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Review article

Participatory quantitative health impact assessment of urban and transport planning in cities: A review and research needs

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ABSTRACT

Introduction: Urban and transport planning have large impacts on public health, but these are generally not explicitly considered and/or quantified, partly because there are no comprehensive models, methods and tools readily available. Air pollution, noise, temperature, green space, motor vehicle crashes and physical activity are important pathways linking urban and transport planning and public health. For policy decision-making, it is important to understand and be able to quantify the full-chain from source through pathways to health effects and impacts to substantiate and effectively target actions. In this paper, we aim to provide an overview of recent studies on the health impacts related to urban and transport planning in cities, describe the need for novel participatory quantitative health impact assessments (HIA) and provide recommendations.
Method: To devise our searches and narrative, we were guided by a recent conceptual framework linking urban and transport planning, environmental exposures, behaviour and health. We searched PubMed, Web of Science, Science Direct, and references from relevant articles in English language from January 1, 1980, to November 1, 2016, using pre-defined search terms.
Results: The number of HIA studies is increasing rapidly, but there is lack of participatory integrated and full-chain HIA models, methods and tools. These should be based on the use of a systemic multidisciplinary/multisectorial approach and state-of-the-art methods to address questions such as what are the best, most feasible and needed urban and transport planning policy measures to improve public health in cities? Active citizen support and new forms of communication between experts and citizens and the involvement of all major stakeholders are crucial to find and successfully implement health promoting policy measures.
Conclusion: We provided an overview of the current state-of-the art of HIA in cities and made recommendations for further work. The process on how to get there is as important and will provide answers to many crucial questions on e.g. how different disciplines can effectively work together, how to incorporate citizen and stakeholder opinion into quantitative HIA modelling for urban and transport planning, how different modelling and measurement methods can be effectively integrated, and whether a public health approach can bring about positive changes in urban and transport planning.

Contents

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1. Introduction

Over 50% of people worldwide live in cities and this is to increase up to 70–80% over the next 20 years (United Nations, 2014). The United Nations projected that nearly all global population growth from 2016 to 2030 will be absorbed by cities, about 1.1 billion new urbanites over the next 14 years. The UN Habitat New Urban Agenda (UN Habitat, 2016) and the Sustainable Development Goals (SDG, 2015) have provided new impetus into the urban development agenda. Cities have long been known to be society's predominant engine of innovation and wealth creation, yet they are also a main source of pollution, disease and crime (Bettencourt et al., 2007). Cities provide good opportunities for policy change as cities have direct local accountability and are more agile to act than national governments, in terms of governance structures. Well-designed and efficient urban planning and transport systems are essential for cities to thrive. Cities are complex and vary greatly in terms of design, density, diversity and distance to people's destinations. Current urban and transport processes have been less than optimal, creating air pollution, noise exposures, heat islands, lack of green space and sedentary behaviour, to name a few (Nieuwenhuijsen, 2016).

Within and between cities, there is considerable variation in the levels of important environmental exposures such as air pollution, noise, temperature and green space, and in physical activity and motor vehicle crashes, partly due to urban and transport planning practices (Nieuwenhuijsen, 2016). Air pollution (Beelen et al., 2014; Héroux et al., 2015), noise (Basner et al., 2014; Halonen et al., 2015) and temperature (Gasparrini et al., 2015) cause adverse health effects including increased morbidity and premature mortality. Green space has predominantly been associated with positive health outcomes (Hartig et al., 2014, Gascon et al., 2016a, 2016b), but, also some negative impacts such as urban sprawl, gentrification and spread of infectious diseases (Cucca, 2012; Hartig et al., 2014; Lõhmus and Balbus, 2015). Physical activity has many health benefits (Woodcock et al., 2011), Approximately 3–4 million deaths each year are attributable to ambient air pollution and 2.1 million deaths to insufficient physical activity (Forouzanfar et al., 2015). Motor vehicles crashes cause around 1.24 million global deaths annually (WHO, 2015), and some 78 million injuries (Bhalla et al., 2014). We recently showed that 20% of premature mortality in a city like Barcelona is related to urban and transport planning related exposures, including air pollution, noise, temperature, green space, and physical activity, not meeting international exposure level guidelines (Mueller et al., 2016).

Environmental factors are highly modifiable, and environmental interventions at the community level, such as urban and transport planning, have been shown to be promising and more effective than interventions at the individual level (Chokshi and Farley, 2012). Further, changes in the urban environment are long lasting and are arguably permanent while behavioural change campaigns and programs are rarely maintained (Saelens et al., 2003). In order to implement interventions for the urban environments, however, decision-makers need to have a good understanding of the linkages between urban and transport planning, environmental exposures, behaviour and human health and their magnitude to be able to know at which level and to what extent their actions can be targeted effectively. Furthermore, they also need to build an effective dialogue with the population that produces environmental stressors and is impacted at the same time, ensuring in this way public awareness and acceptance, as some measures can be restrictive in nature and therefore be politically unpopular (e.g. vehicle restricted areas and congestion charging zones). Participation should also include a variety of professionals and stakeholders that are already acting towards improving health in cities. At the moment, in cities and related research communities there are often silos of urban planning and development, mobility and transport, parks and green space, environmental departments, and (public) health departments that do not work together well enough, while multi-sectorial and systemic approaches are needed to tackle the multi-faceted environmental and health problems (Nieuwenhuijsen, 2016).

Various ideas and measures have been proposed to promote healthy urban living including the greening of cities (Nieuwenhuijsen et al., 2017, Khreis et al., 2016a) and moving away from car dominated cities towards car free cities (Nieuwenhuijsen and Khreis, 2016; Khreis et al., 2016a). However, these have been only described in qualitative ways and no quantification has been accepted of the actual potential health impacts.

Health Impact Assessment (HIA) has been proposed as one of the main tools to integrate evidence in the decision-making process, and introduce health in all policies (WHO, 1999; Ståhl et al., 2006; NAS, 2011). Multiple international and national organizations proposed HIA as a tool to promote and protect public health in multiple sectors (WHO, 1999; Ståhl et al., 2006; NHS, 2002; IFC, 2009). But until now, in urban and transport planning, HIAs have been used either to assess qualitatively urban interventions without offering more useful/powerful estimations to stakeholders (as mortality, morbidity, life expectancy or monetary estimations) (Shafiea et al., 2013). When quantitative assessments were implemented, these did not entail the stakeholders and citizens' visions and necessities, losing the opportunity of successful implementation or policy utility.

As we show in the literature review included in this paper, currently there are no participatory, integrated full-chain HIA models to assess the overall burden of mortality and morbidity related to urban and transport development and planning in cities. The availability of such participatory, integrated full-chain HIA would allow policy makers to estimate the positive and negative health impacts of current and future policy scenarios. Specifically, in integrated full-chain HIA modelling, the assessment would consider the full-chain from source, through pathways to health impacts, considering multiple exposures and complexities, interdependencies and uncertainties of the real world. These models and tools, if available, should be able to answer various questions such as: what are the best, most feasible and needed urban and transport planning policy measures to improve public health in cities? And are these policy measures acceptable and possible to implement?

The aim of the paper is to review what is currently being done in quantitative HIA of urban and transport planning, identifying the barriers and opportunities and to make recommendations for novel participatory, integrated full-chain quantitative HIA methods. Specific emphasis is given to models and tools that effectively involve citizens and other stakeholders.

2. Methods

To devise our searches and narrative, we were guided by a conceptual framework linking urban and transport planning, environmental exposures, behaviour and health (Fig. 1 after Nieuwenhuijsen, 2016). In this framework, urban and transport planning and design, including land-use and the provision of specific transport infrastructure, leads to certain behaviours including transport mode choice and certain transport planning patterns. Transport mode choice is associated with a range of environmental exposures such as air pollution and noise, which in turn are associated with morbidity and mortality. Increases in public and active transportation may lead to a reduction in environmental exposures and increased physical activity levels, leading to reduced morbidity and mortality. Finally, green space provision may lead to e.g. improved mental health and more physical activity and social contacts and therefore reduce morbidity and mortality. The health effects of urban and transport related exposures and behaviours such as air pollution, noise, temperature, green space, physical activity, motor vehicle crashes have recently been extensively reviewed and we will not discuss them any further (Nieuwenhuijsen, 2016, Nieuwenhuijsen and Khreis, 2016, Khreis et al., 2016a).

Following an initial rapid review of the literature of the topic area and the authors´ knowledge, we searched PubMed, Web of Science, Science Direct, and references from relevant articles in English language from Jan 1, 1980, to November 1, 2016, using the search terms: "city", "urban", in combination with "traffic", "air pollution", "noise", "temperature", "green space", "heat island", "physical activity", "sedentary behaviour", "carbon emissions", "built environment", "walkability", "cycling" and/or "mortality", "respiratory disease", "cardiovascular disease", "hypertension", "blood pressure", "annoyance", "cognitive function", "reproductive outcomes", "health impact assessment", "risk assessment" "participatory approaches" "citizen participation" "empowerment". We do not systematically report the results, but focus on studies, systematic reviews, and meta-analyses published in the past five years (i.e. 2012 to 2016); to provide the latest and most up to date information. We use older articles if they represent seminal research or are necessary to understand more recent findings. We furthermore searched Google for any other material related to "health impact assessment" and "urban and transport planning". We focus our following reporting on 3 areas in particular; HIA, exposure assessment, and citizen and stakeholder participation.

3. Results

3.1. Quantitative health impact assessment

HIA is a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential impacts on the health of a population, and the distribution of those impacts within the population. The most common HIAs are qualitative, aiming only to identify the range of the health determinants associated with a policy, intervention or scenario, and the direction of its impacts (risk or benefit). HIAs can also include a quantitative assessment following a comparative risk assessment approach estimating first the burden of disease (e.g. cases of disease, injuries, deaths, or disability adjusted life years [DALY]), and then comparing this burden of disease (BOD) with the health impacts of a future change associated with a proposed intervention or policy (Briggs, 2008; WHO, 2015) (Fig. 2). The aim is to provide a quantitative estimate of the expected health impact and the distribution thereof for the exposed population that is attributable to an environmental exposure and/or policy. Quantitative assessments include a number of steps (Table 1), and a range of potential scenarios could be evaluated (Table 2). As it stands, the use of quantitative HIA is generally limited to research and academic purposes and the scenarios used in these models are usually judged to be plausible but are optimistic and often not under consideration by local authorities or policy makers. This, in part, is perhaps a reflection of a communication gap between the sectors where non-academic stakeholders lack the tools, knowledge and interest to carry out a quantitative HIA while academics/researchers lack the expertise and understandings as to what extent scenarios are plausible, realizable and acceptable to local authorities or policy makers.

Estimates of the Global Burden of Disease (GBD), the largest BOD study to date, have been produced at national or regional levels (Forouzanfar et al., 2015). In these estimates, physical inactivity and ambient air pollution were estimated to cause more than five million global premature deaths each year, ranking them among the leading risk factors in the global burden of disease study (Forouzanfar et al.,

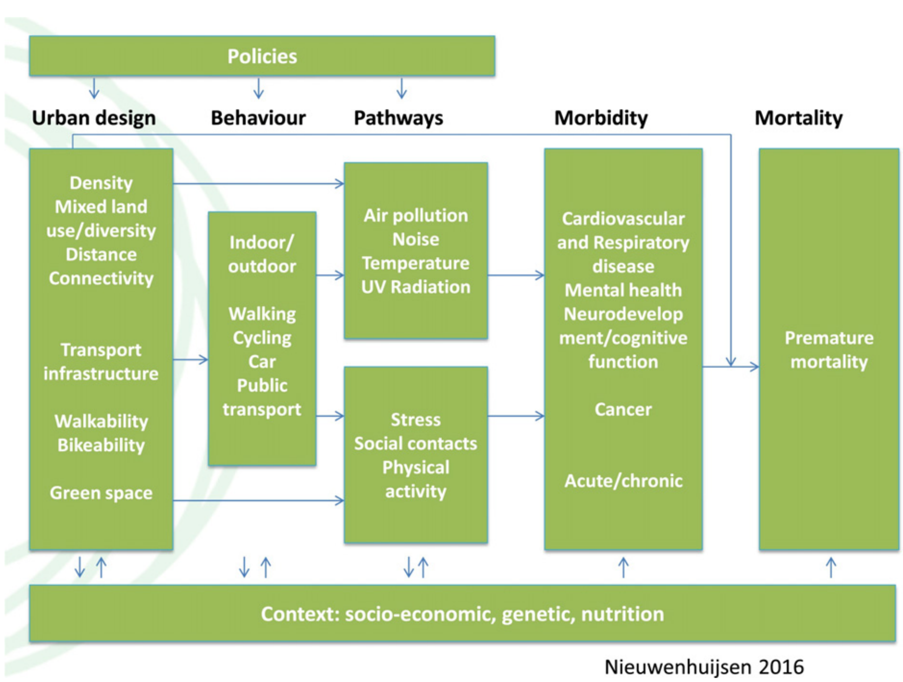

Fig. 1. Conceptual framework of links between urban and transport planning, environmental exposures, physical activity and health (after Nieuwenhuijsen, 2016).

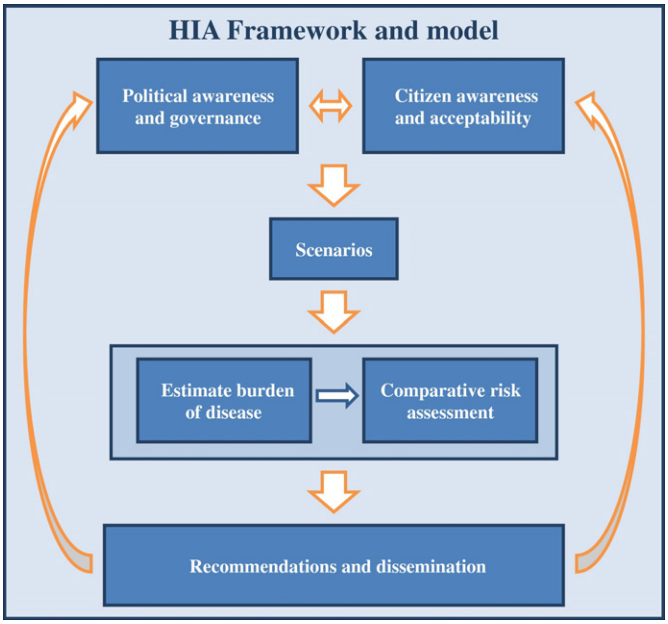

Fig. 2. Connection between parts of the work in a Health Impact Assessment framework.

2015). In another exercise, Lelieveld et al. (2015), estimated that land traffic emissions, on a country level, may be responsible for about one-fifth of the mortality attributable to ambient PM2.5 and O3 in Germany, the UK and the USA, while they globally account for about 5% of the 3.3 million annual premature deaths due to outdoor air pollution. Hanninen et al., 2014 estimated in an environmental BOD assessment the DALYs attributable to the environmental stressors of benzene, dioxins, second-hand smoke, formaldehyde, lead, traffic noise, ozone, particulate matter (PM2.5), and radon, in six European countries and found that about 3–7% of the annual BOD in the six countries is associated with the considered environmental stressors. A study for sparsely populated New Zealand, estimated 25,000 DALYs attributable to traffic incidents, air pollution and noise (Briggs et al., 2016), while a study for the region of Flanders, Belgium found that 11% of the population were severely annoyed and 7% were highly sleep disturbed from environmental noise (Stassen et al., 2008). Finally, Ling-Yun and Lu-Yi, 2016 estimated the effect of reducing the kilometres travelled by Chinese residents by 5% and 10% via increasing cycling, and suggested this would lead to around 1.56% and 3.11% decrease in annual average concentrations of SO2, and 1.40% and 2.80%, 3.09% and 6.18%, 2.93% and 5.86% decrease in NO_2, PM2.5 and PM10, respectively. The number of associated preventable deaths from air pollution-related disease per year were estimated to range from 568.96 thousand to 4515.95 thousand (depending on the scenario being tested), and these health improvements were estimated to save 3433.25 to 27,337.1027 billion Yuan.

GBD estimates or existing national and regional BOD estimates are less useful for city governments and local authorities who must take decisions at the local scale. This draws attention to the need to address and estimate the health impacts of urban life on the local scale. Currently, BOD studies for cities are sparse. Tobías et al., 2014 estimated that 470 deaths were attributable to a theoretic traffic noise exposure decrease by solely 1 dB(A) in Madrid. A recent study for Warsaw estimated more than 40,000 DALYs attributable to air pollution, noise and traffic injuries, with traffic noise contributing the largest (Tainio, 2015). In Barcelona, Mueller et al. (2016) estimated that almost 3000 deaths, making up almost 20% of annual mortality in Barcelona, could be prevented if international recommendations for performance of physical activity, exposure to air pollution, noise, heat, and access to green space were complied with.

Other studies have evaluated specific transport policy measures in cities. Woodcock et al. (2009) estimated the health effects of alternative urban land transport scenarios for two settings-London, UK, and Delhi, India and found that a combination of active travel and lower-emission motor vehicles would give the largest benefits (7439 DALYs in London, 12,995 in Delhi). Creutzig et al. (2012) provided scenarios of increasingly ambitious policy packages, reducing greenhouse gas emissions from urban transport by up to 80% from 2010 to 2040. Based on stakeholder interviews and data analysis, the main target was a modal shift from motorized individual transport to public transit and non-motorized individual transport (walking and cycling) in four European cities (Barcelona, Malmö, Sofia and Freiburg). The authors reported significant concurrent co-benefits of better air quality, reduced noise, less traffic-related injuries and deaths, increased physical activity, alongside less

Table 1
Steps in a HIA and added value in the participatory integrated full-chain (PIF) HIA approach.

HIA steps	HIA task	Added value in the PIF-HIA approach
1. Screening	Selecting proposals.	Proposals selection using stakeholders and citizen participation approaches.
2. Scoping	Identifying health effects and the population groups affected. Describes research questions, data sources, the analytic plan, data gaps, and how gaps will be addressed.	Identification of relevant health effects and populations affected including stakeholders and citizen perspectives. Introduce integrated, full-chain and complex system approach in the analytic plan.
3. Appraisal	Collecting and analyzing quantitative and qualitative data on health effects in various population groups.	Introduce integrated, full-chain and complex system approach. Stakeholders and citizens are informed of the preliminary results and their feedback is integrated at this stage too.
4. Recommendations	Identifies alternatives to proposal or actions that could be undertaken to avoid, minimize, or mitigate adverse effects and to optimize beneficial ones. Proposes a health management plan to identify stakeholders who could implement recommendations, indicators for monitoring, and systems for verification.	Introduce integrated, full-chain and complex system vision in the alternatives to proposal or actions. Include citizens and stakeholder perspectives to prioritize and implement recommendations, to increase their social acceptation and impact. Propose citizen science approaches to complement monitoring and evaluation processes.
5. Reporting and dissemination	Writing an HIA report based on the results. Disseminating the report.	Introduce novel channels of communications through citizens and stakeholder participation.
6. Monitoring and evaluation	Evaluating the process Evaluating the outcome (or results) Evaluating the impact (effectiveness)	Introduce the stakeholder and citizen perspective in the evaluation of the process, based on an iterative process to strength the citizens and stakeholder capacities. Perform outcome evaluation at the citizen's level, through citizen's science approaches, with an integrated, full-chain and complex system vision. Include an evaluation with an integrated, full-chain and complex system vision.

Table 2
General description of examples of Urban and Transport Policies/Interventions/Scenarios that could be modelled using health impact assessment.

Policy area	Description	Types	Examples
Land-use planning	Land-use systems that increase density, diversity of uses and connectivity	Density	Compact cities
		Diversity	Increase horizontal land-use
			Increase vertical land-use
Built environment	All of the physical parts of where we live and work (e.g., homes, buildings, streets, open spaces, and infrastructure).	Design	Improve connectivity
		Maintenance	Control temperature and humidity
		Availability	Increase accessibility
Green spaces	Vegetation in the streets (trees, grass, etc.), squares and parks.	Infrastructure	Increase and improve green spaces
		Management	Improve access and quality of green spaces
		Promotion	Promote use of green spaces
Blues paces	Surface water in urban public spaces (fountains, lakes, rivers, sea front, etc.).	Infrastructure	Increase and improve blue spaces
		Management	Improve access and quality of blue spaces
		Promotion	Promote use of blue spaces
Public transport	Investment in and provision of transport network space for rapid transit/public transport infrastructure	Infrastructure	Improvement and increase of public transport infrastructure
		Management	Improve public transport service
			Reduce public transport costs
		Promotion	Public transport promotion
Active transport (walking and cycling)	Investment in and provision of transport network space for pedestrian and cycle infrastructure	Infrastructure	Improvement and increase of active transport infrastructure
		Management	Improve active transport service
		Promotion	Active transport promotion
Traffic regulation	Reduce car use	Infrastructure	Reduce public space for cars (car lanes and parking)
		Management	Road use an parking pricing
		Promotion	Promote alternative modes of transport
Vehicles & fuels	Invest in new technologies and fuels	Infrastructure	Create city grid for electric vehicles
		Management	Technology and fuels pricing
		Promotion	Promote technological transitions (e.g. electric car or autonomous cars)
Traffic safety	Engineering and speed reduction measures to moderate the leading hazards of road transport	Infrastructure	Built environment changes to reduce speed
		Management	Speed regulations
		Promotion	Traffic safety campaigns

congestion and monetary fuel savings. Perez et al. (2015) modelled various scenarios in Basel including particle emissions standards for diesel cars, increase in active travel and electric vehicle introduction and estimated that the first measure would result in a reduction of premature mortality by 3%, the second one would have little effect and the third one would have the largest effect, as the electricity would come from renewable resources. Ji et al. (2012) compared emissions (CO2, PM2.5, NOX, HC) and environmental health impacts (primary PM2.5) from the use of conventional vehicles (CVs), electric vehicles (EVs) and electric bikes (E-bikes) in 34 major cities in China. E-bikes yielded lower environmental health impacts per passenger-km than gasoline cars (2×), diesel cars (10×), and diesel buses (5×). McKinley et al. (2005) quantified cost and health benefits from a subset of air pollution control measures (taxi fleet renovation, metro expansion and use of new hybrid buses replacing diesel buses) in Mexico City and found that the measures reduced air pollution by approximately 1% for PM10 and 3% for O3. The associated health benefits were substantial and their sum over the three measures was greater than the measures' investment costs (benefit to cost ratio was 3.3 for the taxi renovation measure; 0.7 for the metro expansion measure and 1.3 for the new hybrid buses measure). Xia et al. (2015) estimated that the shifting of 40% of vehicle kilometres travelled to alternative transport in Adelaide, South Australia, would reduce annual average PM2.5 by a small margin of 0.4 μg/m3; preventing 13 deaths a year and 118 DALYS. A range of HIA studies evaluating mortality and other health effects of increases in active transport were recently reviewed and estimated considerable reductions in premature deaths and other negative health outcomes with most benefits attributable to increases in physical activity and low risks of motor vehicles crashes and air pollution for those who switched to public and active transport (Mueller et al., 2015; Tainio et al., 2016).

Furthermore, just recently, studies started evaluating the health impacts of urban planning policy measures in cities. Reisi et al. (2016) evaluated 3 urban planning scenarios in Melbourne for 2030: base case scenario based on governmental plans, fringe focus scenario based on expansive urban development patterns and activity centres scenario based on compact urban development patterns and estimated that the latter resulted in the least greenhouse and other emissions, as well as a reduction of mortality when compared to the other scenarios. Stevenson et al. (2016) estimated the population health effects arising from alternative land-use and transport policy initiatives in six cities. Land-use changes were modelled to reflect a compact city in which land-use density and diversity were increased and distances to public transport were reduced with the objective to reduce private motorized transport and promote a modal shift to walking, cycling, and public transport use. The modelled compact city scenario resulted in health gains for all cities.

Most models have been static (e.g. no feedback loops) and thus insensitive to feedback loops and time delays. Few exceptions emerge in the literature, such as the work of Macmillan et al. (2014). These authors used participatory system dynamics modelling (SDM) to compare the impacts of realistic policies, incorporating feedback effects, nonlinear relationships, and time delays between variables in a study on cycling and societal costs including those related to health impacts. Participatory SDM involves citizen, academic, and policy stakeholders in a process that explores the dynamic effects of realistic policies (Richardson, 2011).

BOD assessments and HIAs encounter many challenges in terms of data availability and assumptions that need to be made and are sensitive to the contextual setting and underlying population parameters. Some of the main problems conducting quantitative HIAs on a city level are the lack of availability of baseline data for some of the exposures and health outcomes, the implied need to make assumptions of these parameters and how to deal with uncertainty.

Finally, there is a general lack of integrated full-chain HIA models. In integrated full-chain HIA modelling for urban and transport planning, the work considers the full-chain from exposure source, through pathways to health endpoints, considering multiple exposures and complexities, interdependencies and uncertainties of the real world and examining multiple scenarios generally. Moreover, the clear majority of HIAs do not involve any form of citizen and stakeholder participation or consultation, despite that these have been recommended in the literature as necessary for public acceptability of proposed interventions and to deal with increasing complexity of the urban realm. Both issues will be addressed in the next sections.

3.2. Full-chain exposure assessment

Exposure assessment, which provides input into HIA is often considered as the weakest part in the HIA chain, particularly if it does not fully incorporate the full characteristics of the exposure, including its sources, pathways and variations. These characteristics are important as the source and pathways of the exposure informs effective mitigation policies. There is considerable variation in exposure levels of urban and transport planning related exposures such as air pollution, noise, temperature and green space. To a large extent, exposure variations depend on urban and transport related indicators. For example, traffic indicators such as distance to roads, surrounding road length, traffic density, and urban indicators such as household density, industry and natural outdoor environments including green space explain a large proportion of the variability of air pollution levels within urban areas (Eeftens et al., 2012a; Beelen et al., 2013). Levels of air pollutants are generally higher at street locations compared to urban background locations (Eeftens et al., 2012b). Also, the levels of ambient noise are associated with e.g. building density, road network, traffic flow, speed and volume, junctions, acoustics and meteorological conditions in cities (Foraster et al., 2011, Bell and Galatioto, 2013, Zuo et al., 2014). Noise levels are significantly higher on high traffic roads compared to acoustic shadows in residential tertiary streets (Bell and Galatioto, 2013). Urban heat islands form where open, wooded or green areas are replaced by concrete and asphalt. They depend e.g. on human activity, population density, green vegetation, urban design and albedo effects (Zhang et al., 2013; Gago et al., 2013; Petralli et al., 2014). Finally, the amount of green space varies considerably between and within cities with green space coverage ranging from 1.9% to 46% (Fuller and Gaston, 2009).

The contribution of different sources to the overall environmental exposures is often unclear and is highly variable depending on source and context. For example, car traffic contributes to a significant proportion of ambient air pollution in cities, but the extent varies depending on factors such as car density, car fleet make-up, traffic conditions, street design, city design and dispersion factors (e.g. wind speed and direction and cloud cover). Traffic contribution to urban PM10 and PM2.5 levels in Europe are on average 39% (range 9–53%) and 43% (range 9–66%), respectively, and are up to over 80% for NO_2 (Sundvor et al., 2012).

To improve understanding and target the right sources with the right mitigation policies, it is important to understand the full-chain of events from sources, through pathways to health, but very few, if any studies have done so. For example, in the case of air pollution exposures, the common lack of full-chain assessment limits disentangling the health impacts of traffic-related air pollution (TRAP) from the health impacts of other emission sources, and vice versa (Khreis et al., 2016b). It also limits the comprehensibility of, and confidence in recommending fleet specific and traffic planning or management specific interventions which would be valuable and desirable for policy makers.

Full-chain assessments could be obtained by coupling existing models of source activity, source emissions, and pathways of exposure, to predict final human exposures and associated health impacts. Again, in the case of TRAP, as an example, this can be done by integrating existing models of traffic activity, traffic emissions, and air dispersion to predict air quality and people's exposure and subsequently estimate associated health impacts (Fig. 3). Data on traffic counts, origin and destination zones and fleet composition can be used to construct traffic activity models for cities (Van Vliet, 1982; Saturn Manual, 2015). The outputs from traffic activity models, most importantly the traffic flows and average traffic speeds, are then linked with vehicle emissions models such as the European leading emission model known as COPERT (Gkatzoflias et al., 2007). Vehicle emission inventories are calculated from this data and are then entered into air dispersion models such as ADMS-Urban (McHugh et al., 1997), which uses this data alongside terrain, meteorological and boundary layer data, to estimate seasonal and/or annual air pollution concentrations in cities.

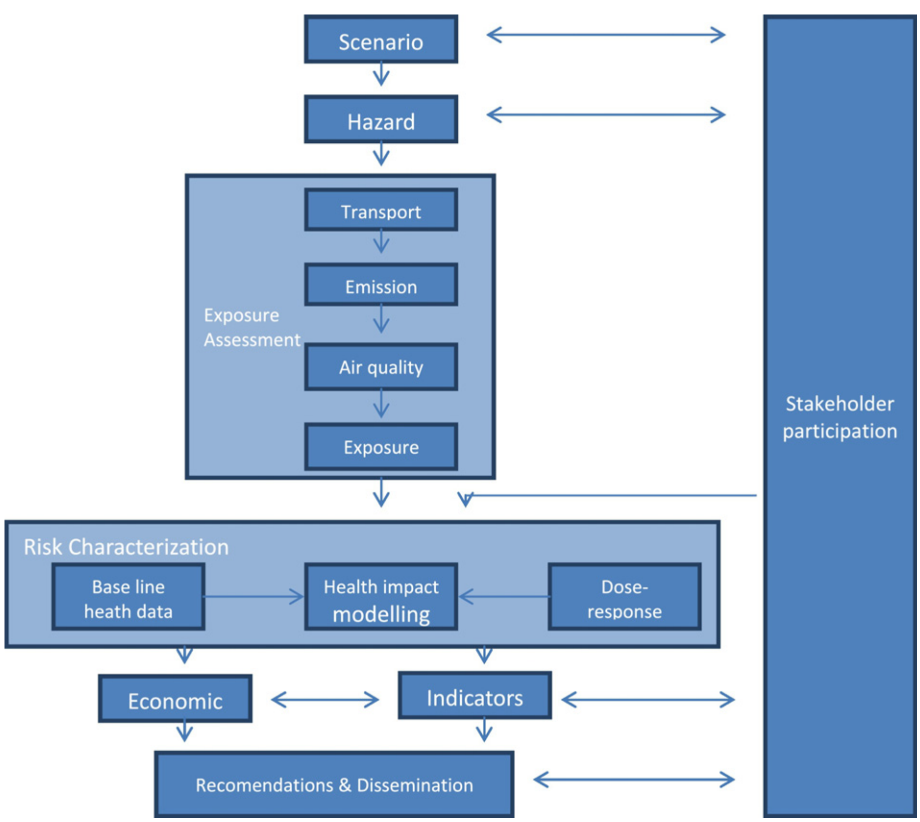

Fig. 3. Participatory full-chain health impact assessment with an example for air quality.

Studies which undertake this full-chain assessment, however, are very few (e.g. Namdeo et al., 2002; Hatzopoulou and Miller, 2010; Wang et al., 2016). Often, such assessments can be problematic as the referred to models are data and labor intensive and require expertise from different scientific disciplines. These models are also not easy to obtain or run due to their high commercial prices, their complex setups and the occasional need for specific arrangements e.g. dedicated UNIX workstation. Furthermore, there are challenges regarding the performance and accuracy of the multiple models used in the exposure assessment chains. Traffic activity models such as SATURN which are used to provide input data for emission models, tend to underestimate congestion and over predict the average traffic speeds over the road network lending inaccuracy to the final emission estimates which are generally higher at the lower average speeds. Vehicle emission models, especially at lower average speeds which incorporate significant proportions of high emitting, fuel consuming, stop-start driving, are uncertain (Health Effects Institute, 2010; Khreis, 2016), and tend to underestimate TRAP emissions. Air dispersion models can over or under predict air pollution levels, in part due to inaccurate traffic and emission inputs, but also due to inherent limitations in these models (Williams et al., 2011) and the incompletion and/or inaccuracy of input data. This causes a propagation of uncertainties and inaccuracies through a complex chain of models involved and is a problem whose implications are not fully understood and is not yet addressed in practice and policy.

Similar approaches as for air pollution could be used for example noise using deterministic models such as the Traffic Noise Exposure model (TRANEX) (Gulliver et al., 2015) or the Common Noise Assessment method in Europe (CNOSSOS-EU) (Morley et al., 2015). For temperature, more empirical models have been used (Zhang et al., 2013; Petralli et al., 2014), while the assessment of green space has relied on remote sensing data and land-use maps (Nieuwenhuijsen et al., 2014).

Finally, there are important issues with the exposure assignment, as people do not simply stay at home but move around the city, which could cause considerable variation in personal exposures. Further work is needed to incorporate the mobility of people and related exposures to obtain better exposure estimates and reduce uncertainty, as for example air pollution exposures during commuting may be much higher than when at home (Nieuwenhuijsen et al., 2015). These patterns of exposure may be hard to model, and to some extent we may have to rely on measurements which are generally more difficult and costly to obtain.

3.3. Citizen and other stakeholder involvement

Changes in city urban and transport planning are difficult to achieve and sustain without direct support of politicians, decision makers, and citizens. There is a considerable body of literature that stresses the importance of citizens' participation in improving planning and decision making in a number of aspects and today participation is recognised to be a fundamental requirement for sustainable development and environmental decision-making (Banister, 2008; Linzalone et al., 2016).

Firstly, involving stakeholders into a decision-making process allows more view-point to contribute to the interpretation of complex issues (Mumpower, 2001). Participation allows planners and decision makers to gain a deeper a more detailed knowledge on stakeholders behaviours, desires, necessities and preferences, becoming an invaluable tool to backup evaluation and assessment procedures such as HIA and allowing better informed decisions (Lowndes et al., 2001; Innes and Booher, 2004; Palerm, 2000). Secondly, participation allows to increase public acceptability of decisions and to build stronger consensus, reduce conflicts and produce shared projects and visions (van de Kerkhof, 2006; Innes and Booher, 2004). As such it can be used to support public decisions. Thirdly, participation can be used as a process to inform and empower citizens developing healthier democratic practices and more fair and just solutions (Palerm, 2000; Bailey and Grossardt, 2010; Bailey et al., 2012; Innes and Booher, 2004; Renn and Webler, 1995). Finally, participation can generate in itself spaces of information diffusion, knowledge exchange and creation, becoming a space in which practices and behaviours can be transformed and social learning built (Sagaris, 2014; Kesby, 2005; Palerm, 2000; Reed, 2006).

With these benefits, participation can assume a variety of formats and forms of engagement that span from surveys, interviews, online interaction, to more dialogic spaces such as focus groups, citizen juries, and community planning events (Lowndes et al., 2001, Arnstein, 1969 Pretty, 1995, Farrington, 1998, Goetz and Gaventa, 2001, Lawrence, 2006, Souza, 2001).

In the specific content of (qualitative) HIA, participation has been considered fundamental under the assumption that that health must be generated within people and monitored by them (Cave and Curtis, 2001; Chadderton et al., 2017; Kearney, 2004). In 1999, the Gothenburg Consensus paper (ECHP, 1999) considered bounding together HIA and participatory approaches central to HIA democracy, equity and ethical use of evidence. Later, participation was recommended by the Merseyside Guidelines as needed thought-all the HIA process (Scott-Samuel et al., 1998). Specifically, authors such as Chadderton et al. (2017), Linzalone et al. (2016) have indicated how participation within HIA can contribute to the development of a democratic society; empower communities, build a sense of responsibility and ownership that are in themselves health benefits; and integrate citizens' knowledge and values with specific attention to disadvantaged groups. These other forms of knowledge can support the evidence built with quantitative measurements with nuanced qualitative inputs and local knowledge on political and social circumstances (Linzalone et al., 2016) and to formulating more sustainable recommendations contributing to raised awareness of health impacts, increasing effectiveness and applicability of the outcomes.

However, the overall implementation of participatory approaches within HIA is not widespread, particularly not in quantitative HIA. The literature reports only a few studies in which stakeholders have been consulted during HIA (e.g. Kearney, 2004, Greig et al. 2004, Creutzig et al., 2012, Macmillan et al., 2014, Linzalone et al., 2016); among which only very few used participatory methodologies in combination with quantitative assessments. For example, Linzalone et al., 2016 integrated a quantitative HIA based on epidemiological study of plausible causes of mortality and morbidity with the Agenda21 methodology for participation, based on focus groups and meetings with community stakeholders all along the process. With this methodology, the authors prepared the terrain for new forms of HIA to overcome the barriers between various forms of technical knowledge and these local knowledges. Following this, it is clear that there is a need for citizens and stakeholder participation in HIA, especially those parties with vested interest that may be affected by the proposed or investigated scenarios. We advocate for it, being however aware that participation can have its shortcoming and can be not as effective as expected especially when lacking adequate time resources or when not specifically addressing power unbalances and communication issues (Elvy, 2014).

In HIA, citizens and stakeholder participation should occur in the selection of the scenarios, identification of health effects and vulnerable populations, selection and periodization of recommendations; identifying the best channels of dissemination and monitoring and evaluation (Table 1). Particularly important is to include more vulnerable groups such as those with low socio economic status, children, pregnant women and the elderly who all have their specific needs. More and more often, new kind of citizen participation, as citizen's science, have begun to offer new tools to assess and include the citizens' perspective in the public health arena.

New models of HIA need to take advantage of these innovative citizens' participation approaches to improve the utility, social acceptance and impact of their results. As such they can build a dialogue among different sectors and actors, avoiding to reproduce a pattern in which the use of quantitative HIA is limited to academia. Incorporating other views can indeed enhance the understanding of how plausible, realizable and acceptable scenarios developed by HIA practitioners are and whether authorities would ever consider them for implementation.

4. Discussion and research needs

4.1. In summary

The number of HIA studies related to urban and transport planning is increasing rapidly, but there is a need for novel participatory integrated full-chain HIA models, methods and tools that assess the full-chain of events from initial planning decisions and scenarios linking sources, emissions, exposures and health impacts, and considering multiple exposures and complexities, interdependencies and uncertainties of the real world. There is a need to develop these models and tools specifically for application in cities which have now come to the forefront of providing solutions for environmental and health issues. Decision-makers need to have a good understanding of the linkages between urban and transport planning, environmental exposures, behaviour and human health and their magnitude through the different pathways to be able to know at which level and to what extent their actions can be targeted effectively. They also need to build this in dialogue with the public and other stakeholders, creating an environment of collaboration and feedback and guaranteeing public acceptance of proposed policy measures. Participatory HIA can increase the public's level of awareness of preventable health hazards in cities. The lack of public awareness has been previously suggested to reinforce the lack of political commitment and initiative to address these problems (Khreis et al., 2016a). A full-chain approach also allows decision makers to target their actions at different stages in the chain so they can make cost effective decisions at each stage.

This approach could answer various pressing questions such as: what are the best and most feasible urban and transport planning policy measures to improve public health in cities? (Table 2) The process on how to get there is as important as the actual output of the project, as the process may provide answers to important questions as to how different disciplines/sectors can effectively work together and develop a common language, how to best incorporate citizen and stakeholder into quantitative HIA modelling, how different modelling and measurement methods can be effectively integrated, and whether a public health approach could make changes in urban and transport planning.

4.2. Quantitative and qualitative approaches

Currently there is no overarching HIA model for cities that can deal with multiple exposures and complexities, data limitations, location-specific effects, errors etc., and we must work with separate quantitative and qualitative models/modules which from one perspective may be considered as an advantage to reduce the complexity and burden of this work. In our experience, the quantitative estimates that have been produced so far have been useful for policy makers by placing actual numbers of health impacts on different policy scenarios. This policy-specific quantification has been an advantage when compared to a qualitative approach, but both approaches have their merit and can co-exist. In particular, we believe that qualitative studies should be performed in preparation of quantitative ones, preparing the terrain -in terms of accessing the data, but also influencing the political and policy discourses-, and informing on the necessity and utility of a full quantitative HIA. A qualitative approach may be preferred in cases where there is no good quality quantitative data available.

Quantitative HIAs are unlikely to be conducted for small projects, where generally little funding is available, although if models are previously set-up and exposures are readily available for the area, then undertaking the assessment would be feasible. However, we are also aware that a qualitative approach in some of these cases may suffice or at least be used successfully to prepare the favourable terrain to gather more resources for more comprehensive studies. On the other side, we stress that large infrastructure projects or comprehensive urban planning projects which are long-lasting, highly impactful on the population's exposures, and highly consuming of public money could highly benefit from participatory quantitative HIAs. HIAs can be particularly effective especially when different options/scenarios are available for the future, and a political decision has not been made yet or is difficult to reach. Knowing and disseminating the possible scenarios and the associated health impacts can then play an important role, especially bringing the public's attention to what new policies and projects mean for their communities' health. The concept of 'health' is usually a strong argument for the public (or the population affected) to be in favour for a certain policy to be implemented. Being able to demonstrate the magnitude of expected health benefits – as possible with participatory, quantitative HIAs – can influence the acceptance/ decision process. Health has not been high on the agenda for such projects, but, as the current national and international debates across Europe and beyond demonstrate, more and more citizens rate health highly. They also would object to large changes when they have not been involved in decision making (e.g. Barcelona SuperIlles). Although more expensive, a participatory quantitative HIA may pay off in the long term by providing positive and sustainable changes with the least adverse health impacts and greatest acceptability. Relevant stakeholders can contribute in this process with their expertise. A participatory, quantitative HIA ensures that no aspect is forgotten, that the process is inclusive and comprehensive and that a consensus can be reached at the end by weighing the estimated risks against the benefits.

As indicated in the review, there are already a few quantitative HIA models and tools that have been used in specific case studies, for example the Health Economic Assessment Tool (HEAT) for walking and cycling, the Integrated Transport and Health Impact Modelling Tool (ITHIM), the Transportation, Air pollution and Physical Activities (TAPAS) model, or the Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) model. Except for HEAT, these tools and models still tend to be research tools that are being further developed and improved, but have the potential to be used in practice. The way these studies have been performed also shows how multidisciplinary teams of academics, both from qualitative and quantitative backgrounds, would can take the process through all its phases.

4.3. Challenges

One challenge for HIA is getting good input data for e.g. exposure, exposure-response relationships and health outcomes, and this type of high quality data may not be always available. Previous models and tools have been solving this challenge accessing input data through multiple official databases from public entities, identifying information on health, exposures and population. What stands out is also the importance of developing a comprehensive search strategy for input data, from different data sources, languages and time periods, and also the importance of data quality assessment and final comprehensive models validation. The input data identification is without doubt one of the most important steps in the quantitative HIA process, and cannot be achieved without a close collaboration with the stakeholders. The participation of different stakeholders, approached with a variety of methods and participatory tools, is crucial for the identification of specific and high quality data.

With regard to epidemiological input data on the exposure-response functions, performing a systematic review of the literature will be the key point for identifying the most robust evidence to quantify the health impacts. Quantitative HIA have limitations in assessing the complexity of real policies or scenarios, mainly because of the unavailability of the needed amount of quantitative evidence, limiting the results of a quantitative HIA to those exposures and outcomes that can be quantified. Quantitative HIA can highlight these limitations and also be combined with qualitative HIA, so to generate recommendations able to involve and inform the stakeholders in a broader dimension.

A further challenge is now to make models accessible, so that they can be used outside the research community by practitioners and policy makers. Only in this way we can ensure that HIA has the needed wide uptake in cities across countries. Simplification without losing the essence may be the answer and this is for example the approach in the PASTA project. Similarly, models that are coupled with qualitative evidences and built with the collaboration of stakeholders might have wider impact on the policy realm and as such be more easily disseminated across different actors and cities, becoming best practice in the process of policy transfer and policy learning.

4.4. Further research needs

An important component of further research is the improvement or further development of conceptual frameworks for urban and transport planning, environmental exposures, behaviour and health bringing in aspects of the full-chain of events and considering multiple exposures and complexities, interdependencies and uncertainties of the real world (Briggs, 2008; de Nazelle et al., 2011; Macmillan et al., 2014; Nieuwenhuijsen, 2016; Giles-Corti et al., 2016; Verbeek and Boelens, 2016). These frameworks may go well beyond what actually can be quantitatively modelled, at the time being, but at least allow for assessment of model uncertainty and potential bias recognizing aspects that have not previously been taken into account.

Furthermore, there is a need for effective, realistic and feasible scenarios for the assessment of current status and development of further scenarios of urban and transport planning for the next 20–30 years in cities (e.g. compact vs sprawl growth, changes in public and green space, changes in transport modes such as no cars or x% in car reduction, different provisions of public and active transportation, changes in vehicle fleet composition including fuels, vehicle emission standards and technology adaptation e.g. electric cars and autonomous vehicles) (Table 2). So far scenarios have tended to be fairly simplistic, partly to enable the modelling but the reality is more complex and there are limitations to what can be achieved. Also, in many cases the scenarios considered may be overly optimistic in the eyes of policy makers and stakeholders and therefore HIAs results bear little relevance and importance to these groups. A system dynamics modelling approach with appropriate feedback mechanisms is needed to account for the complexity of real-world responses to scenarios implementation (Macmillan et al., 2014). An important aspect in the scenario development is to bring together different (technical) stakeholders including e.g. urban and transport planners, environmentalists, health professionals, economists and citizens to allow for inclusive and feasible scenarios incorporating multiple views. These different sectors/disciplines have all their own languages which complicates the process, but developing a common language is part of the process, and engagement may facilitate change.

Many of the current models focus only on a few exposures e.g. air pollution, physical activity or road safety (Mueller et al., 2015), or start with a given exposure level (Mueller et al., 2016) without trying to identify the sources and pathways (i.e. full-chain). There are currently no integrated full-chain quantitative HIA model for mortality and morbidity for urban and transport related exposures and lifestyles including e.g. air pollution, noise, temperature, green space, motor vehicle crashes and physical activity and there is a need to develop such model(s) and parameterize them with the best available evidence, with regular updates. There is a large and still growing evidence base that needs to be reviewed, synthesized and implemented in a model/tool that can be used extensively by relevant stakeholders. For example, the quantity and quality of the exposure response information for the various exposures varies considerably with, for example, good evidence available for air pollution and physical activity, but less so for, for example, noise and green space. There is an urgent need to fill some of these gaps and obtain similar quality of evidence. Also, the model generation will require multisectorial/multidisciplinary input from urban, transport, environmental and health professionals and social scientist which will make it more challenging, given the different methods and languages used.

A further research need is how to have citizens participate in the process and get to grips with the complexities that may occur especially when aiming to develop quantitative models. As Macmillan et al. (2014) showed, it can be challenging to maintain channels for citizens input throughout all the assessment process. Despite these challenges, it is important for these channels to be maintained if aiming at a true form of participation, beyond tokenism (Arnstein, 1969). Insight from citizen science literature (e.g. Irwin, 1995), and the development of a practice of knowledge coproduction from which both citizens and practitioners can learn, can help in this direction (Khreis et al., 2016a).

Further work is also needed on the assessment of governance structure in cities and to obtain political input on urban and transport planning effects on population health, acceptability, facilitators and impediments to any recommended interventions. How does one integrate these different views into a coherent framework for decision making and model selection? Which governance setting and structures are or should be in place to be receptive to these new inputs? How can one make sure public health is properly considered during decision making? Insights from a more holistic approach to governance, in line with what has been called an 'adaptive co-management' (Folke et al., 2005; Reed, 2006) in the resilience literature, can be a starting point also for effective participatory HIA. Better governance is needed to introduce health in all polices, and multisectoral approaches and the integration of multiple levels of government (local, regional and national) to effectively implement the evidence in the decision making process. Specific recommendation for different sectors that could be implemented are given in Table 3.

4.5. Uncertainty

An important issue is how to deal with uncertainty. Uncertainty may occur when conceptualising the problem, during analysis and/or while communicating the results (Briggs et al., 2009). Much focus has been placed on characterising and quantifying the analysis and various statistical methods have been developed to estimate analytical uncertainties and model their propagation through the analysis (Mesa-Frias et al., 2013). As described before, transport, emission and air quality modelling each have their uncertainties and these are propagated through the chain. Validation and uncertainty assessment is needed at every stage, but is rarely conducted. On the other hand, larger uncertainties may be associated with the conceptualisation of the problem i.e. the scenarios building and communication of the analytical results, both of which depend on the perspective and viewpoint of the observer (Briggs et al., 2009). Therefore, more participatory approaches to investigation, and more qualitative measures of uncertainty, are needed, not only to define uncertainty more inclusively and completely, but also to help those involved better understand the nature of the uncertainties and their practical implications (Briggs et al., 2009).

4.6. How are HIA used or perceived?

The outcomes of HIAs on decision making, or perceptions of the process have not been well documented in the literature. However, a good example comes from the City of Bradford Metropolitan District Council who had recently undertaken a low emission zone feasibility study, which involved stakeholders, researchers and practitioners from different disciplines including transport planning, environmental sciences, public health and health economics alongside collaboration with other city councils in the West Yorkshire region, UK (e.g., Leeds City Council). In this study, the relative impact of several transport interventions scenarios beyond the 'business as usual' case was modelled. The impacts that these scenarios may have on projected air quality concentrations, health of the local population and the costs and benefits associated

Table 3
Recommendations for politicians/authorities, urban and transport experts, public health practitioners and researchers.

	Recommendations
Politicians/authorities	A) Introduce a health impact assessment approach as part of the decision making process in policies, plans or programs. B) Implement health in all policies perspective. C) Promote better governance, with special attention to strengthen the collaboration between sectors/departments, and different levels of government (local, regional and national). D) Promote citizens participation
Urban and transport experts	A) Introduce a health impact assessment approach as part of the decision making process in policies, plans or programs. B) Strengthen the collaboration with other sectors, departments (especially with the health sector), and different levels of government (local, regional and national). C) Provide a clear definition of urban and transport policies or interventions, describing the expected changes in mobility (e.g. modal share, number of trips, etc.), land-use (density and diversity), built environment (e.g. type of infrastructure), between others, with temporal and geographical definitions. D) Promote citizens participation
Public health practitioners	A) Promote health impact assessment as a tool to achieve health in all policies. B) Strengthen the collaboration with other sectors, departments and levels of government (local, regional and national). C) Develop comprehensive and harmonize health databases (e.g. incidence, prevalence, injuries, life tables, etc.). D) Develop comprehensive and harmonize environmental exposure databases (e.g. air pollution, noise, green spaces, etc.). E) Promote environmental health equity approach. F) Strengthen stakeholder participation in public health. G) Develop citizen science approaches in public health. F) Implement complex system approach in public health.
Researchers	A) Develop epidemiological studies (including meta-analysis) on multiple environmental risk factors, sources, pathways and populations; with special attention to provide dose-response functions, with harmonized exposure and outcome definitions. B) Develop exposure assessment studies on environmental risk factors; with special attention to provide harmonized exposure definitions and measurements. C) Include environmental health equity. D) Strengthen stakeholder participation in HIA. E) Develop citizen science approaches in HIA. F) Implement complex system approach in HIA.

with each intervention measure were calculated and presented in a final report, which was widely disseminated. These results were the basis for transport policy making in the area including for example buses replacement with low emission ones (https://www.bradford.gov.uk/media/1384/reportofthelezfeasibilitystudy.pdf). Many HIAs are being conducted that may not be published. Many practitioners do not publish their findings, but websites in the U.S. such as the Health Impact Project (http://www.pewtrusts.org/en/projects/health-impact-project) and others outside the U.S. catalogue HIAs and provide a good resource for practitioners.

Often, there is a disconnect between researchers who understand the value of the quantitative HIA process and practitioners who feel they lack the time and/or expertise to conduct a quantitative HIA, and rely more on qualitative approaches. Also, researchers may not have a complete understanding of the political climate and other factors that influence policy and project decisions. It is therefore important that the two communities come together and make use of each other's expertise and vision to comprehensively assess policies and projects on strength of scientific evidence, effectiveness, political climate and public acceptability. HIA is generally part of a much larger process. There are several factors influencing the final decisions and policy making beyond the variables and the outputs of the HIA. For this reason, it is very important for researchers and practitioners to work together to bring health up to the transport and urban planning and policy agenda.

4.6.1. Educational needs

There is also still a lack of capacity to conduct (quantitative) HIA, partly because of the lack of teaching the topic in many public health curricula and the lack of short courses. There is an urgent need to incorporate the topic. A curriculum for health impact assessors is important as there is a need for qualified personnel or teams able to understand and handle or coordinate such a wide-ranging and complex process. To influence decision makers, HIA professionals should be credible and knowledgeable. A training curriculum should include skills to understand the HIA process, identify stakeholders, analyze policies, identify and quantify health impacts by drawing on epidemiological concepts, communicate results, and better understand the land-use and transport planning and policy agenda (Malizia, 2005). HIA professionals should also be trained and able to work in multidisciplinary teams. We need people that know a little of the many different aspects of HIA, and we do not think that that currently exists. Most likely this type of person is part of/leading a team of experts that may take care of some aspects e.g. running the model, or involving stakeholders.

4.6.2. Low and medium income countries

Finally, most of the work so far has been done in high income countries. There is a need for this type of work outside high income countries, where urbanization rates are the highest, where there is the greatest burden of disease related to non-communicable diseases and where many cities are in the process of being shaped leaving room for timely interventions. This also brings forward specific challenges because often there is a real lack of data to conduct the work (Gascon et al., 2016a, 2016b) in combination with a lack of vision on the future health necessities and the lack of governance and institutional strength. Yet, at the same time low and medium income regions and countries have a real opportunity ahead, to improve and consider public health in the urban and transport development, avoiding the mistakes made by developed countries.

5. Conclusions

There is a need to improve healthy life through healthy urban and transport planning. Novel participatory full-chain quantitative HIA methods, models and tools are needed for evidence based decision making and to obtain and implement the most feasible and acceptable urban and transport policy measures to improve public health in cities.

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