week for health preservation (WHO 2010). Nonetheless, nowadays one third of the world's population is estimated to be physically inactive (Hallal et al. 2012), ranking physical inactivity among the leading risk factors in the Global Burden of Disease (GBD) Study (Forouzanfar et al. 2015).

Insufficient levels of PA are estimated to cause more than 2 million premature deaths globally each year (Forouzanfar et al. 2015) and aside from strong associations with mortality, insufficient levels of PA contribute to low energy expenditure and give rise to the global obesity epidemic (Hill & Peters 1998; Church et al. 2011; Ng et al. 2014). Insufficient levels of PA are further associated with a wide range of morbidity outcomes, including cardiovascular disease (CVD), cerebrovascular disease, type 2 diabetes, some cancers and neurodegenerative disease (Monninkhof et al. 2007; Hamer &

Chida 2008; Hamer & Chida 2009; Kyu et al. 2016). Finally, insufficient levels of PA were estimated to account for a large economic burden and resulted in almost 12 billion US$ of direct health care expenditure in Europe in 2013 (Ding et al. 2016).

1.1.2 Traffic incidents

While physically-intensive mobility activities have decreased over the decades, motor vehicle use is still on the rise. Continuing expansions of road and highway infrastructure as well as increasing motor vehicle sales and ownership are contributing factors to increasing motor vehicle volumes and associated risks (Bhalla et al. 2014). By 2030, car ownership is expect to rise to 2 billion motor vehicles worldwide (Sperling & Gordon 2008).

While in high income countries rates of fatal traffic incidents have declined over the last decades, owing to successful implementation of road safety programs, at the global level, road traffic fatality rates are still increasing and are linked to economic growth and rapid motorization (Bhalla et al. 2014). Traffic – and the physical hazard it constitutes – is, likewise as physical inactivity, a leading risk factors in the GBD Study (Bhalla et al. 2014). Each year, fatal traffic incidents are estimated to account for 1.3 million premature deaths globally and are the leading cause of premature death among young adults aged 15 to 24 years (Bhalla et al. 2014). In addition, traffic results in a large global injury burden with 78.2 million incidents annually that require medical care (Bhalla et al. 2014).

1.1.3 Air pollution

High levels of air pollution have become a global crisis and are a popular matter of societal concern. Air pollution can be found, similarly to insufficient levels of PA and the risk of traffic incidents, among the leading risk factors in the GBD Study and is estimated to cause 5.5 million premature deaths globally each year (Forouzanfar et al., 2015). Half of these premature deaths result of indoor air pollution that is due to cooking with solid fuels (Forouzanfar et al. 2015), which is a public health issue foremost prominent in the developing world. The other half of these premature deaths, however, is due to ambient air pollution (Forouzanfar et al. 2015) that is generated by power stations, factories, construction, heating, and – especially in the urban context – by motor traffic and the incomplete combustion of fossil fuels (Colvile et al. 2001).

Ambient air pollution is a complex issue to address due to its many sources, and pollutant-dependent different levels of interactions and dispersions. Compositions of air pollution have been changing over the decades which are linked to changes and advances in social structures, fuel compositions and technologies (Royal College of Physicians 2016). While today, unlike 70 years ago, concerns on black smoke and sulfur dioxides (SO_2) resulting from coal burning have greatly relapsed, concerns on particle pollution, nitrogen dioxides (NO_2) and other traffic-related air pollution (TRAP) have emerged and have become a popular matter of concern (Royal College of Physicians 2016).

Particulate matter (PM) with aerodynamic diameters less than 2.5 µm (i.e. $PM_{2.5}$) is a generic background marker and a good proxy for all fossil fuel combustion sources, including motor vehicle exhaust (Mueller et al. 2015). PM originates from local and remote sources and the precise chemical composition varies from place to place. PM can consist of carbon, ammonium nitrate and ammonium sulfate, oxides, salts, metals and organic materials (Royal College of Physicians 2016). Unlike to NO_2, PM has limited spatial variation and thus represents well the overall air pollution burden of a specific context.

In the present thesis, the term 'air pollution' and '$PM_{2.5}$' have to be understood interchangeably as in the subsequent analyses $PM_{2.5}$ was applied as the proxy for the overall air pollution burden of the study contexts, which is common practice in transport HIAs (Mueller et al. 2015). Nonetheless, other TRAPs that the present thesis does not consider, such as nitrogen oxides (NO_x), black carbon (BC) or ozone (O_3), are suggested to have independent effects on human health (Dhondt et al. 2013; Tainio et al. 2016; Héroux et al. 2015). The WHO recommends annual mean $PM_{2.5}$ levels to not exceed 10 $\mu g/m^3$ for health preservation (WHO 2006). Despite air pollution currently being of international concern with increasing efforts to reduce air pollution levels, threshold values are yet far exceeded in many countries. The European Environment Agency (EEA) estimated 85% of Europeans to be exposed to annual mean $PM_{2.5}$ concentrations exceeding the 10 $\mu g/m^3$ health threshold of the WHO (Guerreiro et al. 2016). The European Commission's (EC) Clean

Air for Europe (CAFE) Study suggested that the statistical life expectancy of a European citizens is shortened by 8.1 months due to $PM_{2.5}$ exposure (Amann et al. 2005). Despite premature mortality, $PM_{2.5}$ has also been associated with a large number of morbidity outcomes, including CVD, cerebrovascular disease, type 2 diabetes, adverse reproductive outcomes, preterm birth and low birth weight (Sapkota et al. 2010; Pedersen et al. 2013; WHO. Regional Office for Europe 2014b; Cesaroni et al. 2014; Stafoggia et al. 2014; Eze et al. 2015; Lafuente et al. 2016; Mahalingaiah et al. 2016).

1.1.4 Noise

Likewise being linked to continuing urbanization processes, densely-constructed urban designs and increasing motor traffic volumes, acoustic nuisance (i.e. noise) has become an increasingly important to consider environmental stressor in the urban context (WHO. Regional Office for Europe 2011). The dominating noise source in cities is in fact motor traffic, with noise levels being further amplified by multiple interactions of noise waves with construction facades that frame the street network (Van Renterghem et al. 2015). The WHO recommends day time noise levels (7:00-23:00 h) and night time noise levels (23:00-7:00 h) to not exceed equivalent sound pressure levels of 55 A-weighted decibel [dB(A)] and 40 dB(A), respectively (WHO 1999; WHO. Regional Office for Europe 2009). However, an estimated 40% of Europeans are exposed to day time noise levels exceeding the health threshold of 55 dB(A) and even an estimated 20% of Europeans is exposed to levels above 65 dB(A) (WHO 1999). While evidence on threshold exceedance of night time levels is scarce, there are suggestions that noise exposure during night time may in particular be harmful, impairing restorative processes in the body during sleep (WHO. Regional Office for Europe 2009).

Growing research interest in noise epidemiology has associated noise with a wide range of health outcomes including premature mortality, CVD, cerebrovascular disease, hypertension, type 2 diabetes, obesity, cognitive impairment, well as annoyance and sleep disturbance at night (Schultz 1978; Fidell et al. 1991; Miedema et al. 2003; Miedema & Vos 2007; Sørensen et al. 2011; WHO. Regional Office for Europe 2011; van Kempen & Babisch 2012; Babisch 2014; Dzhambov 2015; Dzhambov & Dimitrova 2016).

1.1.5 Heat

Climate change projections predict increasing frequency and severity of heat waves (Gunawardena et al. 2017). Especially in the urban context, the impacts of extreme temperatures can be severe. Summer temperatures in cities can be amplified by solar energy absorption, re-radiation effects of dense urban construction and anthropogenic heat as released by motor traffic and can result in the so-called urban heat island (UHI) effect (Zhao et al. 2014). The UHI effect describes a climatic phenomenon in which urban areas have higher air temperatures than surrounding rural areas (Shahmohamadi et al. 2011). Under the UHI effect urban temperatures are stagnant throughout day and night time and urban temperatures are most commonly increased by 3 to 5 ºC compared to rural surroundings, but also extreme increases of up to 10 ºC have been observed (Moreno-Garcia 1994; Shahmohamadi et al. 2011).

The increasing frequency of heat waves together with UHI effects, challenge sustainable urban growth and emphasize the importance of the relationship between land use and urban climate (Gunawardena et al. 2017). Expected temperature rises and extreme urban temperatures have important implications for population health. Heat exposure has been associated with premature mortality, CVD and respiratory morbidity, but also traffic incidents with injury and preterm birth (Michelozzi et al. 2009; Guo et al. 2014; Basagaña et al. 2015; Schifano et al. 2016).

1.1.6 Green spaces

Urban land use is severely challenged by increasing population densities and motor vehicle use that need to be catered for resulting in competing land use interests and general space scarcity. Only little space in cities is assigned to green spaces that could provide urban resilience, would beautify our cities and could be used for recreational purposes and to promote PA (Nieuwenhuijsen & Khreis 2016; Eakin et al. 2017). Green spaces are thought to be an important urban and transport planning management tool (Mueller et al. 2017). The more space that is assigned to parks and green belts, the less space there is available for construction or roadways and the hazardous traffic it accommodates (i.e. replacement effect).

Recently, research interest emerges in the beneficial effects of green spaces and surrounding greenness (i.e. street trees, greenways, gardens etc.) on human health. Findings demonstrate that green spaces are inversely associated with premature mortality and positively associated with well-being and positive affect, improved cognitive functioning and mental health outcomes such as reduced depression (Triguero-Mas et al. 2015; Gascon et al. 2015; Wolf & Robbins 2015; Gascon et al. 2016; Zijlema et al. 2017). Also the WHO and the EC have recognized the beneficial effects of green spaces in urban environments and recommend living within 300 m linear distance to a green space of ≥0.5 ha (WHO. Regional Office for Europe 2016; European Commission 2001).

Until now the precise mechanisms of green spaces affecting human health are not completely understood (Gascon et al. 2016). Suggested mechanism are: (1) green spaces providing a pleasant space for PA engagement (Gladwell et al. 2013; Shanahan et al. 2015; Wolf & Robbins 2015); (2) visual access to green spaces providing restoration, positive affect, improved cognitive functioning and mental health (Triguero-Mas et al. 2015; Wolf & Robbins 2015; Zijlema et al. 2017); (3) the biodiversity associated with green spaces stimulating human immune system response (Rook 2013); and (4) vegetation providing mitigation of air pollution, noise and heat (Gascon et al. 2016).

Nonetheless, in urban environments where space is limited, providing the recommended amounts of green space is challenging.

There is also uncertainty on the necessary size and composition of green space which relates to the uncertainty on the mechanisms of beneficial effects (Gascon et al. 2016; Gascon et al. 2015; Triguero-Mas et al. 2015). If the health benefits resulted indeed through increased performance of PA in green spaces, or through mitigation of hazardous environmental exposures of air pollution, noise and heat, then large green spaces would be needed. Though, if the benefits resulted indeed through nature viewing and visual access to greenness then surrounding greenness (i.e. street trees, greenways, urban gardens etc.) would be more important.

2. RATIONALE

Continuing urbanization processes and its implications for human health put sustainable urban development in the spotlight. Contemporary sedentarism, high levels of air and noise pollution, the increasing frequency of extreme temperatures, the risk of physical hazards (i.e. traffic incidents with injury) and the lack of green spaces all present challenges to healthy urban living. Despite consensus that these environmental exposures related to urban and transport planning influence human health and well-being, there is only little quantification of the magnitude of these health risk factors in the urban context.

Quantitative HIA, despite being a relatively new research field, can provide these required numeric indices and can inform on the health benefit-risk tradeoff of public policies. Therefore, quantitative HIA can add value and defensibility to the public policy decision-making process. By combining different methods and procedures, exposure pathways and associated health impacts and their distribution among the population under study are systematically judged. Results of quantitative HIAs are meant to influence the policy debate and provide a rubric to integrate health into planning and policy. Advocating for the implementation of urban and transport planning policies that maximize health benefits for citizens is of outmost importance for sustainable and healthy urban development. Consequently, there is a strong need for comprehensive HIA that quantifies and provides numeric indices of the expected health impacts of urban and transport planning policies.

3. OBJECTIVES

3.1. General objectives

The two general objectives of the present thesis are to (1) understand, conduct and improve quantitative HIA of scenario analyses of urban and transport planning policies in order to (2) evaluate whether these policies have the potential to help overcome the current physical inactivity and environmental pollution burden in the urban context.

3.2 Specific objectives

1. To identify exposures related to urban and transport planning practices and quantify their impact on mortality and life-expectancy in the case study city of Barcelona, Spain (Paper I).
2. To identify exposures related to urban and transport planning practices and quantify their impact on morbidity, burden of disease and direct health care expenditure in the case study city of Barcelona, Spain (Paper II).
3. To systematically review the literature on quantitative HIA of active transport (i.e. walking and cycling for transport in combination with public transport) in order to understand the health benefit-risk tradeoff and evaluate the potential of active transport to be a policy solution to overcome the contemporary physical inactivity crisis and environmental pollution burden (Paper III).

4. To conduct a quantitative HIA of cycling network expansions in 167 European cities in order to understand the potential of cycling network expansions to be a policy solution to overcome the contemporary physical inactivity crisis and environmental pollution burden (Paper IV).

4. METHODS

The following paragraphs will summarize the methodology of HIA and its evolvement – with a special focus on quantitative HIA. Currently existing tools to quantitatively assess the health impacts of urban and transport policies will be discussed. As most commonly quantitative HIA follows a comparative risk assessment approach (Mueller et al. 2015; Nieuwenhuijsen et al. 2017), this approach will be explained in detail. In addition, the contexts for the scenario analyses linked to (1) the case study city of Barcelona, Spain (Paper I and Paper II) and (2) the Physical Activity through Sustainable Transport Approaches (PASTA) project (Paper III and Paper IV) will be provided.

4.1 Health impact assessment

Social, economic and other public policies in the public and private sector are often so closely interrelated that a decision in one sector affects the objectives and performance of another sector (WHO. Regional Office for Europe 1999). To acknowledge this, in the past, policies have been assessed on their environmental, economic, or social impacts considering for instance expected differences in impacts by age or sex. The impacts of public policies on population health, however, have until recently, only been considered to a limited extent (WHO. Regional Office for Europe 1999). An important step forward in the European Union (EU) has been taken with the 'health in all policies' principle that recognizes intersectoral action and healthy public policy-making as central elements of health promotion in all European Community activities (Ståhl et al. 2006). Resulting attempts of taking integrated approaches towards healthy public policy-making has increasingly put HIA on the agendas of policy-makers.

HIA is a tool that can help policy-makers to foresee how different policy options will affect health by informing on their associated health benefits and risks (Ståhl et al. 2006). HIA combines different methods and procedures to systematically identify and judge all relevant – whether intended or unintended – exposure pathways and health effects the proposed policy might have on the health of a population and the distribution of those effects within this population (Mindell & Joffe 2003; WHO. Regional Office for Europe 1999).

HIAs can be carried out retrospectively, concurrently or prospectively (Joffe & Mindell 2005). Nonetheless, as implied by 'assessment' in contrast to 'evaluation', most HIAs are formative and are indeed carried out prospectively and aim to give an outlook on expected health consequences in the future (Wismar et al. 2007). As 'health' is usually a strong-weighing factor to the public (with strong self-interest) (Jacobs & Shapiro 1994; Burstein 1998), outcomes of HIAs can raise health awareness and advocacy and can influence often 'hotly-debated' policy proposals. Therefore, HIA can have a strong bearing on policy decision-making processes (Wismar et al. 2007).

4.1.1 Qualitative and quantitative health impact assessment

HIA models can be qualitative or quantitative in nature. Both methods can co-exist and can profit from each other (Nieuwenhuijsen et al. 2017). While qualitative HIA can be carried out rapidly and is less resources-extensive, it does not provide objective information on the magnitude and direction of the expected health impacts. Qualitative HIA most likely draws on information and evidence that is already available or easily accessible (Mindell et al. 2003).

Quantitative HIA, on the other hand, informs numerically on the expected health benefits and risks of the proposed policy and therefore provides a direction and magnitude of expected health impacts. Quantitative HIA may be of special importance for influencing policy proposals, because decision-makers may give more weight to outcomes that are measurable (Joffe & Mindell 2005). Having indications on the effect size of expected impacts can help distinguish between main issues and details and can provide clarity on the tradeoffs (Veerman et al. 2005). Quantitative HIA is unlike to qualitative HIA less sensitive to societal opinions, notions or perceptions. Instead, quantitative HIA draws on best available quantitative scientific evidence. Consequently, quantitatively estimated health impacts might better reflect the real situation and true impact to be expected with the adoption of the proposed policy. Therefore, quantitative HIA estimates can be a defensible and convincing argument in the policy decision-making process.

4.1.2 Health impact assessment of urban and transport planning policies

Urban and transport planning are two public policy sectors that are increasingly recognized to affect human health through the previously described exposure pathways of performance of PA, risk of traffic incidents with injury, exposure to air pollution, noise and heat and determining access to green spaces and surrounding greenness. In fact, urban and transport planning are two of the most common public policy sectors where HIA is applied (Wismar et al. 2007) and quantitative assessments are still on the rise as seen by the rapidly increasing number of quantitative HIA studies published in the (grey and) academic literature in recent years (Mueller et al. 2015; Doorley et al. 2015).

Despite the emerging interest in HIA of urban and transport planning policies, currently only few established quantitative HIA models are available. The few existing ready-to-use quantitative HIA models so far focused almost exclusively on transport planning related policies such as the Health Economic Assessment Tool (HEAT) for walking and cycling (WHO. Regional Office for Europe 2014a), the Transportation, Air pollution and Physical ActivitieS (TAPAS) Model (Rojas-Rueda et al. 2011; Rojas-Rueda et al. 2012), the Integrated Transport and Health Impact Modelling Tool (ITHIM) (Woodcock et al. 2009; Jarrett et al. 2012; Maizlish et al. 2013), or the compact city HIA framework (Stevenson et al. 2016). These existing models exclusively consider exposures of PA, air pollution and the risk of traffic incidents with injury. No quantitative HIA model so far exists that considers the wider urban environment and other related exposures such as the impacts of noise nuisance, land use (e.g. access to green space and surrounding greenness) and climate (e.g. heat).

4.1.3 Comparative risk assessment

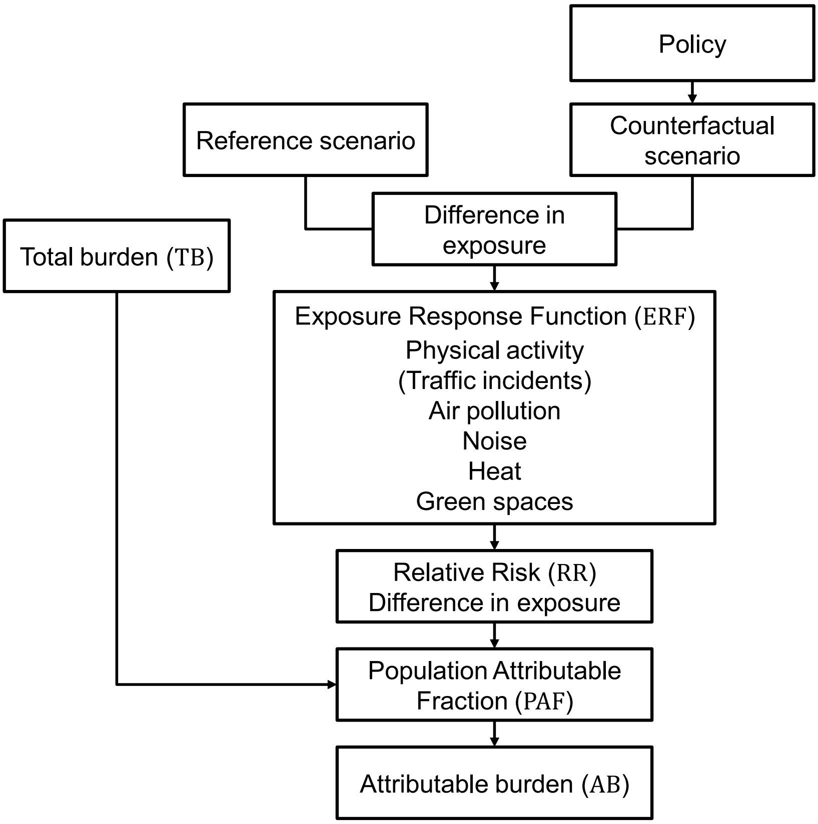
Quantitative HIAs most likely follow a comparative risk assessment methodology that identifies and compares all relevant benefits and risks to health of the proposed policy. Most commonly multiple exposure pathways and their causal networks are considered to allow making inferences about combinations of risk factors, interactive effects and their strength of association with population health (Murray et al. 2004).

The measures of health impacts can be quite diverse across different studies ranging from more general measures such as premature deaths (Rojas-Rueda et al. 2011; Rojas-Rueda et al. 2012) to specific measures such as prevalence of obesity (Woodcock et al. 2009), kilo of adipose tissue (Lindsay et al. 2011) or activity-restriction days (Grabow et al. 2012). Cases of morbidity can be used to demonstrate the variety of health outcomes the policy is associated with. The choice of health outcome is justified by the specific research question the HIA tries to answer. However, it is recommended to additionally study health impacts with a summary health outcome measure (Murray et al. 2002; Murray et al. 2004; Veerman et al. 2005). This summary health measure is used to make health benefits and health risks comparable and represents the net health impact as a single numerical index. The summary health measure can take different natures:

- Premature mortality (and changes in life-expectancy) can be used to estimate the number of all additional or prevented premature deaths associated with the policy (if all considered exposures have been associated previously with mortality).
- A burden of disease measure can be applied such as disability-adjusted life-years (DALYs) that define years of ‘healthy’ life lost due to a certain health condition. DALYs consist of years of life lost (YLLs) due to premature mortality and years lived with disability (YLDs) due to the health condition. Thus, DALYs can make different health conditions with different severities comparable and have been widely used in the GBD Study (Forouzanfar et al. 2015).
- Estimated health risks and benefits can be monetized if it is intended to describe the economic impact of the evaluated policy from a health perspective.

The following paragraphs will explain step by step the methodology of comparative risk assessment that quantitative HIA most commonly applies (Figure 4.1):

Figure 4.1 The comparative risk assessment framework



After Mueller et al. 2017

1. A counterfactual scenario is defined which describes the hypothetical exposure level that is aimed at with the implementation of the proposed policy. Ideally, the policy aims at the minimum-risk exposure distribution (Vander Hoorn et al. 2004). However, as this scenario is most likely unrealistic to achieve, other standards and thresholds can be used as the counterfactual scenario.

2. In the policy context health-relevant exposures need to be identified and exposure levels need to be quantified.

3. The aimed at exposure levels of the counterfactual scenario are compared to the exposure levels in the reference scenario (Vander Hoorn et al. 2004). The reference scenario most commonly describes baseline (i.e. current state-of-the-art), but can also describe any other reference level desired.

4. The health outcome of interest needs to be defined (e.g. mortality, morbidities, DALYs, etc.) that were shown by epidemiological studies to be associated with the exposures. The total burden (TB) of the health outcome needs to be available for the population under study. Incidence rates are preferred over prevalence proportions, because only new cases expected over a given time (i.e. incident cases) are preventable under the assumption that exposure levels will change.

5. An exposure response functions (ERF) that quantifies the strength of association between the exposure and the health outcome needs to be available. This ERF needs to be of best available evidence. In an ideal case, the ERF was estimated particularly for the population under study reflecting most accurately the level of risk the population is exposed to. However, as a particular ERF for the population under study is most likely not available, the ERF should preferably be a

pooled and generalized estimate coming from a meta-analysis (or a large longitudinal study).

6. Exposure levels of the counterfactual scenario are compared to exposure levels of the reference scenario. The relative risk (RR) obtained from the ERF quantifies the strength of association between the exposure and the health outcome. The RR needs to be scaled to the difference in exposure level between the counterfactual and reference scenario (Murray & Lopez 1999; Murray et al. 2004). The scaling is done as follows:

$$RR_{exposure\_difference} = e^{\left(\left(\frac{\ln RR}{E_{RR\_unit}}\right)\times E_{exposure\_difference}\right)}$$

where RR is the relative risk obtained from the ERF;
where E_{RR_unit} is the exposure unit that corresponds to the RR obtained from the ERF;
where $E_{exposure\_difference}$ is the difference in the exposure level between the counterfactual scenario and the reference scenario;
where $RR_{exposure\_difference}$ is the scaled RR that corresponds to the difference in exposure level between the counterfactual and the reference scenario.

In order to calculate the $RR_{exposure\_difference}$ the natural logarithm to the base of e is taken of the RR obtained from the ERF. The ln(RR) is scaled to the exposure level difference between the counterfactual and reference scenario. In order to take the anti-log, the ln(RR) is exponentiated. The exponentiated ln(RR) is the RR corresponding to the exposure level difference between the counterfactual and the reference scenario.

7. The population attributable fraction (PAF) is calculated. The PAF defines the proportional health burden of the health outcome of interest that is attributable to the difference in exposure level between the counterfactual and the reference scenario (Murray et al. 2004; Vander Hoorn et al. 2004). The PAF is calculated as follows:

$$\mathrm{AF} = \frac{\sum_{i=1}^{n} \left(\mathrm{RR}_{\mathrm{exposure\_difference}} - 1\right)}{\sum_{i=1}^{n} \left(\mathrm{RR}_{\mathrm{exposure\_\ difference}} - 1\right) + 1}$$

where P is the proportion of the exposed population;
where $\mathrm{RR}_{\mathrm{exposure\_difference}}$ is the previously scaled RR that corresponds to the difference in exposure level between the counterfactual and the reference scenario.

8. The attributable burden (AB) describes the burden of the health outcome of interest that is attributable to the difference in exposure level between the counterfactual and reference scenario (Murray et al. 2004). The AB is calculated as follows:

where TB is the total burden of the health outcome of interest among the population of interest;

where the PAF defines the previously calculated proportional health burden that is attributable to the difference in exposure level between the counterfactual and the reference scenario.

4.2 The case study city of Barcelona, Spain

To achieve the first and second objective of the present thesis, Barcelona, Spain will be used as the case study city. Barcelona will be assessed on its provision of healthy urban living. Compliance of international exposure recommendations for performance of PA, exposure to air pollution, noise, and heat and access to green spaces among the Barcelona adult population (≥ 20 years) will be used as the counterfactual policy scenarios (Paper I and Paper II).

The city of Barcelona is located on the Spanish northeastern peninsula. Currently, about 1.6 million residents live on a city area of about 100 km^2 (Barcelona City Council 2012). Barcelona has a Mediterranean climate (classified as dry-summer subtropical) with an annual mean temperature of 18 ºC with mild winters and hot summers (Barcelona City Council 2012; Brines et al. 2015). Temperature levels in the densely-inhabited center of Barcelona can be up to 8 ºC higher compared to spacious surrounding areas, because of the UHI effect (Moreno-Garcia 1994). Air pollution and noise levels are amongst the highest in Europe, due to Barcelona's high population and traffic density, a large share of diesel-powered vehicles, low precipitation and an urban design of narrow street canyons framed by semi-tall buildings of 5-6 stories (Nieuwenhuijsen et al. 2014). In turn, green space is mainly located at the hilly west side of Barcelona and only 6.8 m^2 is available on a city-wide average per resident (Barcelona City Council 2012).

4.3 The PASTA project

To achieve the third and fourth objective of the present thesis, data of the Physical Activity through Sustainable Transport Approaches (PASTA) project will be used (Paper III and Paper IV). The PASTA project is a 4-year EC-funded project running between 2013 and 2017. The PASTA project consists of seven case study cities (i.e. Antwerp, Barcelona, London, Örebro, Rome, Vienna and Zurich) that study how active transport (i.e. walking and cycling for transport in combination with public transport) can lead to a healthier, more physically active population despite providing other health and environmental co-benefits (Figure 4.2) (Gerike et al. 2016; Dons et al. 2015). The PASTA project looks into determinants and behaviors of active transport and associated health impacts.

Figure 4.2 The seven PASTA case study cities

The project compromises different project components such as literature reviews on the determinants of active transport as well as on associated health impacts (Paper III); a longitudinal study of 2-year follow-up that studies routine transport behavior of over 10,000 study participants; three add-on studies (i.e. 'health add-on', 'tracking add-on' and 'crashes add-on') that provide insight into transport-related PA and air pollution exposure, into route-choice behavior and linked geo-locations as well as into traffic incident risk related to transport behavior (Gerike et al. 2016; Dons et al. 2015).

The PASTA project also aims to derive parameters for quantitative HIA of active transport policies as there is still uncertainty about methodologies, relevant health exposure pathways, ERFs and other HIA model input parameters (Gerike et al. 2016). Particularly, regarding mode shift scenarios (i.e. from motor transport to active transport) and associated health impacts, there is still uncertainty about and a lack of understanding on:

- the health benefit-risk tradeoff of changed exposure levels of PA, personal air pollution exposure and the risk of traffic incidents;
- wider societal co-benefits such as reductions in air or noise pollution resulting of reduced motor traffic volumes;
- traffic safety and a potential safety-in-numbers effect describing a non-linear increase in the risk of traffic incidents with increasing active transport volume (Elvik & Bjørnskau 2017);
- how population parameters, such as age, sex, socio-economic status or ethnicity, may be of influence in the association between transport behavior and health impacts;
- morbidity, burden of disease (i.e. DALYs) and economic impacts associated with active transport.

Paper III and Paper IV will address some of these uncertainties.

5. RESULTS

5.1 Paper I

Urban and transport planning related exposures and mortality: a health impact assessment for cities

5.2 Paper II

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

5.3 Paper III

Health impact assessment of active transportation: a systematic review

5.4 Paper IV

Health impact assessment of cycling network expansions in European cities

References can be found in the reference section of each paper.

5.1 Paper I

Mueller N, Rojas-Rueda D, Basagaña X, Cirach M, Cole-Hunter T, Dadvand P, et al. Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment for Cities. Environ Health Perspect. 2017 Jan;125(1):89–96. DOI: 10.1289/EHP220

5.2 Paper II

Mueller, N., Rojas-Rueda, D., Basagaña, X., Cirach, M., Cole-Hunter, T., Dadvand, P., Donaire-Gonzalez, D., Foraster, M., Gascon, M., Martinez, D., Tonne, C., Triguero-Mas, M., Valentín, A., Nieuwenhuijsen, M.

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

Under Review in Environment International

Mueller N, Rojas-Rueda D, Basagaña X, Cirach M, Cole-Hunter T, Dadvand P, et al. Health impacts related to urban and transport planning: A burden of disease assessment. Environ Int. 2017 Oct;107:243–57. DOI: 10.1016/j.envint.2017.07.020

5.3 Paper III

Mueller N, Rojas-Rueda D, Cole-Hunter T, de Nazelle A, Dons E, Gerike R, et al. Health impact assessment of active transportation: A systematic review. Prev Med (Baltim). 2015 Jul;76:103–14. DOI: 10.1016/j.ypmed.2015.04.010

Supplementary Material
Paper III

Due to its file size, the supplementary material for Paper III can be found online at:

http://www.sciencedirect.com/science/article/pii/S0091743515001164

5.4 Paper IV

Mueller, N., Rojas-Rueda, D., Salmon, M., Martinez, D., Ambros, A., Brand, C., de Nazelle, A., Dons, E., Gaupp-Berghausen, M., Gerike, R., Götschi, T., Iacorossi, F., Int Panis, L., Kahlmeier, S., Raser, E., Nieuwenhuijsen M., on behalf of the PASTA consortium

Health impact assessment of cycling network expansions in European cities

Submitted to Preventive Medicine

Mueller N, Rojas-Rueda D, Salmon M, Martinez D, Ambros A, Brand C, et al. Health impact assessment of cycling network expansions in European cities. Prev Med (Baltim). 2018 Apr;109:62–70. DOI: 10.1016/j.ypmed.2017.12.011

6. DISCUSSION

In order to address the thesis' objectives to understand, conduct and improve quantitative HIA of scenario analyses of urban and transport planning policies and evaluate whether these policies have the potential to help overcome the current physical inactivity and environmental pollution burden, four research papers were presented. Two original quantitative HIAs of scenario analyses were conducted that assess the mortality, life-expectancy, morbidity, burden of disease and economic implications of current urban and transport planning practices (Paper I and Paper II). One original HIA and one systematic review contribute to the understanding of how active transport may be a policy solution to overcome the current physical inactivity crisis and urban environmental pollution burden (Paper III and Paper IV).

In Paper I and Paper II, it was estimated that almost 3,000 premature deaths (or a 1-year loss in statistical life-expectancy), over 50,000 DALYs and 20 million € of direct health care costs were attributable to non-compliance of internationally-recommended exposure levels of PA, air pollution, noise, heat and access the green spaces in Barcelona. Paper III demonstrated that active transport is a promising policy strategy to overcome low levels of PA and high levels of environmental pollution, and it was estimated that a mode shift to active modes would provide net health benefits. Paper IV demonstrated that the expansion of cycling networks in European cities may be a particular policy option to facilitate a mode shift to active transport. Expansions of cycling networks were associated with increases in cycling mode share and were estimated to provide net health and economic benefits.

The following sections aim at providing an overall and integrated interpretation of the present thesis by discussing main findings (Table 6.1) and contributions to current knowledge, methodological considerations, implications for public health and advancements in quantitative HIA, and finally future research and practice needs.

6.1 Main findings and contribution to current knowledge

6.1.1 Urban and transport planning related exposures and health

In the present thesis, for the first time, multiple urban and transport planning-related exposures and health were linked in an integrated way. Besides the commonly considered exposures of PA, traffic incidents and air pollution, also the exposures of noise, heat and green spaces were considered and quantified, which is novel in quantitative HIA of urban and transport planning. The Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) tool was developed and its utility of estimating the mortality and burden of disease impacts of current urban and transport planning practices was demonstrated on the case study city of Barcelona. Tools such as UTOPHIA are essential for urban and transport planners to integrate 'health' into planning. The planning community requires straightforward yet comprehensive tools to advance this matter.

Table 6.1 Summary of the main findings of the four papers included in the present thesis

Paper	Counterfactual scenario	Setting	Exposures	Summary health outcome	Overall results
Paper I Original HIA	Compliance of international exposure recommendations	Barcelona, Spain	PA, air pollution, noise, heat, green spaces	Mortality, life expectancy, economic savings of avoided mortality	Mortality↓, life expectancy↑, economic savings of avoided mortality↑
Paper II Original HIA	Compliance of international exposure recommendations	Barcelona, Spain	PA, air pollution, noise, heat, green spaces	Morbidity, DALYs, direct health care costs	Morbidity↓, DALYs↓, direct health care costs↓
Paper III Systematic review	Mode shift scenarios from motor transport to active transport	International	PA, air pollution, noise, traffic incidents with injury	Mortality, life expectancy, morbidity, DALYs, direct and indirect health costs	Mortality↓, life expectancy↑, morbidity↓, DALYs↓, direct and indirect health costs↓
Paper IV Original HIA	Cycling network expansion scenarios	167 European cities	PA, air pollution, traffic incidents with injury	Mortality, economic savings of avoided premature mortality	Mortality↓, economic savings of avoided premature mortality↑

With the application of the UTOPHIA tool to the case study city of Barcelona, it was estimated that almost 20% of premature mortality (or a loss of 1-year in statistical life-expectancy), over 50,000 DALYs (i.e. 38,601 YLLs and 13,400 YLDs) as well as over 20 million € of direct health care costs are preventable annually under the assumption that internationally-recommended exposure levels for PA, air pollution, noise, heat and access to green spaces were met (Paper I and Paper II). The estimated 20 million € of direct health care costs is probably a conservative estimate as it only considers direct health care costs of attributable cases (that we were able to quantify) (Paper II). The Value of Statistical Life (VoSL) estimate, which describes the monetary value a society is willing to collectively pay to prevent one statistical death (Andersson & Treich 2011), yielded potential savings of 9 billion € (Paper I).

The in the present thesis estimated health impacts of urban and transport planning related exposures have probably general validity. Impacts of the same scale can be expected in many other cities worldwide that have similar settings and population parameters. Despite the remaining question of how realistic and pursuable the assessed scenario of compliance of international exposure recommendations for PA, air pollution, noise, heat and green spaces truly is, policy-makers and authorities should show commitment and adopt policies that warrant adherence to these standards as much as possible for favorable health outcomes.

Paper I and Paper II also provided insight into the different repercussions of the individual exposures and demonstrated that urban and transport planning-related exposures have different impacts in terms of mortality and burden of disease. Whereas Barcelonians were estimated to die more prematurely from physical inactivity and air pollution exposure (Paper I and Paper II), noise exposure was associated with a larger burden of disease, with especially noise annoyance and sleep disturbance being highly prevalent and contributing largely (i.e. 10548 DALYs) (Paper II). It was also estimated that Barcelonians would be willing to collectively pay 7 million € annually to avoid health risks associated with traffic noise exposure (Paper II), which emphasizes the severity of noise being perceived as a serious health threat (Istamto et al. 2014). With continuing urbanization processes and increases in motor transport volumes, motor transport is nowadays the dominating noise source in cities (Van Renterghem et al. 2015), and thus noise is becoming an increasingly important to consider environmental stressor in the urban context. Generally, heat exposure and green spaces were estimated to have smaller health impacts (i.e. in terms of mortality and burden of disease) (Paper I and Paper II), however, also these two exposures gain in importance in times of climate change (i.e. expected increase in frequency of heat waves) and continuing urbanization processes (i.e. more and more people moving into cities where space is limited). Further consideration and quantification of these exposures in future quantitative HIA of urban and transport planning is desirable.

6.1.2 Mitigation effects of active transport

Results of the present thesis emphasize the importance and necessity to reduce the overwhelming motor transport burden in cities, which was identified as an important cause for low levels of PA and high levels of environmental pollution (i.e. air pollution, noise and heat) (Paper I and Paper II). As a possible policy solution a mode shift from motor transport to active transport has been suggested and the overall health benefit-risk tradeoff of this mode shift was assessed for the first time (Paper III). Active transport was identified to have the potential to increase PA levels and to reduce motor transport-associated emissions (i.e. air pollution, noise and heat). The benefits of increases in PA levels resulting of a mode shift to active transport were found to outweigh the detrimental effects of personal air pollution exposure and the risk of traffic incidents. In addition, a mode shift to active transport was estimated to provide societal co-benefits of reduced air and noise pollution as well as reductions in greenhouse gas emissions and thus active transport can contribute to combating climate change (Tainio et al. 2017). These findings were irrespective of geographical location, suggesting that net benefits of active transport are universally valid (Paper III). Despite all studies, except one study (i.e. 27 out of 28 studies), being conducted in high income settings, subsequent studies (Doorley et al. 2015; Tainio et al. 2016; de Sá et al. forthcoming) support the findings of the systematic review and also provide new evidence that the findings likewise hold true in low/ middle income settings (de Sá et al. forthcoming). It was noted, however, that in a very small number of cities with the highest air pollution levels worldwide, the risks of air pollution exposure might potentially outweigh benefits of PA (Tainio et al. 2016). Despite the latter, and in overall conclusion, the present thesis assessed active transport to be a policy solution that has the potential to overcome the current physical inactivity crisis and environmental pollution burden associated with contemporary motor transport in cities.

Paper III also provided a first insight into health equity implications of active transport. Older people (typically >45 years) were estimated to benefit more from a mode shift to active transport than younger people (typically <30 years). This finding is due to that older people are at increased risk for chronic degenerative disease and increases in PA (best if uptake occurs at younger ages and is sustained throughout the lifespan) can substantially reduce the absolute risk for disease development (Chodzko-Zajko et al. 2009; Vogel et al. 2009). Therefore, in older people the benefits of PA were estimated to greater outweigh the detrimental effects of air pollution exposure and traffic incidents (de Hartog et al. 2010; Dhondt et al. 2013; Edwards & Mason 2014; Woodcock et al. 2014; Xia et al. 2015). Assumptions that health benefits of PA are in fact long-term benefits supports the argument that older people benefit more overall from active transport and thus from any urban and transport planning related intervention where health benefits are expected to predominantly result of increases in PA. In times of demographic change and increasing aging populations this is important to keep in mind in the planning process. Looking exclusively at traffic safety, younger people were estimated to experience a gain in traffic safety when switching to active modes because younger drivers (i.e. car or motorcycle) experience the largest risks for traffic incidents (Stipdonk & Reurings 2012; Schepers & Heinen 2013). On the other hand, in terms of traffic safety, older people were estimated to be more vulnerable in active modes (de Hartog et al. 2010; Stipdonk & Reurings 2012; Dhondt et al. 2013; Schepers & Heinen 2013). Nonetheless, in geographical contexts were walking or cycling for transport is especially risky compared to driving, especially younger people will disbenefit from a mode shift because injury or death at a younger age translates into a larger burden of disease due to higher statistical life-expectancy (Edwards & Mason 2014; Woodcock et al. 2014). Uncertainty on sex effects of active transport mode shift benefits remain. Paper III identified males to benefit more overall from a mode shift to active modes than females, due to (1) males potentially being less likely to achieve PA recommendations (Olabarria et al. 2012), (2) distinct chronic disease development risks between the sexes (Woodcock et al. 2014), and (3) males benefiting more from the reduced motor traffic incident risk (as men generally experience higher risks for severe and fatal incidents as drivers) (Dhondt et al. 2013; Santamariña-Rubio et al. 2014). Clarity on health benefits of active transport and other urban and transport planning-related interventions are pending for socially-disadvantaged and ethnic sub-populations. However, if the benefits are explained, likewise as for older people, through absolute risk reductions in chronic disease incidence [for which socially-disadvantaged and ethnic sub-populations most likely have higher incidence rates (Mackenbach et al. 2008; Modesti et al. 2016)], then these sub-populations are expected to benefit in particular. Albeit, estimated health benefits are only indicative as it is unknown to which extent these subpopulation are responsive to urban and transport planning interventions that require behavior change and associated adherence (Conner et al. 2013). Throughout all health impact estimations (Paper I - Paper IV), it was simply assumed that the uptake of healthy behaviors (e.g. active transport) is habitual; although it is unknown whether healthy behaviors are truly sustained in the long-term.

In Paper IV, cycling network expansions were presented as a potential policy solution to facilitate a mode shift to active transport. As the exposure response relationship between cycling networks and cycling mode share was unknown in European cities, Paper IV provided, for the first time, a continuous ERF, based on publicly-accessible open data for 167 European cities (i.e. OpenStreetMap (OSM) data for cycling ways and European Platform on Mobility Management (EPOMM) data for cycling mode share). The use of open data in Paper IV ensures transparency and reproducibility which adds value to the paper. Moreover, a great strength of Paper IV is that it reflects plausible mode shift scenarios resulting of realistic increases in cycling networks (i.e. S1-S3). Even though, a causal relationship between cycling network and cycling mode share cannot be inferred due to the nature of the study design (i.e. ecological design), expansions in cycling networks were associated with increases in cycling mode share.

Cycling infrastructure was previously identified as one of the most important factors for preferring cycling for transport (de Geus et al. 2008; Pucher et al. 2010; Buehler & Pucher 2012; Heesch et al. 2015; Mertens et al. 2016), thus expansions of cycling networks will most probable lead to the uptake of cycling. In return, increases in cycling mode share were estimated to provide considerable net health benefits across European cities (Paper IV). Cycling network expansions were also estimated to be a cost-effective policy solution as monetized health benefits offset implied construction and maintenance costs in the long-term. The provided ERF between cycling network and cycling mode share may be of particular value to city governments for cycling network planning purposes.

In line with findings of Paper III, in Paper IV the benefits of increases in cycling mode share were estimated to result of increases in PA levels that outweighed detrimental effects of increased personal air pollution exposure and the risk of traffic incidents. Thus, adding to further evidence that active transport provides indeed net health benefits. Interestingly to note, in contrast to some studies (Holm et al. 2012; Rabl & de Nazelle 2012; Dhondt et al. 2013; Woodcock et al. 2014; Buekers et al. 2015), but in agreement with other studies (Rojas-Rueda et al. 2011; Rojas-Rueda et al. 2012), air pollution exposure for the cyclist was found to be a greater premature mortality risk than having a fatal traffic incident. This finding can be explained by the modeling assumptions applied. In contrast to most existing active transport HIA studies (Holm et al. 2012; Rabl & de Nazelle 2012; Dhondt et al. 2013; Woodcock et al. 2014; Buekers et al. 2015), Paper IV contains the assumption that each public transport trip includes a total 10 minute walk to and from public transport. Across all PASTA cities, walking was the most hazardous mode of transport. Thus, the assumption that 75% of the new cycling trips are substituted by previous public transport trips also shifts the risk of having a fatal traffic incident. The reduced risk of having a fatal traffic incident while walking to or from public transport makes the estimated increased risk of having a fatal traffic incident when shifting to cycling appear less severe.

6.1.3 Mitigation effects of green spaces

Paper I and Paper II proposed the reinforcement of green spaces to be a further policy strategy to overcome low levels of PA and high levels of environmental pollution. Despite the fact that green spaces were estimated to provide smaller direct health benefits (Paper I and Paper II), green spaces were suggested to be a tool to improve the total urban environment due to its intrinsic mitigation properties and are therefore an important urban and transport planning management tool.

Green spaces may provide – complementary to active transport – (1) opportunities for PA engagement by providing a pleasant space where people like to become physically active in (Gladwell et al. 2013; Lee et al. 2015); and (2) mitigation of motor transport-associated emissions as vegetation has air pollution absorbing properties (Abhijith & Gokhale 2015), is a natural noise barrier

(Van Renterghem et al. 2015) and can provide shading and cooling of the surroundings by evapo-transpiration of water (Doick et al. 2014; Raji et al. 2015). Moreover, in the urban context where space is limited, the more space that is assigned to publicly-accessible parks and green belts, the less space is available for roadways and the hazardous motor traffic it accommodates (i.e. replacement effect). In addition, vegetation offsets greenhouse gas emissions through carbon dioxide (CO_2) absorption and thus green spaces are likewise as active transport a promising strategy to combat climate change (Pataki et al. 2011; Lee et al. 2015).

6.2 Methodological considerations

This thesis presented three original HIAs (Paper I, Paper II and Paper IV) and one systematic review of HIAs of active transport (Paper III) that shed light on the usefulness of quantitative HIA as a methodology to comprehensively assess non-healthcare policy interventions on their health consequences. Nonetheless, quantitative HIA is limited by the many uncertainties implied. Both, the uncertainties and the utility of quantitative HIA will be discussed in the following sections.

6.2.1 Uncertainty in quantitative health impact assessment

Quantitative HIA modeling is still a fairly new research field that emerged in recent years and is becoming more sophisticated as time progresses. There is currently a lack of standards and best practices. Quantitative HIA carries uncertainties in the estimation of health impacts and is rather an indicative than an empirical research tool (Parry & Stevens 2001). The predictive validity and plausibility of quantified health impacts depends on the application and interpretation of the available supportive evidence (Thomson et al. 2008). Uncertainty is introduced where epidemiological evidence is lacking and causality has not been established. HIA draws on assumptions and extrapolation, where gaps in knowledge on the true properties of parameters exist. A set of decision rules according to the researcher's judgment is applied in the case of uncertainty (Briggs 2008).

Uncertainty related to the scenario definition

Until now, quantitative HIA modeling was restricted mainly to research and academia. Most often HIAs are prospective in nature and make use of hypothetical counterfactual scenarios that describe an ideal situation. However, this ideal situation is often too optimistic and bears little relevance to local authorities and policy-makers (Nieuwenhuijsen et al. 2017) (e.g. assumptions on full compliance of international exposure recommendations in Paper I and Paper II are probably too overeager). Most ambitious scenarios will produce the largest health impacts, whether plausible or not (e.g. see the All-streets scenario (S4) in Paper IV). As it stands, there is a lack of communication between the different policy sectors and interest groups. Non-academic stakeholders often lack expertise to carry out quantitative HIAs and academia is incapable of understanding as to what extend scenarios are plausible, acceptable by local authorities and wanted by the public (Nieuwenhuijsen et al. 2017).

Uncertainty related to the contextual setting

HIAs are fundamentally different from evaluation studies and most likely do not have pre-policy and post-policy evaluation data available; whether health impacts truly occur as previously estimated remains most likely unknown. Therefore, estimated benefit-risk tradeoffs can only be interpreted as an indication of the magnitude of expected health impacts based on best available evidence. Generally, health impact estimations are sensitive to the contextual setting and underlying population parameters. Estimations of health impacts depend largely on the baseline exposure levels of the considered health pathways and the general health status of the population. Thus, varying results can be expected in different settings and contexts. Further, HIA is incapable of capturing and reflecting personal choices or intrinsic motivations for behavior change (e.g. choosing the bicycle over the car) and associated exposure alterations. Therefore, in Paper IV, despite cycling network expansions being associated with increases in cycling mode share, intrinsic motivations of the studied populations to perform a mode shift to cycling are disregarded.

Uncertainty related to the exposure assessment

HIA draws on exposure proxies that are unable to fully capture the actual variability of exposure levels within the population under study. This results in uncertainty in the exposure characterization and may lead to exposure misclassification. In Paper I and Paper II, exposure levels were assigned on census tract level. Despite the fact that there is high variability of exposure levels within the census tracts, it is also unknown whether people actually spend most of their time in the census tract that their residential address is at. In Paper IV, baseline PA levels were available from regional or national health and travel surveys and were extrapolated to the populations under study (i.e. residents of PASTA cities) without certainty that these PA levels reflect the true PA levels of these populations. Moreover, the chosen exposure proxies might be limited in comprehensively representing the full repercussions of the exposure. In Paper I and Paper II, for reflecting heat exposure, temperature means and maximums were used, however, these proxies might not necessarily reflect heat stress, because other factors that have influence such as humidity, solar radiation or wind force were ignored. Also, in Paper I and Paper II, for reflecting green space exposure, ‘access to green space’ was used. Nevertheless, it remains uncertain which exposure unit (i.e. access to green space versus surrounding greenness) better reflects the true association with health since the mechanisms of green spaces providing health benefits are not yet fully understood. In Paper I, Paper II and Paper IV, $PM_{2.5}$ was used as a proxy to reflect air pollution exposure, but $PM_{2.5}$ might vary from place to place in its chemical composition and associated toxicity. In the same context, in Paper I and Paper II, total PA levels of the study population may have been underestimated, because both papers looked at the WHO recommendation on PA. The WHO recommendation, however, only refers to PA levels of moderate-intensity and vigorous-intensity PA (WHO 2010). Therefore, the contribution of light-intensity PA [such as walking, which is especially important in the Barcelona context with a walking mode share of 32% (Barcelona City Council 2013)] was overlooked. As a consequence, Barcelonians may be more physically active than previously estimated, which distorts the estimated health benefit-risk tradeoff.

Uncertainty related to ERFs

Typically, local ERFs and risk estimates (i.e. RRs) are not available and a multitude of risk estimates is obtained from elsewhere and is extrapolated to the population under study (Paper I, Paper II, Paper IV). First, this limits comparability of HIA studies as different risk estimates for the same exposure-health outcome combination may be used. Second, extrapolating risk estimates from one population to another implies that causality of the health effect in the population under study is simply assumed. While estimates that come from meta-analyses are preferred, they are limited in the sense that they only represent a pooled, generalized estimate. Differences in risk between different studies and therefore different populations may actually reflect true variability of the association between the exposure and the health effect and therefore different susceptibilities, especially if the underlying study population parameters vary by a lot. Thus, extrapolation of risks from one population to another introduces uncertainty to HIA.

Furthermore, some exposure-health outcome combinations are easier to quantify than others. As a result, the attributable burden can only be calculated for those exposures that were previously shown by epidemiological studies to have causal health effects (Murray et al. 2004). The more holistically an exposure is assessed, the larger will be the contribution of this exposure to the health burden (Stansfeld 2015). For instance, in Paper I the associations between noise and green spaces with mortality were less certain as seen by the wide confidence intervals (Gascon et al. 2016; Halonen et al. 2015). Moreover, in Paper II, especially the exposures of heat and green spaces were found to show little (quantifiable) associations with morbidity outcomes. The scarce evidence on noise, heat and green spaces might be simply due to the fact that not much research interest existed in these exposures until recently. On the other hand, the more health outcomes an exposure can be associated with and the stronger the exposure-risk gradients (i.e. the larger the RRs) the larger will be the associated burden (Paper II). 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 relationships are suspected (Ezzati et al. 2004). For example, no evidence exists on the association between night time noise exposure and mortality, even though, there are suggestions that noise exposure during night time may in particular be harmful, disturbing restorative processes in the body during sleep (WHO. Regional Office for Europe 2009). In addition, an association between green space and social cohesion has been claimed (Shinew et al. 2004; Wolf & Robbins 2015; Shanahan et al. 2015), however, establishing causality has been difficult, because defining and quantifying green space as well as social cohesion appears complex and challenging. In the same context, 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) as well as with obesity (Dzhambov & Dimitrova 2016), but these associations could not be quantified in Paper II because of the absence of continuous ERFs that would allow scaling of the risk estimate (i.e. RR) to the measured exposure level.

Uncertainty related to health outcomes

Besides drawing on exposure proxies, also health outcomes might need to be approximated if not available for the population under study. While mortality rates most likely are available on city level, morbidity and burden of disease rates (i.e. YLLs, YLDs and DALYs) probably are not. In this case, national estimates have to be used and need to be scaled down to the population under study (Paper II). This scaling, however, despite possibly being sensitive to age and sex variations, is most likely insensitive to other influential population parameters such as differences in health status between city dwellers versus rural populations, ethnicity, socio-economic status, etc., leading to misclassifications of the true health burden for the population under study. In addition, DALYs have been estimated with different methods in the past according to researchers' judgment. While we (i.e. Paper II) estimated DALYs by applying all-cause mortality RRs to estimate natural-cause YLLs and cause-specific RRs to estimate cause-specific YLDs (similar as Tainio et al. 2015); other studies applied cause-specific RRs directly to cause-specific YLLs and YLDs (Ding et al. 2016; Stevenson et al. 2016). We believe that our approach reflects the attributable burden of disease more broadly than would be possible relying on the selected cause-specific RRs only. We believe that this way we also capture (mortality impacts of) associated health outcomes that we were unable to quantify because of the absence of continuous ERFs. Moreover, results of HIAs can be controversial when comparing the health burden of less severe but common health outcomes to severe but rare outcomes (Hänninen & Knol 2011; Tainio 2015). In Paper II, most of the preventable DALYs were estimated to be due to noise exposure, with especially annoyance and sleep disturbance contributing largely (i.e. over 10,000 DALYs). Despite 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 (i.e. many people suffering from noise annoyance and noise-related sleep disturbance) was estimated to contribute to a substantial burden of disease.

Uncertainty related to effect modification

Further uncertainty is introduced when health effects of one exposure are truly depended on another exposure (i.e. effect modification). Consequently, estimated health effects may be unintentionally double-counted. As demonstrated in Paper I, air pollution, noise and heat are all associated with mortality. All three exposures share the common source of ‘motor traffic’ in cities as well as the common mitigators of ‘active transport’ and ‘green spaces’. Therefore, estimated mortality effects might not be independent and synergies may exist between the exposures. While recent reviews suggest physiological mechanisms of air pollution and noise to be different and thus suggest to treat both exposures as separate risk factors in HIA studies (Tétreault et al. 2013; Stansfeld 2015), effect modification of air pollution exposure by temperature has recently been suggested (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 health effects may not be independent (Gascon et al. 2016). Therefore, results of Paper I and Paper II need to be interpreted with caution as synergetic effects of the five exposures cannot be ruled out.

Uncertainty related to time-lags in benefit estimations

In addition, the applied time horizons and possible time-lags in benefit estimations are important to consider. It takes time for health benefits to build-up as achieved through the uptake and sustainment of healthy behaviors (e.g. cycling instead of using the car). Paper III identified (most) benefits of PA to be long-term in nature (Reiner et al. 2013; Chevan & Roberts 2014). Hence, health benefits of PA occur with delay. In the same context, Paper III claims that benefits that occur in the future are less valuable than benefits that occur immediately. To address these issues, in Paper IV we considered a 5-year build-up of health benefits and discounted monetized health benefits by 5%. Comparing health benefits that occur in the future (i.e. PA benefits) with immediate risks to health (i.e. traffic incidents with injury) can distort the overall health benefit-risk tradeoff. Delayed health benefits from PA, but immediate detriments from traffic incidents makes habitual walking or cycling for transport less attractive for younger people, but reinforces the importance for older people (Paper III).

Uncertainty related to the summary health measure

Finally, the interpretability of the summary health measure needs to be discussed. The choice of the summary health measure depends on the target audience the HIA is conducted for. When using premature mortality, misunderstandings can occur because mortality as such is not preventable. The right interpretation is that a risk factor can cause death to occur earlier than expected, as determined by life expectancy. Nonetheless, the concept of life expectancy can be arbitrary in itself, especially if a large number of persons lives past the cutoff age in a good quality of life (Thacker et al. 2006). Moreover, using premature mortality can result in an underestimation of the overall health effect as mortality is an extreme event and only 'the tip of the iceberg' (Künzli et al. 2010; Van Brusselen et al. 2016). Non-fatal outcomes (e.g. hospital admissions, doctor visits, medication use, activity-restriction, etc.) will be impacted before effects in mortality will be noticeable. Using morbidity outcomes is useful to demonstrate the range of health outcomes an exposure has been associated with. Albeit, comparing the disabilities these health outcomes produce is difficult (e.g. comparing a case of hypertension with a case of breast cancer is delicate, because these health outcomes produce different disability weights). Burden of disease concepts such as DALYs (and its components of YLLs and YLDs) are useful measures to compare different health conditions (National Research Council Of The National Academies 2011). Nevertheless, the comprehension and interpretability of DALYs by non-health care professionals (i.e. urban and transport planners and policy-makers) may be limited and currently the use of DALYs is rather bound to academia and science. Monetization of health impacts can be useful as 'money' is universally understood, but it is important to consider that monetary values have different underlying concepts and are context-specific. The VoSL describes a population's collective willingness to pay to reduce the risk of death, which depends on how severe this population perceives the risk of death from a particular cause and the economic wealth of the country (e.g. in Paper IV, VoSL values ranged between 3 and 7 million €) (Bosworth et al. 2017). Therefore, VoSL/ willingness to pay estimates should not necessarily be understood as avoidable costs. Moreover, monetary values fail to reflect alterations in health-related quality of life (e.g. pain and suffering, psychological distress, etc.) (Thacker et al. 2006). Comprehensively considering and quantifying all direct (i.e. health care) and indirect costs (i.e. work absence, productivity loss, reoccupation costs, etc.) a health condition produces is nearly impossible.

6.2.2 Utility of quantitative health impact assessment

Despite the many uncertainties implied, the utility of quantitative HIA needs to be emphasized. HIA is increasingly recognized to be essential for health promotion. In line with the 'health in all policies' principle, quantitative HIA provides opportunities to place 'health' on the agendas of urban and transport planners (and other non-healthcare policy sectors), local authorities and policy-makers and advocates for healthy public policy-making by providing objective evidence.

Utility of disentangling the health benefit-risk tradeoff

Quantitative HIA adds to the comprehension of causes of illness and the role of policy in shaping and determining health outcomes. HIA can help overcome misperceptions that health disparities are exclusively due to lifestyle choices, genetic predispositions and access to medical care (National Research Council Of The National Academies 2011). In contrast to risk assessment that focuses rather on agents and events, HIA focuses on policies and interventions (Briggs 2008). Moreover, HIA provides an alternative paradigm by acknowledging that the environment is not just a hazard but equally provides benefits through ecological services (e.g. habitat, nutrition, access to green space, etc.) (Briggs 2008). Hence, health outcomes cannot exclusively be explained by the exposure to risk factors, but also strongly depend on the effects of positive factors. Urban environments are complex systems with many (positive and negative) exposures operating at the same time. Quantitative HIA of urban and transport planning is trying to disentangle this complexity by comprehensively assessing the multitude of exposures, their often non-linear causal pathways, synergetic operations, and associated health effects (Briggs 2008). Quantitative HIA provides insight into the direction and magnitude of each exposure and thus allows comparison of severities and ramifications across the exposures that with other study designs would not be possible [e.g. Paper I estimated physical inactivity and air pollution exposure to have strong premature morality implications (i.e. large YLL burden), while Paper II estimated noise to cause the largest burden of disease (i.e. large YLD burden)]. The overall outcome of quantitative HIA is an indication of the expected benefit-risk tradeoff of the proposed policy.

Utility of stimulating policy-relevant scientific research

Quantitative HIA can stimulate policy-relevant scientific research. The application of HIA can help identify knowledge gaps and evidence needs and can provide motive for new empirical studies and evidence synthesis. Quantitative HIA can help identify new data sources to answer important pending question, which in return will provide better causal inferences in future HIAs (National Research Council Of The National Academies 2011).

Utility of informed policy-making

Failure to consider the health consequences of public policies can result in unintended health harms and lost opportunities for health promotion (National Research Council Of The National Academies 2011). Identifying and quantifying all relevant benefits and risks to health that a public policy proposal implies, allows policy-makers to take informed and responsive-supporting decisions and actions. 'Health' is usually a strong argument and of importance to the public (with strong self-interest) (Jacobs & Shapiro 1994; Burstein 1998), thus demonstrating intended and unintended health effects can be a defensible and convincing argument in often 'hotly-debated' policy decision-making processes and ensures that health impacts are acceptable and practicable (Wismar et al. 2007). Outcomes of quantitative HIAs can be compared with established numerical criteria or threshold levels that define the significance of the effect (e.g. the international exposure level recommendations studied in Paper I and Paper II). Moreover, quantitative outcomes allow comparison of alternatives (i.e. scenarios) and shed light on the best available choice in terms of health implications. Finally, due to its properties of providing outlooks for the future, outcomes of HIAs can be used for economic evaluations, which is important for planning purposes and resource allocation.

Utility of contributing to health equity

Quantitative HIA provides an assessment of the overall health gains and losses associated with a proposed policy and the distribution of these effects within the population. Quantitative HIA can help uncover vested and manipulative interests of a policy proposal by identifying subpopulations that would unequally be affected or would be disadvantaged. Hence, outcomes of quantitative HIA can provide valuable information on unjust differences and possible gradients of susceptibility (by for instance income, educational level, ethnicity etc.) and can therefore contribute to social equity and the elimination of health inequalities (Collins & Koplan 2009; Forsyth et al. 2010; Joffe & Mindell 2005).

Utility of promoting interdisciplinarity and participation

HIA is an independent discipline that lies at the intersection of science, policy-making, community engagement and outreach. HIA can offer a way to engage different policy-sectors, stakeholders, interests groups and communities as they usually do not work together because of differing priorities, authorities and objectives (National Research Council Of The National Academies 2011). Thus, HIA can contribute to interdisciplinarity and can help overcome the designated silos of each actor and can ensure that all aspects and matters are thoroughly considered. Quantitative HIA provides a platform for scientists to get directly involved in the application of the science they produce to improve public health. At the same time, quantitative HIA can help improve the ability of policy-makers to better understand health implications. Outputs of HIAs can mobilize advocacy and draw the public attention to health issues that were disregarded before. Active engagement of the communities affected by the proposed policy, at all stages of the assessment process, helps to gain a better understanding of their behaviors and necessities and helps to gain their trust and cooperation. This way it is ensured that outcomes in the end are realistic, practicable and acceptable. Hence, quantitative HIA can contribute to democratic planning and decision-making.

6.3 Implications for public health and advancements in quantitative health impact assessment

6.3.1 Implications for public health

Car-centric urban and transport planning practices have contributed to a concerning physical inactivity crisis and high levels of environmental pollution, resulting in a substantial burden of disease in the urban context (Paper I and Paper II). Compliance with international exposure recommendations for PA, air pollution, noise, heat and green spaces should be pursued as much as possible for favorable health outcomes. Overwhelming motor vehicle fleets (facilitated by car-centric city designs) occupy large amounts of public space in cities and have social and equity implications. Reducing private motor transport through the promotion of active transport and the reinforcement of green spaces can help narrowing social and health inequities by making cities equally accessible to all – irrespective of social strata.

Promotion of active transport

Active transport provides the dual purpose of mode of transport and accessible form of PA. Moreover, active transport is economically affordable. Therefore, active transport might have appeals to population subgroups that are commonly irresponsive to the benefits of exercising and leisure time PA (Dons et al. 2015). A mode shift to active transport has been suggested as a promising policy solution to overcome low levels of PA and high levels of environmental pollution (and can possibly contribute to combating climate change and narrowing health inequities). A mode shift from private motor transport to active transport was estimated to result in net health benefits, which was irrespective or geographic context and thus is suggested to be universally valid (Paper III). Hence, as it stands, active transport should be enabled as a means of public health promotion.

Cycling network expansions were proposed as a particular and feasible policy strategy to facilitate a mode shift to active transport. Cycling network expansions were associated with increases in cycling mode share and in return, increases in cycling mode share were estimated to provide considerable net health and economic benefits. Hence, cycling networks expansions are a practical public policy that has the potential to improve public health and should be to be promoted (Paper IV).

Reinforcement of green spaces

Reinforcement of green spaces was proposed as a further policy strategy to overcome the urban physical inactivity crisis and environmental pollution burden. Despite the fact that green spaces were estimated to provide smaller direct health benefits, green spaces were suggested to be a policy tool to improve the total urban environment due to its mitigation properties. Green spaces can provide – complementary to active transport – opportunities for PA engagement by providing a pleasant space where people like to be physically active in and additionally, green spaces can provide mitigation of motor transport-associated emissions of air pollution, noise and heat (Paper I and Paper II). Furthermore, vegetation offsets greenhouse gas emissions and thus is essential for climate change mitigation. Green spaces and surrounding greenness can beautify cities and can add aesthetical appeal, which might be of particular importance for explaining other potential health pathways such as improving mental health and cognitive functioning and providing restoration and positive affect (Triguero-Mas et al. 2015; Wolf & Robbins 2015; Zijlema et al. 2017). In addition, green spaces can help overcome social inequity associated with the occupation of public space (i.e. reduce roadways and replace with green space). Publicly-accessible green spaces are suggested to provide social cohesion (also for deprived communities) and social cohesion is itself important for physical and mental well-being (Groenewegen et al. 2012; Shanahan et al. 2016). However, maintenance, aesthetical appeal and compactness of green spaces are important in order to avoid urban sprawl (Richardson et al. 2012). Concluding, well-maintained green spaces (and surrounding greenness) need to be reinforced in urban environments for favorable public health outcomes.

6.3.2 Implications for advancements in quantitative health impact assessment

There is a strong need for integrated interdisciplinary planning efforts to move away from single sector-planning. Despite sophisticated quantitative HIA modeling still being mainly restricted to research and academia, there is a general consensus that 'health' should be an integrated component of urban and transport planning and needs to be moved onto the agendas of local authorities and policy-makers (Nieuwenhuijsen et al. 2017). Nonetheless, action still needs to be brought forward jointly by health and urban and transport planning professionals in order to ensure that ‘health’ is acknowledged and becomes the guiding subject across the sectors.

Currently, quantitative HIA draws on policy scenarios that are often too optimistic and therefore bear little relevance to urban and transport planners, local authorities and policy-makers. As a matter of fact, there is a communication gap between the different policy sectors. Non-academic stakeholders lack expertise to carry out quantitative HIAs and academia is incapable of fully understanding as to what extend scenarios are relevant and realistic. Therefore, participatory quantitative HIAs that involve all relevant stakeholders at all stages are urgently needed (Nieuwenhuijsen et al. 2017). Knowledge transfer and collaborations in policy, research and practice are essential and will play a key role in promoting healthy public policy-making (including urban and transport planning). Involvement of stakeholders, interest groups and the communities affected ensures that contextual factors are considered, equity impacts are brought to the table and research, policy and practice are made more democratic and inclusive (Bach et al. 2017). Considering health impacts should not be viewed by urban and transport planners as a constraint, but rather as an additional objective that adds value to their plans and will lead to agreement and support of the communities affected. In this context, planners and practitioners require easy-to-use yet comprehensive tools that can assess the health impacts of urban and transport designs. The research community on the other hand needs to become more acquainted and involved with the political scene and increase awareness on implied health impacts through public outreach and advocacy (Nieuwenhuijsen et al. 2017). Participatory research can help communicate epidemiological findings through means that reach far beyond the scientific community (Bach et al. 2017).

6.4 Future research and practice needs

Several future research and practice needs have been identified that should be addressed in subsequent quantitative HIA of urban and transport planning policies.

6.4.1 Research needs

- Need for consideration and quantification of urban and transport planning related exposures that are currently less considered (i.e. noise, temperature, green spaces, etc.) and their associated health effects in order to holistically assess all relevant exposures and their interactive effects in the urban context.
- Need for consideration of effects on health equity, by considering that health impacts might differ by age, sex, ethnicity or socio-economic status.
- Need for local evidence on the exposure-risk gradient for the population under study (i.e. availability of local ERFs) to avoid risk extrapolations.

- Need for further research into the independence of health effects and underlying biological mechanisms in order to rule out effect modification and avoid double-counting of attributable cases.
- Need for further consideration of acute impacts of urban and transport planning policies. For instance, stressing the acute beneficial effects of active transport on quality of life (e.g. less back pain, increased mobility in cities, time savings, less stress, higher life satisfaction, etc.) can emphasize the importance of active transport in cities and can be a convincing argument for policy-makers as effects will be immediate.
- Need for understanding and consideration of time-lags in benefit estimations (i.e. long-term versus immediate impacts) and the implications thereof for the benefit-risk tradeoff.
- Need for sensitivity analysis to test the robustness of applied assumptions and extrapolations because HIA implies a 'set of decision rules' (Briggs 2008).
- Need for further evidence on urban and transport planning associated health impacts in low and middle income settings.
- Need for consideration of impacts of urban and transport policies on other public policy sectors (e.g. impacts on local economies, crime rates, social cohesion, nutrition and food deserts, etc.)

6.4.2 Practice needs

- Need for legislative approaches that support and require quantitative HIA (Winkler et al. 2013). [Need for public resources allocation for routine HIA purposes of public policies.]
- Need for participatory quantitative HIAs that consider all relevant stakeholders, interest groups and the communities affected at all stages.
- Need for support of open access science (i.e. use of open data) to ensure that research activities are transparent, reproducible, accessible to a wider audience and have a positive impact for the communities affected.
- Need for HIA training activities to fill an important educational and human resource gap in public health (Winkler et al. 2013). [Need for basic education and capacity-building in quantitative HIA in (urban and transport) planning programs (Khreis et al. 2016).]
- Need for monitoring and post-policy evaluation studies to validate whether health impacts occurred as previously estimated in prospective quantitative HIA (i.e. validation of methods and applied assumptions and extrapolations).

7. CONCLUSIONS

Overall, and in line with the objectives, the current thesis contributed to the (1) understanding, conducting and improving of quantitative HIA of scenario analyses of urban and transport planning policies, and (2) evaluated whether assessed policies have the potential to help overcome the current physical inactivity and environmental pollution burden in the urban context.

A considerable mortality and morbidity burden was estimated to be attributable to contemporary urban and transport planning practices in cities. The promotion of active transport together with the reinforcement of green spaces were identified as important policy strategies that have the potential to overcome contemporary low levels of PA and high levels of environmental pollution associated with overwhelming motor transport fleets in urban environments.

Quantitative HIA has been identified as a useful tool to quantify associated health benefits and risks associated with current urban and transport planning practices and thus can support informed policy decision-making, aiming at health risk mitigation and benefit maximization for citizens. The wider routine application of quantitative HIA in public policy-making is strongly encouraged in order to provide healthy future urban living.

REFERENCES

Abhijith, K. & Gokhale, S., 2015. Passive control potentials of trees and on-street parked cars in reduction of air pollution exposure in urban street canyons. *Environmental Pollution*, 204, pp.99–108.

Amann, M. et al., 2005. CAFE Scenario Analysis Report Nr. 6. A final set of scenarios for the Clean Air For Europe (CAFE) programme. Available at: http://ec.europa.eu/environment/archives/cafe/activities/pdf/cafe_scenario_report_6.pdf [Accessed April 26, 2017].

Andersson, H. & Treich, N., 2011. The Value of a Statistical Life. In A. de Palma et al., eds. *The Handbook of Transport Economics*. Cheltenham, UK: Edward Elgar, pp. 396–424.

Babisch, W., 2014. Updated exposure-response relationship between road traffic noise and coronary heart diseases: a meta-analysis. *Noise & Health*, 16(68), pp.1–9.

Bach, M. et al., 2017. Participatory epidemiology: the contribution of participatory research to epidemiology. *Emerging Themes in Epidemiology*, 14(2), pp.1–15.

Barcelona City Council, 2012. Barcelona Data Sheet 2012 Barcelona City Council, ed. Available at: http://barcelonacatalonia.cat/b/wp-content/uploads/2012/12/datasheet-2012-angles.pdf [Accessed December 18, 2016].

Barcelona City Council, 2013. Dades bàsiques de mobilitat 2013. Available at: http://prod-mobilitat.s3.amazonaws.com/DADESBASIQUES2013_p1_1.pdf [Accessed April 30, 2017].

Basagaña, X. et al., 2015. High Ambient Temperatures and Risk of Motor Vehicle Crashes in Catalonia, Spain (2000-2011): A Time-Series Analysis. *Environmental Health Perspectives*, 123(12), pp.1309–1316.

Bhalla, K. et al., 2014. Transport for Health: The Global Burden of Disease from Motorized Road Transport. Available at: http://documents.worldbank.org/curated/en/984261468327002120/pdf/863040IHME0T4H0ORLD0BANK0compressed.pdf [Accessed December 5, 2016].

Booth, F.W. et al., 2008. Reduced physical activity and risk of chronic disease: the biology behind the consequences. *European Journal of Applied Physiology*, 102(4), pp.381–390.

Bosworth, R., Hunter, A. & Kibria, A., 2017. *The Value of a Statistical Life: Economics and Politics*, Available at: http://vti.diva-portal.org/smash/get/diva2:669387/FULLTEXT01.pdf.

Briggs, D.J., 2008. A framework for integrated environmental health impact assessment of systemic risks. *Environmental Health*, 7(61), pp.1–17.

Brines, M. et al., 2015. Traffic and nucleation events as main sources of ultrafine particles in high-insolation developed world cities. *Atmospheric Chemistry and Physics*, 15(10), pp.5929–5945.

Van Brusselen, D. et al., 2016. Health impact assessment of a predicted air quality change by moving traffic from an urban ring road into a tunnel. The case of Antwerp, Belgium. *PLoS ONE*, 11(5), p.e0154052.

Buehler, R. & Pucher, J., 2012. Cycling to work in 90 large American cities: New evidence on the role of bike paths and lanes. *Transportation*, 39(2), pp.409–432.

Buekers, J. et al., 2015. Health impact model for modal shift from car use to cycling or walking in Flanders: Application to two bicycle highways. *Journal of Transport and Health*, 2(4), pp.549–562.

Burstein, P., 1998. Bringing the Public Back in: Should Sociologists Consider the Impact of Public Opinion on Public Policy? *Social Forces*, 77(1), pp.27–62.

Cesaroni, G. et al., 2014. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. *BMJ*, 348(f412), pp.1–16.

Chevan, J. & Roberts, D.E., 2014. No short-term savings in health care expenditures for physically active adults. *Preventive Medicine*, 63, pp.1–5.

Chodzko-Zajko, W.J. et al., 2009. Exercise and Physical Activity for Older Adults. *American College of Sports Medicine*, 41(7), pp.1510–30.

Church, T.S. et al., 2011. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PloS One*, 6(5), p.e19657.

Collins, J. & Koplan, J., 2009. Health Impact Assessment: A Step Toward Health in All Policies. *JAMA*, 302(3), pp.315–317.

Colvile, R.N. et al., 2001. The transport sector as a source of air pollution. *Atmospheric Envrionment*, 35(9), pp.1537–1565.

Conner, M. et al., 2013. Moderating effect of socioeconomic status on the relationship between health cognitions and behaviors. *Annals of Behavioral Medicine*, 46(1), pp.19–30.

Dhondt, S. et al., 2013. Integrated health impact assessment of travel behaviour: Model exploration and application to a fuel price increase. *Environment International*, 51, pp.45–58.

Ding, D. et al., 2016. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet*, 388, pp.1311–1324.

Doick, K.J., Peace, A. & Hutchings, T.R., 2014. The role of one large greenspace in mitigating London's nocturnal urban heat island. *Science of the Total Environment*, 493, pp.662–71.

Dons, E. et al., 2015. Physical Activity through Sustainable Transport Approaches (PASTA): protocol for a multi-centre, longitudinal study. *BMC Public Health*, 15(1126), pp.1–11.

Doorley, R., Pakrashi, V. & Ghosh, B., 2015. Quantifying the Health Impacts of Active Travel: Assessment of Methodologies. *Transport Reviews*, 35(5), pp.559–582.

Dzhambov, A.M., 2015. Long-term noise exposure and the risk for type 2 diabetes: a meta-analysis. *Noise & Health*, 17(74), pp.23–33.

Dzhambov, A.M. & Dimitrova, D.D., 2016. Long-term self-reported exposure to occupational noise is associated with BMI-defined obesity in the US general population. *American Journal of Industrial Medicine*, 59(11), pp.1009–1019.

Eakin, H. et al., 2017. Opinion: Urban resilience efforts must consider social and political forces. *Proceedings of the National Academy of Sciences*, 114(2), pp.186–189.

Edwards, R.D. & Mason, C.N., 2014. Spinning the wheels and rolling the dice: life-cycle risks and benefits of bicycle commuting in the U.S. *Preventive Medicine*, 64, pp.8–13.

Elvik, R. & Bjørnskau, T., 2017. Safety-in-numbers: A systematic review and meta-analysis of evidence. *Safety Science*, 92, pp.274–282.

European Commission, 2001. *Towards a Local Sustainability Profile. European Common Indicators. Methodology Sheets*, Luxembourg.

Eze, I.C. et al., 2015. Association between ambient air pollution and diabetes mellitus in Europe and North America: systematic review and meta-analysis. *Environmental Health Perspectives*, 123(5), pp.381–389.

Ezzati, M. et al., 2004. Mortality and burden of disease attributable to individual risk factors. In M. Ezzati et al., eds. *Comparative Quantification of Health Risks. Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Geneva: World Health Organization, pp. 2141–2166.

Fidell, S., Barber, D. & Schultz, T., 1991. Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise. *Journal of the Acoustical Society of America*, 89, pp.221–233.

Forouzanfar, M. et al., 2015. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*, 386(10010), pp.2287–2323.

Forsyth, A., Schively Slotterback, C. & Krizek, K., 2010. Health Impact Assessment (HIA) for Planners: What Tools Are Useful? *Journal of Planning Literature*, 24(3), pp.231–245.

Gascon, M. et al., 2015. Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review. *International Journal of Environmental Research and Public Health*, 12(4), pp.4354–4379.

Gascon, M. et al., 2016. Residential green spaces and mortality: a systematic review. *Environment International*, 86, pp.60–67.

Gerike, R. et al., 2016. Physical Activity through Sustainable Transport Approaches (PASTA): A study protocol for a multicentre project. *BMJ Open*, 6(e009924), pp.1–11.

De Geus, B. et al., 2008. Cycling to work: influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and quality of life. *Scandinavian Journal of Medicine & Science in Sports*, 18(4), pp.498–510.

Gladwell, V.F. et al., 2013. The great outdoors: how a green exercise environment can benefit all. *Extreme Physiology & Medicine*, 2(3), pp.1–7.

Grabow, M.L. et al., 2012. Air quality and exercise-related health benefits from reduced car travel in the midwestern United States. *Environmental Health Perspectives*, 120(1), pp.68–76.

Groenewegen, P.P. et al., 2012. Is a Green Residential Environment Better for Health? If So, Why? *Annals of the Association of American Geographers*, 102(5), pp.996–1003.

Guerreiro, C. et al., 2016. Air quality in Europe — 2016 report. *European Environment Agency*, (28), pp.1–83. Available at: http://www.eea.europa.eu//publications/air-quality-in-europe-2016 [Accessed March 6, 2017].

Gunawardena, K.R., Wells, M.J. & Kershaw, T., 2017. Utilising green and bluespace to mitigate urban heat island intensity. *Science of The Total Environment*, 584-585, pp.1040–1055.

Guo, Y. et al., 2014. Global variation in the effects of ambient temperature on mortality: a systematic evaluation. *Epidemiology*, 25(6), pp.781–9.

Hallal, P.C. et al., 2012. Global physical activity levels: surveillance progress, pitfalls, and prospects. *The Lancet*, 380(9838), pp.247–257.

Halonen, J. et al., 2015. Road traffic noise is associated with increased cardiovascular morbidity and mortality and all-cause mortality in London. *European Heart Journal*, 36, pp.2653–2661.

Hamer, M. & Chida, Y., 2008. Active commuting and cardiovascular risk: a meta-analytic review. *Preventive Medicine*, 46(1), pp.9–13.

Hamer, M. & Chida, Y., 2009. Physical activity and risk of neurodegenerative disease: a systematic review of prospective evidence. *Psychological Medicine*, 39(1), pp.3–11.

Hänninen, O. & Knol, A., 2011. *European Perspective on Environmental Burden of Disease.Estimates for Nine Stressors in Six European Countries*, Helsinki.

De Hartog, J. et al., 2010. Do the health benefits of cycling outweigh the risks? *Environmental Health Perspectives*, 118(8), pp.1109–16.

Heesch, K.C., Giles-Corti, B. & Turrell, G., 2015. Cycling for transport and recreation: Associations with the socio-economic, natural and built environment. *Health and Place*, 36, pp.152–161.

Héroux, M.E. et al., 2015. Quantifying the health impacts of ambient air pollutants: recommendations of a WHO/Europe project. *International Journal of Public Health*, 60(5), pp.619–627.

Hill, J.O. & Peters, J.C., 1998. Environmental contributions to the obesity epidemic. *Science*, 280, pp.1371–1374.

Holm, A.L., Glümer, C. & Diderichsen, F., 2012. Health Impact Assessment of increased cycling to place of work or education in Copenhagen. *BMJ Open*, 2(e001135), pp.1–8.

Vander Hoorn, S. et al., 2004. Estimating attributable burden of disease from exposure and hazard data. In M. Ezzati et al., eds. *Comparative Quantification of Health Risks. Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Geneva: World Health Organization, pp. 2129–2140.

Huai, P. et al., 2013. Physical activity and risk of hypertension a meta-analysis of prospective cohort studies. *Hypertension*, 62(6), pp.1021–1026.

Istamto, T., Houthuijs, D. & Lebret, E., 2014. Willingness to pay to avoid health risks from road-traffic-related air pollution and noise across five countries. *Science of the Total Environment*, 497-498, pp.420–429.

Jacobs, L.R. & Shapiro, R.Y., 1994. Questioning the Conventional Wisdom on Public Opinion toward Health Reform. *Political Science and Politics*, 27(2), pp.208–214.

Jarrett, J. et al., 2012. Effect of increasing active travel in urban England and Wales on costs to the National Health Service. *The Lancet*, 379, pp.2198–2205.

Joffe, M. & Mindell, J., 2005. Health Impact Assessment. *Occupational and Environmental Medicine*, 62(12), pp.907–912.

Van Kempen, E. & Babisch, W., 2012. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. *Journal of Hypertension*, 30(6), pp.1075–86.

Khreis, H. et al., 2016. The health impacts of traffic-related exposures in urban areas: Understanding real effects, underlying driving forces and co-producing future directions. *Journal of Transport and Health*, 3(3), pp.249–267.

Künzli, N., Perez, L. & Rapp, R., 2010. Air Quality and Health. *European Resipratory Society*, pp.1–66. Available at: http://www.ersnet.org/images/stories/pdf/web-AQ2010-ENG.pdf [Accessed April 26, 2017].

Kyu, H.H. et al., 2016. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ*, 354(i3857), pp.1–9.

Lafuente, R. et al., 2016. Outdoor air pollution and sperm quality. *Fertility and Sterility*, 106(4), pp.880–896.

Lee, A.C.K., Jordan, H.C. & Horsley, J., 2015. Value of urban green spaces in promoting healthy living and wellbeing: Prospects for planning. *Risk Management and Healthcare Policy*, 8, pp.131–137.

Li, J. et al., 2017. Modification of the effects of air pollutants on mortality by temperature: A systematic review and meta-analysis. *Science of the Total Environment*, 575, pp.1556–1570.

Lindsay, G., Macmillan, A. & Woodward, A., 2011. Moving urban trips from cars to bicycles: impact on health and emissions. *Australian and New Zealand Journal of Public Health*, 35(1), pp.54–60.

Litman, T., 2014. Introduction to Multi-Modal Transportation Planning: Principles and Practices. *Victoria Transport Policy Institute*.

Mackenbach, J. et al., 2008. Socioeconomic Inequalities in Health in 22 European Countries. *The New England Journal of Medicine*, 358(23), pp.2468–2481.

Mahalingaiah, S. et al., 2016. Adult air pollution exposure and risk of infertility in the Nurses' Health Study II. *Human Reproduction*, 31(3), pp.638–647.

Maizlish, N. et al., 2013. Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay area. *American Journal of Public Health*, 103(4), pp.703–709.

Mertens, L. et al., 2016. Differences in environmental preferences towards cycling for transport among adults: a latent class analysis. *BMC Public Health*, 16(782), pp.1–10.

Michelozzi, P. et al., 2009. High Temperature and Hospitalizations for Cardiovascular and Respiratory Causes in 12 European Cities. *American Journal of Respiratory and Critical Care Medicine*, 179(5), pp.383–389.

Miedema, H., Passchier-Vermeer, W. & Vos, H., 2003. Elements for a position paper on night-time transportation noise and sleep disturbance. *TNO Inro report 2002-59*. Available at: http://www.bruit.fr/images/stories/pdf/TNO_2003_effets_bruit__transport_sur_sommeil.pdf [Accessed July 2, 2015].

Miedema, H. & Vos, H., 2007. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. *Behavioral Sleep Medicine*, 5, pp.1–20.

Mindell, J., Ison, E. & Joffe, M., 2003. A glossary for health impact assessment. *Journal of Epidemiology and Community Health*, 57(9), pp.647–51.

Mindell, J. & Joffe, M., 2003. Health impact assessment in relation to other forms of impact assessment. *Journal of Public Health Medicine*, 25(2), pp.107–112.

Modesti, P.A. et al., 2016. Chronic disease in the ethnic minority and migrant groups: time for a paradigm shift in Europe. *Internal and Emergency Medicine*, 11(3), pp.295–297.

Monninkhof, E.M. et al., 2007. Physical activity and breast cancer: A systematic review. *Epidemiology*, 18(1), pp.137–57.

Moreno-Garcia, M.C., 1994. Intensity and form of the urban heat island in Barcelona. *International Journal of Climatology*, 14, pp.705–710.

Mueller, N. et al., 2015. Health impact assessment of active transportation: A systematic review. *Preventive Medicine*, 76, pp.103–114.

Mueller, N. et al., 2017. Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment for Cities. *Environmental Health Perspectives*, 125(1), pp.89–96.

Murray, C. et al., 2004. Comparative Quantification of Health Risks: Conceptual Framework and Methodological Issues. In

M. Ezzati et al., eds. *Comparative Quantification of Health Risks. Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Geneva: World Health Organization, pp. 1–38.

Murray, C. & Lopez, A., 1999. On the Comparable Quantification of Health Risks: Lessons form the Global Burden of Disease Study. *Epidemiology*, 10, pp.594–605.

Murray, C., Salomon, J. & Mathers, C., 2002. A Critical Examination of Summary Measures of Population Health. In C. Murray et al., eds. *Summary Measures of Population Health: Concepts, Ethics, Measurement and Applications*. Geneva: World Health Organziation.

National Research Council Of The National Academies, 2011. *Improving Health in the United States: The Role of Health Impact Assessment*, Washington, DC: The National Academies Press.

Ng, M. et al., 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*, 384(9945), pp.766–781.

Nieuwenhuijsen, M.J., 2016. Urban and transport planning, environmental exposures and health: new concepts, methods and tools to improve health in cities. *Environmental Health*, 15(Suppl1)(38), pp.161–171.

Nieuwenhuijsen, M.J. & Khreis, H., 2016. Car free cities: Pathway to healthy urban living. *Environment International*, 94, pp.251–262.

Nieuwenhuijsen, M.J. et al., 2017. Participatory quantitative health impact assessment of urban and transport planning in cities : A review and research needs. *Environment International*, 103, pp.61–72.

Olabarria, M. et al., 2012. Health impact of motorised trips that could be replaced by walking. *European Journal of Public Health*, 23(2), pp.217–22.

Parry, J. & Stevens, A., 2001. Prospective health impact assessment: pitfalls, problems, and possible ways forward. *BMJ*, 323(7322), pp.1177–82.

Pataki, D.E. et al., 2011. Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, 9(1), pp.27–36.

Pedersen, M. et al., 2013. Ambient air pollution and low birthweight : a European cohort study (ESCAPE). *The Lancet Respiratory Medicine*, 1(13), pp.695–704.

Pucher, J., Dill, J. & Handy, S., 2010. Infrastructure, programs, and policies to increase bicycling: an international review. *Preventive Medicine*, 50, pp.S106–S125.

Rabl, A. & de Nazelle, A., 2012. Benefits of shift from car to active transport. *Transport Policy*, 19(1), pp.121–131.

Raji, B., Tenpierik, M.J. & van den Dobbelsteen, A., 2015. The impact of greening systems on building energy performance: A literature review. *Renewable and Sustainable Energy Reviews*, 45, pp.610–623.

Reiner, M. et al., 2013. Long-term health benefits of physical activity - a systematic review of longitudinal studies. *BMC Public Health*, 13(813), pp.1–9.

Van Renterghem, T. et al., 2015. Using natural means to reduce surface transport noise during propagation outdoors. *Applied Acoustics*, 92, pp.86–101.

Richardson, E. a et al., 2012. Green cities and health: a question of scale? *Journal of Epidemiology and Community Health*, 66(2), pp.160–165.

Rojas-Rueda, D. et al., 2011. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ*, 343(d4521), pp.1–8.

Rojas-Rueda, D. et al., 2012. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study. *Environment International*, 49, pp.100–9.

Rook, G.A., 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *Proceedings of the National Academy of Sciences of the United States of America*, 110(46), pp.18360–18367.

Royal College of Physicians, 2016. *Every breath we take: The lifelong impact of air pollution. Report of a working party.*, London.

De Sá, T. et al., Health impact modelling of different travel patterns for São Paulo, Brazil. *Environment International*. Forthcoming.

Saelens, B.E., Sallis, J.F. & Frank, L.D., 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25(2), pp.80–91.

Sallis, J.F. et al., 2015. Co-benefits of designing communities for active living: an exploration of literature. *The International Journal of Behavioral Nutrition and Physical Activity*, 12(30), pp.1–10.

Santamariña-Rubio, E. et al., 2014. Gender differences in road traffic injury rate using time travelled as a measure of exposure. *Accident Analysis and Prevention*, 65, pp.1–7.

Sapkota, A. et al., 2010. Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. *Air Quality, Atmosphere & Health*, 5(4), pp.369–381.

Schepers, J.P. & Heinen, E., 2013. How does a modal shift from short car trips to cycling affect road safety? *Accident Analysis and Prevention*, 50, pp.1118–27.

Schifano, P. et al., 2016. Heat and air pollution exposure as triggers of delivery: A survival analysis of population-based pregnancy cohorts in Rome and Barcelona. *Environment International*, 88, pp.153–159.

Schultz, T., 1978. Synthesis of social surveys on noise annoyance. *Journal of the Acoustical Society of America*, 64(2), pp.377–405.

Shahmohamadi, P. et al., 2011. The Impact of Anthropogenic Heat on Formation of Urban Heat Island and Energy Consumption Balance. *Urban Studies Research*, 2011, pp.1–9.

Shanahan, D.F. et al., 2015. Toward Improved Public Health Outcomes From Urban Nature. *American Journal of Public Health*, 105(3), pp.470–477.

Shanahan, D.F. et al., 2016. Health Benefits from Nature Experiences Depend on Dose. *Scientific Reports*, 6(28551), pp.1–10.

Shinew, K.J., Glover, T.D. & Parry, D.C., 2004. Leisure Spaces as Potential Sites for Interracial Interaction: Community Gardens in Urban Areas. *Journal of Leisure Research*, 36(3), pp.336–355.

Sørensen, M. et al., 2011. Road traffic noise and stroke: a prospective cohort study. *European Heart Journal*, 32(6), pp.737–44.

Sperling, D. & Gordon, D., 2008. Two Billion Cars. Transforming a Culture. Available at: http://onlinepubs.trb.org/onlinepubs/trnews/trnews259billioncars.pdf [Accessed March 6, 2017].

Stafoggia, M. et al., 2014. Long-Term Exposure to Ambient Air Pollution and Incidence of Cerebrovascular Events : Results from 11 European Cohorts within the ESCAPE Project. *Environmental Health Perspectives*, 122(9), pp.919–925.

Ståhl, T. et al., 2006. *Health in All Policies. Prospects and Potentials*, Available at: http://www.euro.who.int/__data/assets/pdf_file/0003/109146/E89260.pdf [Accessed March 9, 2017].

Stansfeld, S.A., 2015. Noise effects on health in the context of air pollution exposure. *International Journal of Environmental Research and Public Health*, 12(10), pp.12735–12760.

Stevenson, M. et al., 2016. Land use, transport, and population health: Estimating the health benefits of compact cities. *The Lancet*, 388, pp.2925–2935.

Stipdonk, H. & Reurings, M., 2012. The effect on road safety of a modal shift from car to bicycle. *Traffic Injury Prevention*, 13(4), pp.412–421.

Tainio, M., 2015. Burden of disease caused by local transport in Warsaw, Poland. *Journal of Transport & Health*, 2(3), pp.423–433.

Tainio, M. et al., 2016. Can air pollution negate the health benefits of cycling and walking? *Preventive Medicine*, 87, pp.233–236.

Tainio, M. et al., 2017. Mortality, greenhouse gas emissions and consumer cost impacts of combined diet and physical activity scenarios: a health impact assessment study. *BMJ Open*, 7(e014199), pp.1–11.

Tétreault, L., Perron, S. & Smargiassi, A., 2013. Cardiovascular health, traffic-related air pollution and noise: are associations mutually confounded? A systematic review. *International Journal of Public Health*, 58(5), pp.649–66.

Thacker, S. et al., 2006. Measuring the Public' s Health. *Public Health Reports*, 121(1), pp.14–22.

Thomson, H. et al., 2008. Assessing the unintended health impacts of road transport policies and interventions: translating research evidence for use in policy and practice. *BMC Public Health*, 8(339), pp.1–13.

Triguero-Mas, M. et al., 2015. Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International*, 77, pp.35–41.

United Nations, 2014. *World Urbanization Prospects. The 2014 Revision, Highlights*, New York: United Nations. Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf [Accessed January 15, 2017].

United Nations, 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*, New York. Available at: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

United Nations, 2017. *71/256. New Urban Agenda*, Quito, Ecuador. Available at: http://habitat3.org/wp-content/uploads/New-Urban-Agenda-GA-Adopted-68th-Plenary-N1646655-E.pdf [Accessed April 5, 2017].

Veerman, J.L., Barendregt, J.J. & Mackenbach, J.P., 2005. Quantitative health impact assessment: current practice and future directions. *Journal of Epidemiology and Community Health*, 59(5), pp.361–70.

Vogel, T. et al., 2009. Health benefits of physical activity in older patients: a review. *International Journal of Clinical Practice*, 63(2), pp.303–320.

WHO. Regional Office for Europe, 1999. *Health Impact Assessment: Main concepts and suggested approach. Gothenburg consensus paper*, Gotehnburg.

WHO, 1999. *Guidelines for Community Noise*, Geneva. Available at: whqlibdoc.who.int/hq/1999/a68672.pdf [Accessed September 12, 2016].

WHO, 2006. *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment*, Geneva. Available at: http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf [Accessed April 5, 2014].

WHO. Regional Office for Europe, 2009. *Night noise guidelines for Europe*, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf [Accessed July 26, 2016].

WHO, 2010. *Global Recommendations On Physical Activity For Health*, Geneva. Available at: http://apps.who.int/iris/bitstream/10665/44399/1/9789241599979_eng.pdf [Accessed June 27, 2016].

WHO. Regional Office for Europe, 2011. *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe*, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf [Accessed September 29, 2016].

WHO. Regional Office for Europe, 2014a. *Health economic assessment tools (HEAT) for walking and for cycling, 2014 update*, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0010/256168/ECONOMIC-ASSESSMENT-OF-TRANSPORT-INFRASTRUCTURE-AND-POLICIES.pdf?ua=1 [Accessed February 12, 2017].

WHO. Regional Office for Europe, 2014b. *WHO Expert Meeting: Methods and tools for assessing the health risks of air pollution at local, national and international level*, Copenhagen. Available at: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications [Accessed August 6, 2015].

WHO. Regional Office for Europe, 2016. *Urban green spaces and health: A review of evidence*, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0005/321971/Urban-green-spaces-health-review-evidence.pdf [Accessed December 6, 2016].

Winkler, M.S. et al., 2013. Untapped potential of health impact assessment. *Bulletin of the World Health Organization*, 91(4), pp.298–305.

Wismar, M. et al., 2007. *The effectiveness of health impact assessment: Scope and limitations of supporting decision-making in Europe*, Copenhagen. Available at: http://www.euro.who.int/__data/assets/pdf_file/0003/98283/E90794.pdf [Accessed October 2, 2016].

Wolf, K.L. & Robbins, A.S.T., 2015. Metro Nature, Environmental Health, and Economic Value. *Environmental Health Perspectives*, 123(5), pp.390–398.

Woodcock, J. et al., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*, 374(9705), pp.1930–1943.

Woodcock, J. et al., 2011. Non-vigorous physical activity and all-cause mortality: systematic review and meta-analysis of cohort studies. *International Journal of Epidemiology*, 40(1), pp.121–38.

Woodcock, J. et al., 2014. Health effects of the London bicycle sharing system: health impact modelling study. *BMJ*, 348(g425), pp.1–14.

Xia, T. et al., 2015. Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. *Environment International*, 74, pp.281–290.

Zhao, L. et al., 2014. Strong contributions of local background climate to urban heat islands. *Nature*, 511(7508), pp.216–219.

Zijlema, W.L. et al., 2017. The relationship between natural outdoor environments and cognitive functioning and its mediators. *Environmental Research*, 155, pp.268–275.

Annex I
Co-authorships

Apart from the three original research papers and one systematic review included in this thesis, the PhD candidate co-authored the following publications related to the quantification of health impacts associated with urban and transport planning practices:

Dons, E., Götschi, T., Nieuwenhuijsen, M., de Nazelle, A., Anaya, E., Avila-Palencia, I., Brand, C., Cole-Hunter, T., Gaupp-Berghausen, M., Kahlmeier, S., Laeremans, M**., Mueller, N**., Orjuela, J.P., Raser, E., Rojas-Rueda, D., Standaert, A., Stigell, E., Uhlmann, T., Gerike, R., Int Panis, L. Physical Activity through Sustainable Transport Approaches (PASTA): protocol for a multi-centre, longitudinal study. BMC Public Health 2015; 15(1126):1-11.

Gerike, R., de Nazelle, A., Nieuwenhuijsen, M., Panis, L.I., Anaya, E., Avila-Palencia, I., Boschetti, F., Brand, C., Cole-Hunter, T., Dons, E., Eriksson, U., Gaupp-Berghausen, M., Kahlmeier, S., Laeremans, M., **Mueller, N**., Orjuela, J.P., Racioppi, F., Raser, E., Rojas-Rueda, D., Schweizer, C., Standaert, A., Uhlmann, T., Wegener, S., Götschi, T. Physical Activity through Sustainable Transport Approaches (PASTA): A study protocol for a multicentre project. BMJ Open 2016; 6(e009924):1-11.

Khreis, H., Warsow, K.M., Verlinghieri, E., Guzman, A., Pellecuer, L., Ferreira, A., Jones, I., Heinen, E., Rojas-Rueda, D., **Mueller, N**., Schepers, P., Lucas, K., Nieuwenhuijsen, M. The health impacts of traffic-related exposures in urban areas: Understanding real effects, underlying driving forces and co-producing future directions. Journal of Transport & Health 2016; 3(3):249–267.

Khreis, H., van Nunen, E., **Mueller, N**., Zandieh, R., Nieuwenhuijsen, M.J. Commentary: How to Create Healthy Environments in Cities. Epidemiology 2017; 28(1):60–62.

Nieuwenhuijsen, M.J., Khreis, H., Verlinghieri, E., **Mueller, N**., Rojas-Rueda, D. Participatory quantitative health impact assessment of urban and transport planning in cities : A review and research needs. Environment International 2017; 103:61–72.

Annex II
Media impact (selected)

ara DIMARTS, 28 DE JUNY DEL 2016

SALUT

Barcelona evitaria 3.000 morts a l'any amb un disseny urbà millor

Un estudi xifra per primer cop els costos de fer poc exercici i viure amb massa contaminació, soroll i calor

MARIO MARTÍN MATAS
BARCELONA

Fa temps que les evidències són fermes, però els científics són capaços d'afinar cada cop més els costos negatius de viure en una ciutat contaminada. Sota aquesta premissa, el Centre de Recerca en Epidemiologia Ambiental (CREAL) acaba de fer públic un estudi en el qual, per primer cop, es quantifiquen amb detall els efectes sobre la salut que té viure en un entorn urbà. Per fer-ho, els investigadors s'han centrat en la ciutat de Barcelona, han comparat cinc valors recomanats en l'àmbit internacional amb les exposicions reals i han arribat a una conclusió demolidora: el 20% de les morts atribuïbles a causes naturals es podrien evitar. Això representa gairebé 3.000 defuncions cada any.

"El disseny urbà i el sistema de transport tenen impactes importants en la salut de les persones", resumeix la investigadora principal de l'estudi, Natalie Mueller. Per això, el treball destaca la importància de reduir el trànsit motoritzat, fomentar el transport públic, a peu i en bicicleta, i augmentar la superfície verda que hi ha a la ciutat. Si es fes, i es complissin els nivells recomanats d'activitat física, qualitat de l'aire, soroll, calor i accés als espais verds, l'esperança de vida augmentaria en 360 dies –l'equivalent a posposar unes 3.000 morts cada any–. Encara més, fer-ho permetria un estalvi econòmic de 9.300 milions d'euros, una xifra que els investigadors han calculat tenint en compte el valor estadístic de la vida a Espanya.

L'eina del CREAL, batejada amb el nom d'Avaluació d'Impactes en Salut de la Planificació Urbana i del Transport –Utophia, per les seves singles en anglès–, podria aplicar-se també a altres ciutats. L'any 2050 gairebé el 70% de la població mundial viurà en zones urbanes, raona Mueller, i per això és important que les ciutats es desenvolupin pensant en l'impacte que tenen determinades actuacions. Un exemple d'això seria que cada espai que es guanyés al trànsit servís per augmentar les zones verdes. "Sempre hi ha oportunitats de posar més arbres al carrer. A Barcelona hi ha moltes places que no tenen gens de vegetació", afegeix la investigadora. Després de tres anys de recerca al CREAL, l'estudi que publica la revista *Environmental Health Perspectives* és el resultat del doctorat de Mueller, que insisteix en la importància de reduir el nombre de vehicles de motor, perquè "la infraestructura del cotxe també té el seu cost" i, en el cas de Barcelona, han pogut comprovar que la majoria de trajectes que es fan són inferiors als 5 quilòmetres, una distància que es pot fer amb altres mitjans.

Reduir el trànsit amb un transport públic millor i augmentar el nombre dels carrils bici són les dues receptes que proposa l'estudi. PERE TORDERA

Natalie Mueller
INVESTIGADORA DE L'ESTUDI DEL CREAL
"Mor més gent pels efectes del trànsit que pels accidents"

Primer, l'activitat física

La investigació detalla la diferència entre les mesures reals i el que seria desitjable per a cada indicador, i xifra el nombre de morts associades a cada factor. La falta d'activitat física és el més determinant, perquè provoca més d'un terç del total de morts. Per darrere se situen la qualitat de l'aire, el soroll i la calor. L'accés als espais verds seria el menys important, perquè tan sols provoca unes 116 morts, però Mueller subratlla que la seva vàlua és col·lateral. Les zones verdes animen la gent a fer esport, absorbeixen contaminació, actuen com a barreres de soroll i aporten més zones d'ombra. "Ens connecten amb la natura", afegeix la investigadora.

Barcelona té, a més a més, una sèrie de condicionants peculiars que també es tenen en compte. La zona del centre, més densament poblada, registra temperatures fins a 8 graus centígrads superiors a la d'altres indrets exteriors, simplement per l'efecte de l'illa de calor. Una circumstància que es veu reforçada pels carrers estrets i els edificis consecutius, que impedeixen la circulació de l'aire.

"Malgrat que el nombre estimat de morts evitables per culpa del trànsit és molt més gran que el de les defuncions fruit d'un accident, la seguretat al volant rep molta més atenció", afegeix l'estudi. Amb una flota censada a Barcelona d'uns 500.000 cotxes i 300.000 motos, més enllà de tots els vehicles que entren cada dia a la ciutat, el treball també recull que els trajectes a peu i en bicicleta estan creixent. Per això, els investigadors demanen "més esforços" per consolidar la tendència. L'estudi no podria ser més taxatiu: la vida de 3.000 persones a l'any està en joc.

Cinc recomanacions internacionals molt lluny de complir-se

Exercici físic

L'OMS recomana fer com a mínim uns 150 minuts d'activitat física moderada a la setmana, però el 70% dels barcelonins no ho fan. És la causa de 1.154 morts evitables.

Contaminació de l'aire

La qualitat de l'aire és una gran assignatura pendent. Hi ha una concentració mitjana de 16,6 micrograms per m^3 de partícules petites. No hauria de superar els 10.

Soroll

L'OMS recomana que entre les 7.00 i les 23.00 hores el soroll exterior no superi els 55 decibels, però a Barcelona arriba als 65,1. Això provoca 600 morts prematures.

Calor

La calor excessiva causa 376 morts evitables. Augmentar els espais verds i reduir el trànsit i les superfícies impermeables faria baixar 4 graus la temperatura a l'estiu.

Zones verdes

Es recomana tenir una superfície verda –mitja hectàrea mínim– a 300 metres de distància de casa. A Barcelona només el 30% dels veïns compleixen aquest requisit.

LAVANGUARDIA.com

28 Junio, 2016

Barcelona sufre 3.000 muertes prematuras al año por su diseño urbanístico

La ciudad de Barcelona podría posponer unas 3.000 muertes prematuras cada año con una mejor planificación urbanística y del transporte, según un equipo de investigación liderado por el Centre de Recerca en Epidemiologia Ambiental (CREAL), centro aliado de ISGlobal.

Los científicos se han fijado en los factores perjudiciales para la salud de los urbanitas, entre los que ya se habían contabilizado unas cinco millones de muertes prematuras en todo el mundo. Ahora se fijan en la combinación de cinco factores: un estilo de vida sedentario, la exposición a la contaminación del aire, el ruido y el calor, y la falta de espacios verdes.
Unos 5 millones de personas mueren de forma prematura en ciudades de todo el mundo por contaminación

El resultado de la modelización de estos factores a partir de datos de mortalidad de 1.357.361 residentes en Barcelona mayores de 20 años es extrapolable a otras ciudades, donde también se podrían evitar dos de cada 10 defunciones anuales con un diseño urbanístico más acorde a la salud humana.

“Otras ciudades pueden utilizar nuestra herramienta de modelización para ver los impactos de estos factores en su ciudad”, comenta la primera autora del estudio e investigadora del CREAL sobre UTOPHIA que “por primera vez” analiza el impacto sobre la mortalidad de cinco factores a la vez.

La capital catalana suspende

Barcelona suspende en los cinco factores analizados para los que existe una recomendación internacional de la Organización Mundial de la Salud (OMS). Por ejemplo, los barceloneses solo realizan 77 minutos de **actividad física** semanales mientras que el consejo internacional es de 150 minutos de actividad moderada.
Barcelona no cumple ninguna de las cinco recomendaciones internacionales de la OMS

La **calidad del aire** de la capital catalana también deja mucho que desear. En Barcelona hay 16,6 microgramos de partículas en suspensión por metro cúbico nocivas para la salud, mientras que la recomendación internacional advierte que los niveles deberían ser menores de 10 microgramos de partículas en suspensión.

También en la ciudad condal el ruido supera **el umbral de decibelios (dB)** saludables según la OMS, que los sitúa en 55dB durante el día y en espacios abiertos donde hay ruido. En cambio, Barcelona supera los 65dB.
La capital catalana supera 10dB el umbral aconsejado por los organismos mundiales

Por último, la **temperatura** en Barcelona puede aumentar hasta 8 grados centígrados en zonas del centro más masificadas, en comparación con áreas de alrededor más espaciosas, a causa del efecto isla del calor urbano. Un tercio de sus habitantes vive demasiado lejos de una **zona verde**.

La solución al éxodo urbanita

Las Naciones Unidas calculan que casi tres cuartas partes de la población mundial vivirán en grandes ciudades en el año 2050. Natalie Mueller, comenta que los efectos perjudiciales asociados a las ciudades se podrían revertir con mejores medidas de planificación urbanística y del transporte.

Atasco en Plaça Espanya, en Barcelona (Karen Desjardin#82636 / Getty)

La promoción del transporte público y activo para aumentar la actividad física entre la población y reducir los niveles de contaminación. Mueller también defiende la promoción de más áreas verdes, aunque su efecto directo sobre la salud “es menor” que las otras variables.

“Los espacios verdes animan a la gente a hacer deporte, absorben la contaminación, son un barrera natural contra el ruido y ayudan a refrescar el aire”, defiende sus beneficios.

Los investigadores estiman que el cumplimiento de las recomendaciones podría aumentar la esperanza de vida media en 360 días y un ahorro de 9.300 millones de euros cada año.

ENVIRONMENT

Who's in charge of greening cities?

By 2050, 70 percent of the population is expected to live in urban areas. With pressing environmental problems, it's hoped cities will shift toward sustainability. But without a specific framework, who will lead the way?

Urban population has been increasing for the last decade - along with environmental problems that accompany cities.

Air pollution, noise, too much heat
and a lack of green areas are shared concerns for cities - and all are a result of deficient urban planning.

The magnitude of these problems have been measured in

a recent study carried out in Barcelona,
which has shown that better urban and transport planning in the Spanish city could avoid 20 percent of annual premature deaths.

In light of these problems,

sustainable urban planning
has taken up an important place in the journey toward sustainability across the European Union, where urban areas are home to more than two-thirds of the population.

The European Commission has launched various initiatives, such as the

European Green Capital
competition, and has developed some directives to boost the greening of cities, such as through the implementation of sustainable urban and transport planning.

And national and local governments are starting to make the EU guidelines a reality. In addition to governments, citizens - who are the most affected by the sustainability, or lack thereof, of their cities - are also an important element in building this green future.

But while the need for further sustainable urban planning seems to be shared by both citizens and policy-makers, it is still unclear who should take the lead on such transformation.

Better urban planning is essential for urban areas, which host around 70 percent of European citizens

Clear need for better urban planning

Natalie Müller, leading author of the Barcelona study, told DW that premature deaths due to urban planning has not been of interest until now. "Urban planners have been only considering deaths from traffic accidents."

Developed under a sustainable framework, urban planning could help manage the land use of cities and better cover citizens' basic needs, such as housing and transportation, while reducing the carbon footprint - through less-polluting energy sources and more green areas, among other things.

The EU's Regional Policy has put urban planning as a main focus for the period 2014 to 2020. Around 10 billion euros will be allocated from the European Regional Development Fund (ERDF) for sustainable urban development - not only for the environmental dimension, but also for economic, social and cultural ones.

Maggie Cazal, president and founder of the nongovernmental organization Town Planners Without Borders (USF), told DW that "a good urban planning is the solution to reduce pollution and adapt the city to climate change."

Only 6.8 square meters of green space is available on a city-wide average per resident in Barcelona, the study said

But who moves first?

With the issue on the table, the question remains: Who is in charge of finding a solution? This does not seem to have a clear answer.

Initiatives such as the European Green Capital competition seek to raise awareness among the different EU member states on

how to make cities more sustainable.

The competition's secretariat explained to DW that winners serve as a role model, so that other countries can follow the practices implemented.

They regret, however, that they cannot offer any financial support to the cities - neither before nor after the competition. As in other cases, although the EU mostly elaborates directives to follow, the cities have to figure out the challenge of sustainability mostly on their own - and with the occasional grant from the ERDF.

"The European Commission plays a big role providing the main directives to follow and encouraging governments to act," Cazal said. "But then, each local and national government has to act by itself to implement sustainable urban policies."

Recent signature of the

"Pact of Amsterdam"
seeks to boost direct partnerships between city governments in order to bypass slow movement by national governments and the EU on tackling air pollution.

The German city of Essen was chosen as the European Green Capital for 2017

Bottom-up, global reach

Cazal believes citizens would also have an important role to play. "It would be more interesting if the changes would come from the citizen, from other urban stakeholders, and from the local authorities in a bottom-up way," she said.

Cazal believes active citizen participation and a close relationship with local authorities is the best way to promote more sustainable urban planning - but for that, strong public awareness would be the challenge.

But even supporting a bottom-up approach, Cazal highlighted how the EU could reinforce harmonization of sustainable urban planning norms, such as environmental building standards, or lists of eco-friendly building materials - currently different in each country - and encourage dialogue among countries.

And wherever they start, all initiatives must be accompanied by a global dimension of ecological transformation and include all actors, she concluded.

"The most important thing for sustainable urban planning is to not get deadlocked at local or national borders."

European Commission

Science for Environment Policy

Greener cities and more exercise could dramatically reduce urban mortality rates

Researchers have estimated that, annually, almost 3 000 deaths (i.e. 20% of mortality) in Barcelona, Spain, are premature, and would be preventable if residents lived in urban environments that met international exposure recommendations for physical activity, air pollution, noise, heat and access to green spaces. The results emphasise the need to reduce motorised traffic, promote active and public transport, and provide adequate green space to encourage exercise and mitigate the impacts of environmental hazards in cities.

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Source: Mueller, N., Rojas-Rueda, D., Basagaña X., Cirach, M., Cole-Hunter, T., Dadvand, P., Donaire-Gonzalez, D., Foraster, M., Gascon, M., Martinez, D., Tonne, C., Triguero-Mas, M., Valentín, A. & Nieuwenhuijsen, M. (2016) Urban and transport planning related exposures and mortality: a health impact assessment for cities. *Environmental Health Perspectives*. DOI: 10.1289/EHP220. This study is free to view at: http://ehp.niehs.nih.gov/ehp220/

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Read more about:
Air pollution, Environment and health, Green infrastructure, Noise, Risk assessment, Sustainable mobility, Urban environment

By 2050 almost 70% of people are projected to live in urban environments globally. Certain aspects of urban living, including contemporary car-centric city designs, contribute to a sedentary lifestyle and high levels of air pollution and noise, which are known to contribute to premature death. In addition, cities experience increased heat exposure due to human activities and heat-amplifying effects of the built environment.

Green infrastructure – such as parks, urban gardens and surrounding greenness – can reduce the impacts of these environmental risks and provides well-known benefits for physical and mental health.

In this study, researchers estimated the difference between actual and recommended levels of physical inactivity, exposure to air pollution, noise, heat and insufficient access to green spaces in Barcelona. Barcelona has one of the highest air pollution and noise levels in Europe due to high traffic density, with a high proportion of diesel vehicles, and an urban design of narrow street canyons (where streets are flanked by buildings on both sides) that are shielded by dense construction. The city centre can be up to 8 °C hotter than surrounding areas during summer months and only 7 m^2 of green space is available per resident; green spaces provide benefits in heat reduction and can mitigate traffic noise and possibly air pollution.

The researchers modelled preventable premature mortality and the increase in life expectancy for Barcelona residents if international recommendations for performance of physical activity and exposure to air pollution, noise, heat and provision of green spaces were met.

The researchers used existing international exposure recommendations as follows: physical activity – 150 minutes of moderate intensity or 75 minutes of vigorous intensity aerobic activity per week (World Health Organization — WHO); noise – daytime noise levels not exceeding 55 decibels (dB) (WHO); air pollution – annual mean particulate matter less than 2.5 micrometers in diameter ($PM_{2.5}$) not exceeding 10 micrograms per cubic metre of air ($\mu g/m^3$) (WHO).

Despite no recommendation being available for temperature, it is believed that with changes to the urban plan, such as increasing urban greenery, reducing motorised traffic and improving building design, a cooling effect of up to 4 ºC can be achieved[1]. The recommendation on availability of green spaces was taken from the European Commission's working group 'Measuring, Monitoring and Evaluation in Local Sustainability[2] and the WHO, who both recommend living within 300 m of green space greater than 0.5 hectares in size.

1. Doick *et al.* (2014), Zhao *et al.* 2014
2. Working Groups on Measuring, Monitoring and Evaluation in Local Sustainability, Expert Group on the Urban Environment. *Towards a Local Sustainability Profile: European Common Indicators. Technical Report*. European Commission, 2001.

Science for Environment Policy

Greener cities and more exercise could dramatically reduce urban mortality rates *(continued)*

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Data on current exposure levels for Barcelona residents were taken for: (1) physical activity, from the 2011 Barcelona Health Survey; (2) air pollution, from the European Study of Cohorts for Air Pollution Effects (ESCAPE LUR) 2012; (3) noise, from Barcelona's strategic noise map, 2006 (4) daily mean temperatures for Barcelona from 2009–2014, from the European Climate Assessment and Dataset (Klein Tan 2002) and (5) green space land use, from Urban Atlas, 2007.

The results indicated that over 70% of adults in Barcelona are insufficiently active. Air pollution and traffic noise levels (average current exposure is 16.6 µg/m^3 of $PM_{2.5}$ for air pollution and 65 dB for noise) far exceeded the recommended levels. Summer temperatures in the city exceeded the calculated threshold level on approximately 100 days per year and one third of the population did not live within the recommended distance of a green space.

The researchers estimated that 2 904 premature deaths could be prevented annually if all recommendations were met. This is almost 20% of all annual natural deaths in the city. The largest share of preventable deaths was attributed to insufficient physical activity (1 154 deaths), followed by air pollution (659 deaths), traffic noise (599 deaths) and heat (376 deaths). Access to green spaces was estimated to have the smallest impact on reducing premature mortality (116 deaths).

If these premature deaths were prevented, residents could expect to live, on average, 360 days longer. This benefit to society is valued at around €9.1 billion annually (based on the value-of-statistical-life approach (VoSL) — the amount of money people are willing to spend to save a statistical life).

The researchers acknowledge that the combined effects of the different environmental hazards were not modelled, resulting in potential double counting of deaths. On the other hand, air pollution deaths may also have been underestimated, as certain pollutants, such as nitrogen dioxides, were not considered in this study.

The researchers also acknowledge the limited scientific evidence on the adverse health impacts of noise exposure and beneficial impacts of green spaces. They also point out that the contextual setting and underlying population parameters, such as the general health of the population, personal choices, motivation for behavioural change and time lags between a change and a benefit in any given location, affect human health and the risk of death.

The research, however, does contribute to the understanding of multiple environmental exposures and associated health impacts in an urban setting. The researchers recommend fundamental changes to urban and transport planning. In particular, the use of active and public transport as a means of integrating physical activity into daily life is encouraged and is believed to provide numerous health benefits. Policies to reduce motorised traffic and promote active and cleaner modes of transport should therefore be prioritised. Reinforcement of green infrastructure can also promote engagement in physical activity, mitigate air pollution, noise and heat and has been associated with improvements in mental health, biodiversity and community benefits.