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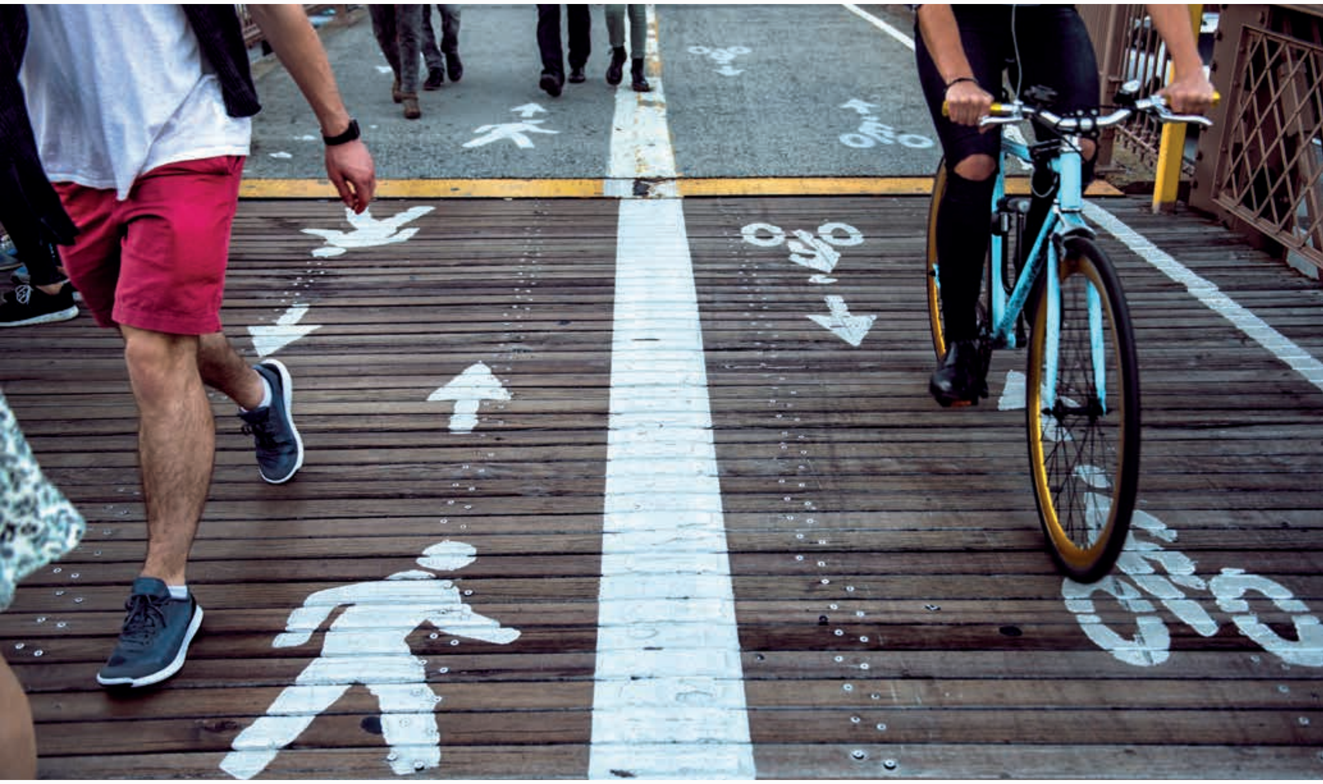

Health economic assessment tools (HEAT) for walking and for cycling

Methods and user guide on physical activity, air pollution, injuries and carbon impact assessments

The 2017 edition of this publication was supported in part by the project Physical Activity through Sustainable Transport Approaches (PASTA), which is funded by the European Union's Seventh Framework Programme under EC-GA No. 602624-2 (FP7-HEALTH-2013-INNOVATION-1).
The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

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Methods and user guide on physical activity, air pollution, injuries and carbon impact assessments

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Keywords

BICYCLING
WALKING
TRANSPORTATION METHODS – ECONOMICS
HEALTH ECONOMICS
COST-BENEFIT ANALYSIS – METHODS
DATA COLLECTION – METHODS
EUROPE

ISBN 978 92 890 5278 8

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Contributors and acknowledgements

The health economic assessment tool (HEAT) has been developed from an original idea of Harry Rutter, London School of Hygiene and Tropical Medicine, United Kingdom. It is based on the principles of HEAT for cycling first published in 2007.

This multi-phase, open-ended project is coordinated by WHO, steered by a core group of multidisciplinary experts and supported by ad hoc invited international experts from various fields who kindly give input for developing and updating of the tool (see also the acknowledgement sections for the various project phases on the right). The affiliations of some of the participants have changed during this project, and the affiliations are listed as they were at the time.

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Photographs:
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Acknowledgements
The 2017 update of HEAT for cycling and walking was supported in part by the project Physical Activity through Sustainable Transport Approaches (PASTA) (http://pastaproject.eu), which is funded by the European Union's Seventh Framework Programme under EC-GA No. 602624-2 (FP7-HEALTH-2013-INNOVATION-1).

The 5th consensus workshop (28–29 March 2017, Copenhagen, Denmark) was chaired by Michal Krzyzanowski, consultant, Poland and facilitated by the University of Zurich, Switzerland.

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Acknowledgements

The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety supported the development of the air pollution module of HEAT and the 2015 version of this publication. The 4th consensus workshop (Bonn, Germany, 11–12 December 2014) was chaired by Michal Krzyzanowski, King's College London and facilitated by the University of Zurich, Switzerland.

1 Introduction

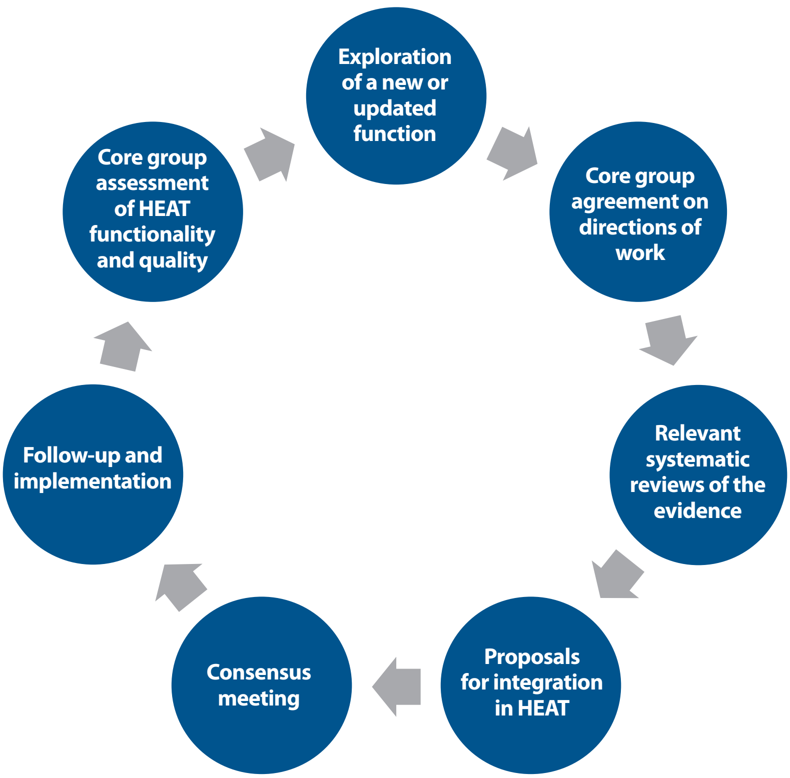
Physical inactivity is a significant public health problem in most regions of the world. It is unlikely to be solved by classical health promotion approaches alone, such as organized forms of sport or exercise done in leisure time. Promoting cycling and walking is a promising route to getting more physical activity, since it can be more readily integrated into people's busy schedules than, for example, leisure-time exercise. It is also a win-win approach: it not only promotes health but can also lead to positive environmental effects, especially if cycling and walking replace short car trips. These forms of physical activity are also more practical for population groups for which sport is either not feasible because of physical limitations or is not an accessible leisure activity for economic, social or cultural reasons. There is great potential for active travel in European urban transport, since many trips are short and would be suitable to being undertaken on foot or by bicycle. This, however, requires effective partnerships with the transport and urban planning sectors, whose policies are key driving forces in providing appropriate and safe conditions for such behavioural changes to take place. Several international policy frameworks have recognized this, such as the Action Plan for the Prevention and Control of Noncommunicable Diseases in the WHO European Region *(1)*. The Action Plan proposes a focus on planning and designing appropriate mobility plans and transport infrastructure as one of the actions to increase physical activity through active transport at all ages. The WHO European Strategy on Physical Activity launched in 2016 includes a specific objective to reduce car traffic and increase walking and cycling suitability *(2)*. The Paris Declaration: City in Motion – People First! adopted by the Fourth High-level Meeting on Transport, Health and Environment in 2014 includes a priority goal on promoting policies and actions conducive to healthy and safe modes of transport, including walking and cycling.

Transport is an essential component of life and a basis for providing access to goods and services. Different modes of transport are associated with specific effects on society, including health, environment and economic effects. Fully appraising these effects is an important basis for evidence-based policy-making. Economic appraisal is an established practice in transport planning. However, techniques for assessing the economic value of the benefits to health of cycling and walking have historically been applied less systematically than the approaches used for assessing the other costs and benefits of transport interventions or new infrastructure.

The valuation of health effects is a complex undertaking, and transport planners are often not well equipped to fully address the methodological complexities involved. A few countries in Europe, such as those working through the Nordic Council (Denmark, Finland, Iceland, Norway and Sweden), have carried out pioneering work in trying to assess the overall costs and benefits of transport infrastructure taking health effects into account, and guidance for carrying out such assessments has been developed. Nevertheless, important questions have remained.

Coordinated by WHO, steered by a core group of multidisciplinary experts and supported by ad hoc invited relevant international experts,[1] this project was started in 2005, aimed at developing guidance and practical tools for economic assessments of the health effects from cycling and from walking. The main product of the project is the health economic assessment tool (HEAT) for walking and cycling, a harmonized method for the economic valuation of health effects of cycling and walking, based on the best available evidence and international expert consensus (Fig. 1).

Fig. 1. Overview of the HEAT development process



[1] See the full lists at www.heatwalkingcycling.org.

Five project phases were carried out aimed at developing guidance and a practical tool for economic assessments of the health effects from (a) cycling and (b) walking. First published in 2007 and officially launched in 2009, a methodological guidance report *(3)* and a health economic assessment tool (HEAT) for cycling *(4)* were presented. In 2011, an updated online version of HEAT for cycling and HEAT for walking *(5)* were published. In 2014, HEAT for walking and cycling were again updated *(6)*. By 2015, an optional module to assess the effects of air pollution on cyclists and pedestrians was prepared *(7)*. In 2017, the latest HEAT version was launched, including optional modules for air pollution, road crashes and carbon effects as well as a new user interface *(8)*.

A core project group steered the implementation of the projects, working in close collaboration with advisory groups of international experts (see the list of contributors above). These experts were specifically selected to represent an interdisciplinary range of professional backgrounds and expertise, including health and epidemiology, air pollution, carbon emissions, road safety, health economics, transport economics, a practice and/or advocacy perspective and policy development and implementation. Close coordination also took place with the Transport, Health and Environment Pan-European Programme (THE PEP) and HEPA Europe (the European network for the promotion of health-enhancing physical activity).

The HEAT development process follows the following main steps:

Based on this approach, the key project steps were as follows.

The project core group commissioned systematic reviews (a) of published economic valuations of transport projects, including a physical activity element (2007 *(9)* and 2010) and (b) of epidemiological literature on the health effects of cycling and walking, especially for transport (2010 and 2013) *(10)* and (c) of air pollution exposure while cycling or walking *(11)*. Purposive literature reviews were carried out on approaches for assessing the health effects of road crashes among cyclists and pedestrians and for assessing the carbon effects of replacing short motorized trips by walking or cycling *(12)*.

The core group considered the results of these reviews and used them to propose options for and guidance towards more harmonized methods.

Draft methodological guidance and proposed options for a practical tool for cycling and for walking were developed.

International consensus meetings with advisory groups on the respective topic were held in 2007, 2010, 2013, 2014 and 2016 to facilitate achievement of scientific consensus on the options proposed in the draft methodological guidance to further develop HEAT.

Based on the meeting recommendations, further bilateral discussions with members of the advisory group and extensive pilot testing of new draft versions of HEAT by additional experts, the products of each project phase were approved for publication. These included: a guidance document *(3)*, an online tool for walking and for cycling *(6)* (based on a previous Excel-based version for cycling only *(4)*) and several versions of this publication on methods and user guide *(5,13)*. Scientific publications include a systematic review of the economic literature *(9)*, a publication on HEAT for cycling applications *(14)* and a publication on the initial HEAT cycling methods *(15)*.

This publication represents a summary of these products. The main results of systematic reviews of economic, health and selected air pollution literature are briefly summarized below. Chapter 1 presents the main conclusions on the methods for economic assessment of transport infrastructure and policies regarding inclusion of the health effects of walking and cycling, taking into account the effects of air pollution and injuries and of carbon emission.

The principles outlined in the guidance have been applied in a web-based, practical calculation tool, showing how the method can be used to assess health effects related to walking or to cycling, respectively. Chapter 2 outlines the main principles and approaches and potential limitations of the approach. The tool is available online *(8)*. If you are mainly looking for guidance on applying HEAT, please go directly to Chapter 2 and then read Chapter 3, which contains a brief user guide with instructions for HEAT for walking and cycling. Further information, hints and tips can be found online (www.euro.who.int/HEAT or directly under www.heatwalkingcycling.org).

Knowledge on the health effects of cycling and walking is evolving rapidly. These projects represent important steps towards agreed harmonized methods. In developing this tool, the advisory groups made expert judgements based on the best available information and evidence on several occasions. The accuracy of the results of the HEAT calculations should therefore be understood as estimates of the order of magnitude, much like many other economic assessments of health effects. Further improvements will be made as new knowledge becomes available.

Feedback to further improve the tool and maximize its user-friendliness is welcome at: heat@euro.who.int.

1.1 Summary of evidence reviews used for developing HEAT

1.1.1 Economic literature

To inform the development of the first version of HEAT for cycling, economic analyses of cycling and walking projects were systematically reviewed in 2007, in collaboration with the National Institute for Health and Care Excellence (NICE) in the United Kingdom *(9,16)*. The review aimed:

- to identify relevant publications through expert consultation and tailored searches of the literature;
- to review the approaches taken to including health effects in economic analyses of transport interventions and projects; and
- to propose recommendations for the further development of a harmonized method, based on the approaches developed to date.

A total of 16 papers were included. As part of the work on developing HEAT for walking and updating HEAT for cycling in 2010, this systematic review was updated to include eight additional papers published on the same topic since 2006 *(16)*. The updated review largely confirmed the findings of the first review: methods varied, with limited transparency and reliance on numerous assumptions. As noted in the previous review, in most cases the health benefits of cycling and walking were based on the literature on physical activity in general, requiring assumptions on the health effects of cycling and walking being equivalent to other forms of physical activity and regarding the absence of activity substitution (that is, the relationship between observed cycling or walking and total physical activity).

It was concluded that the updated literature review supported developing HEAT for walking using a similar approach as for HEAT for cycling: based on a relative risk of all-cause mortality among cyclists or pedestrians compared with non-cyclists or -pedestrians and estimating the value of reduced risk among walkers and cyclists based on the value of a statistical life (VSL). The 2013 consensus meeting confirmed this general approach *(17)*.

The VSL used by HEAT is based on a comprehensive review of VSL studies published by the Organisation for Economic Co-operation and Development (OECD) in 2012 *(18)*, which is further described in section 3.15.1.

1.1.2 Epidemiological literature

The strongest evidence at the time of the first project on the mortality effects of cycling was the relative risk data from two combined Copenhagen cohort studies *(4,5,19)*. This study included about 7000 20- to 60-year-old participants, followed up for average of 14.5 years. It found a relative risk of all-cause mortality among regular commuter cyclists of 0.72 (95% confidence interval (CI): 0.57–0.91) compared with non-cycling commuters for 180 minutes of commuter cycling per week.

In 2013, a new systematic review on the reduced relative risk of all-cause mortality from regular cycling or walking was carried out *(10)*. Seven cycling studies (carried out in China, Denmark, Germany and the United Kingdom) and 14 walking studies (from China, Denmark, Germany, Japan, the United Kingdom and the United States) met the inclusion criteria. A meta-analysis was carried out, combining the results of these studies. Based on this meta-analysis, HEAT uses a relative risk of 0.90 for cycling (representing 100 minutes of cycling per week as a common exposure level, equivalent to meeting the recommended level of at least 150 minutes of moderate-intensity physical activity per week *(20)*), and 0.89 for walking (representing 170 minutes of walking per week), applying a linear dose–response curve and thus a constant absolute risk reduction. For more information, see section 3.4.

1.1.3 Air pollution literature

Calculating the exposure of cyclists or pedestrians to air pollution requires defining the air pollution in the place of interest. HEAT assumes that a certain proportion of the population changes its transport mode from an (unknown) average (non-active) transport behaviour to walking or cycling (see section 3.10). As also assumed in epidemiological studies on the health effects of air pollution, the HEAT model would be based on the assumption that this average transport behaviour corresponds with the urban background air pollution levels. To derive conversion factors between background air pollution levels and exposure while walking or cycling, studies that estimated the concentrations of particulate matter with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) while cycling or walking and background concentrations were reviewed *(7,11)*.

Ten studies that measured various modes of transport, including at least walking or cycling in a simultaneous or quasi-simultaneous design, were included. The data from these studies were harmonized to enable quantitative synthesis of the estimates. Based on this study, the HEAT advisory group supported using a conversion factor of 2.0 for cycling to background and of 1.6 for walking to background; as a simplification, a conversion factor of 2.5 is being used for car versus background (see section 3.10).

One consideration regarding developing a separate HEAT air pollution model concerned possible double counting of the health effects of air pollution by using the relative risk estimates

derived from the meta-analysis of walking and cycling studies, which already included effects from air pollution by using mortality from any cause as a health outcome *(10)*. To further study this aspect, the effect of air pollution on the relative risks of the walking or cycling studies included in the meta-analysis was calculated *(7)*. The change in the relative risks for all-cause mortality and physical activity related to $PM_{2.5}$ during the physical activity reported by each exposure group was less than 5% in all the studies included. Nevertheless, to enable separate effects from physical activity and air pollution to be estimated in HEAT, a relative risk for physical activity that is adjusted for the effects of air pollution is being used when the users select both physical activity and air pollution modules (see section 3.9.2).

1.1.4 Literature on road crashes

To prepare the development of a HEAT module on road crashes, an exploratory literature review was carried out in 2016 to identify the various approaches to assess health effects of road crash risk on cycling based on exposure measures *(12)*. The literature review focused on health impact studies identified by recent reviews *(21,22)* and studies from 2009 onwards *(23–31)*, assuming that the collected publications sufficiently take into account previous literature.

As a result of the exploratory literature review, the following four approaches (in increasing order of complexity) for assessing the health effects of cycling road crashes were considered as possible methodological approaches for the HEAT road crash module at a HEAT core group meeting in November 2016 *(12)*.

A. **Basic approach.** Health effects would be calculated by multiplying a HEAT-provided generic road crash risk estimate with a user-provided measure of exposure for the studied use case. Although this approach is the simplest in terms of calculation efforts, it might lack accuracy in evaluating local cycling projects.

B. **Basic-plus approach.** In addition to the basic approach, this approach would also include risk estimates of specific infrastructure from existing literature *(32)* to enable more accurate evaluation of local cycling projects. The main challenge of this approach is to obtain enough and sufficiently robust relative risk estimates of infrastructure in the literature.

C. **Non-linear approach.** This approach (also sometime referred to as safety-in-numbers effect) is based on the basic and/or basic-plus approach, adding the option of applying a change in risk over time *(27,33,34)*. The reasons for this effect could include car drivers becoming more aware of and used to cyclists, more drivers being cyclists themselves and cyclist advocacy becoming more effective. Nevertheless, infrastructure and other safety improvements may play a role. Thus, HEAT users could adjust (reduce) the HEAT-provided road crash risk estimate when exposure changes over time: that is, in assessing before versus after use.

D. **Interaction approach.** Studies that apply this approach consider interaction effects between cycling and motor vehicle volumes and use coefficients to specify the model equation according to local settings. Although this approach might be conceptually the soundest, it implies a higher burden in terms of user-provided input data (bicycle and car use data) and substantial research efforts to derive local parameters to inform the model, similar to previous studies *(23,30)*.

Following the HEAT aim to provide robust estimates of health effects while putting the smallest possible burden on the user in terms of providing input data, the HEAT core group proposed to further pursue approach A (the basic approach) in combination with approach C (non-linear approach for before versus after assessments). The HEAT consensus meeting adopted this proposal in 2017 *(35)*.

1.1.5 Literature on effects on carbon emissions

In preparation of the development of a HEAT module how replacing motorized trips by walking or cycling affects carbon[2] emissions, it was noted that, although several international, national and local tools and methods for estimating the effects on carbon emissions of transport policies and plans are available (World Bank CURB *(36)*; European Environment Agency COPERT4 *(37)*; the United Kingdom transport appraisal guidance, WebTAG *(38)*; the United Kingdom transport carbon model *(39)*; EmiTRANS for Spain *(40)*), techniques for principally assessing the economic value of walking and cycling interventions reducing carbon emissions have not been well developed *(41,42)*.

Because of the scarcity of literature on how walking and cycling affect the carbon emissions, no formal review was carried out, but relevant approaches were summarized and presented to the HEAT core group in November 2016 *(12)*. Since there was not one agreed methodological approach that HEAT could adopt, it was proposed to base the proposed approach onto the following three main steps:

- assessing mode shift from motorized travel to active travel (or vice versa);
- assessing the carbon emissions from displaced motorized travel and increased walking and cycling; and
- assessing the economic value of the social effects of changes in carbon emissions.

For each of the steps, possible approaches were considered and an approach for further development and presentation to the HEAT consensus meeting in 2017 *(43)* was adopted. The overall approach was supported by the HEAT consensus meeting *(35)* and methods for each of the steps were agreed (see section 3.7).

[2] The term carbon emissions is being used to denote anthropogenic greenhouse-gas emissions relevant to surface transport; carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The composite metric of CO_2 equivalent (CO_2e) aggregates the 100-year global warming potential of these three greenhouse gases into one metric (whereby for surface transport, CO_2e is made up of ~99% CO_2).

2 Guidance on economic appraisal of how walking and cycling affect health and carbon emissions

This chapter summarizes the key methodological issues concerning the economic appraisal of health and carbon effects related to walking and cycling, providing options for and guidance towards more harmonized methods for the economic appraisal of the health effects of walking and cycling.

2.1 Relationship between physical activity and health

Epidemiological studies report relationships between different categories or levels of exposure and health outcomes. For example, a comparison of sedentary people with people who are active beyond a specific threshold (such as 150 minutes of activity per week) may show that active people are healthier. However, a strong consensus indicates that physical activity has a continuous dose–response relationship with most health outcomes: that is, each increase in physical activity is associated with additional health benefits *(20,44)*. This has also been shown by studies specifically examining walking or cycling *(10,45,46)*.

Developing a method to quantify the health effects of active transport requires incorporating a dose–response relationship. For many health outcomes, the exact shape of the curve is still uncertain *(44)* but, for mortality, literature suggests that the relationship is most likely non-linear *(28,47–49)*. Meta-analyses on the risk of all-cause mortality and cycling and walking carried out as part of the HEAT updating process in 2013–2014 *(10)* supported this finding (see section 3.9.2). However, they also showed that differences between various dose–response curves were modest and that a linear function would represent a good fit of the data.

When using a linear dose–response function, users do not have to know the baseline level of physical activity of their subjects, and a constant risk reduction can be applied across the range of exposure for which an incremental reduction of mortality risk can be observed. This approach has therefore been adopted for HEAT (see sections 3.1 and 3.4). An approach based on a non-linear relationship could be adopted as part of future updates of HEAT, when suitable data on the baseline level of physical activity in different populations are available to provide default values for HEAT.

Ideally, appraisals should consider the distribution of physical activity in the population in question. In particular, caution should be exercised in interpreting the results of modelling walking or cycling benefits in groups disproportionately comprising sedentary or very active individuals, since this could lead to a small overestimation of benefits in already active groups of the population and a small underestimation in less active ones.

Some limited evidence indicates a stronger association between the perceived intensity (pace) of walking and health effects than for the volume of walking *(46,50)*. However, these studies did not correct for the fitness of the participants or the true distance covered, and assessing their relative importance remains difficult. In general, taking account of walking or cycling pace might lead to a more accurate assessment of the health effects, for example, by differentiating between the different paces in leisure and transport walking or cycling, but this will also lead to more complicated models and additional uncertainties. HEAT does not take into account differences in the pace (or intensity) of walking or cycling or the possibility that less well-trained individuals may benefit more and better-trained individuals may benefit less from the same amount of walking or cycling.

2.2 Relationship between air pollution and health

For physical activity, a strong consensus indicates a continuous dose–response relationship between air pollution and health outcomes such as mortality from any cause. The dose–response function seems to be non-linear, becoming flat at the higher end of the dose–response curve: at higher pollution levels *(51)*. For applications in a context in which extreme exposure is rare, such as in the European Region, the HEAT advisory group agreed that a linear dose–response function would be an acceptable simplification, so a constant risk increase can be applied across the range of exposure *(7)*.

The inhaled dose is used to estimate the change in relative risk for using an active mode of transport compared with a reference scenario (for example, staying at home). To estimate this risk, a relative risk and a dose–response function from long-term epidemiological studies on the exposure to air pollution and a health outcome are used. This is based on the assumption that the target population of the impact assessment matches that of the underlying epidemiological studies providing the dose–response function, such as with respect to the exposure range as well as demographics, health characteristics and susceptibility to the exposure. In this regard, the following considerations can be made.

- Younger and healthier people are probably more likely to choose active modes of transport and might also be less susceptible to the harmful effects of air pollution.
- In contrast, people with pre-existing cardiovascular or respiratory disease – those responding more rapidly to air pollution exposure during physical activity than non-symptomatic people *(52,53)* – may be more reluctant to walk and cycle.

However, as long as no specific air pollution–related relative risks for such more active groups (pedestrians or cyclists) are available, using a relative risk from long-term studies in the general population, including both more active and less active people, seems to be a reasonable approximation. Nevertheless, this assumption is likely to overestimate the expected health effects of air pollution.

At the same time, particles stemming from motor vehicles may be more toxic than the general background air pollution *(54,55)*, which would lead to underestimating the effects *(56)*. In addition, the air pollution dose also depends on the specific route chosen and distance to the main traffic flow *(57,58)*. If data are available, this can be taken into account in health impact assessment of air pollution on health. For assessment based on an average amount of walking or cycling (such as for HEAT), a mix of everyday cycling and walking behaviour on different routes throughout a city or a country is a reasonable assumption.

Health impact assessment of air pollution can consider the direct effects on cyclists and pedestrians and/or the often considerable effects of reducing air pollution by replacing motorized traffic with walking and cycling *(21,56)*. Assessments should specify whether both effects are included or whether they focus only on the direct effects on pedestrians or cyclists (as HEAT does).

Air pollution is a mixture of substances and particles, which have been associated with various health effects. To assess how air pollution affects pedestrians and cyclists, various air pollutants could be considered. The concentration of $PM_{2.5}$ is used to estimate the health effects of air pollution because a large body of evidence, mainly from cohort studies, supports the quantification of the effects of long-term exposure on mortality and morbidity *(59–61)*.

An alternative approach is using the annual average concentration of PM_{10}, which is more widely available, and applying an internationally accepted conversion factor to estimate the concentration of $PM_{2.5}$.

Evidence shows that, although $PM_{2.5}$ is an established indicator in air pollution studies, it is less directly related to emissions from road traffic than other pollutants, such as elemental carbon, black smoke or ultrafine particles *(62)*. So these can also be used for assessing how air pollution affects pedestrians and cyclists. Since data on these indicators are less widely available, for international assessments using data on particulate matter is often a more feasible approach and consistent with many types of air pollution health impact assessment *(35)*.

2.3 Time needed for health and air pollution effects to build up

The epidemiological evidence on the effects on health of physical activity *(20,44)* implies that economic analysis should be carried out for habitual walking and cycling behaviour.

There will be a time lag between increases in physical activity and measurable benefits to health. Based on expert consensus, five years was adopted as a reasonable assumption to use for such "newly induced physical activity" to reach full effect, with an increment of 20% in benefits each year.

A similar time lag of five years for air pollution effects to build up on mortality was seen as a reasonable and most likely conservative assumption.

2.4 Effects of road crashes

Based on the available literature *(12)*, the effects of road crashes on pedestrians and cyclists can be assessed based on one or a combination of the following four main approaches:

- a basic approach, by multiplying a local (or generic) road crash risk estimate by a measure of exposure (amount of walking or cycling) for the studied use case;
- a basic plus infrastructure approach which, in addition to the basic approach, also includes risk estimates of specific infrastructure, such as from existing literature or local data;
- a non-linear approach, considering a change in road crash risk over time, such as through safer infrastructure or other effects (also

referred to as a safety-in-numbers effect) *(34)*; and

- an interaction approach, considering interaction effects between bicycle and motor vehicle volumes, using coefficients to specify the model equation according to local settings.

Each approach implies a different level of complexity and thus burden in terms of user-provided input data (data on cycling and car use) and research efforts to derive local parameters to inform the model. Although the basic approach has the lowest user burden (and was thus selected as basis for the HEAT approach; see section 3.11), it does not allow project-level assessments (sub-municipal or specific types of infrastructure), which require highly context-specific data.

Road crashes affecting pedestrians and cyclists can lead to injuries as well as mortality. Local assessments should ideally consider both effects, since injuries can have substantial health effects (and costs). However, underreporting, especially of minor injuries, poses a challenge to the accuracy of such assessments; correcting for this effect should be considered. Including injury effects is especially warranted when the positive health effects of walking and cycling on illness and injury are included into assessment to avoid overestimating the health benefits of walking and cycling.

With regard to the international level, the 5th HEAT consensus meeting concluded that the scarcity of comparable data on walking and cycling behaviour and the lack of internationally standardized approaches to definitions and to collecting information on road traffic injuries does not yet enable non-fatal outcomes to be included.

2.5 Interactions between transport-related physical activity, air pollution and road crashes

Transport-related health effects include not only positive effects from physical activity but also possible negative effects from exposure to ambient air pollution or road crashes. The possible interactions between the positive effects of exercise through active transport and such negative effects should be considered in comprehensive assessment of the health effects of transport interventions. At the same time, reviews as well as scenario analysis have showed that the positive health effects of active transport usually greatly outweigh the negative effects of air pollution and road crashes suffered by pedestrians and cyclists *(21,63)*. In addition, societies reap substantial positive effects from reducing air pollution and road crashes *(21,24)*. In addition, using all-cause mortality estimates (see section 2.1) rather than cause-specific ones has the advantage of incorporating the possible harmful effects associated with walking or cycling.

2.6 Effects of changes in carbon emissions

Based on the available literature *(12)*, assessing the economic value of changes in carbon emissions resulting from replacing motorized trips by walking and cycling needs to consider three main steps:

- assessing modal shift from motorized transport to active transport (or vice versa);
- assessing the carbon emissions from displaced motorized travel and increased walking and cycling; and
- assessing the economic value of the social effects of changes in carbon emissions.

The first step estimates the amount of avoided transport (such as in trip numbers and passenger kilometres) by motorized modes (mainly car, van, taxi, motorbike, bus and urban rail) as a result of a given level of or change in active travel. A key consideration is to accurately assess the net mode substitution away from motorized transport, as opposed to using alternative, more convenient routes (route substitution) or newly induced walking or cycling through intervention or policy (both of which do not affect carbon emissions, since they do not substitute for trips previously done by motorized modes of transport). Approaches can be based on complex travel demand models such as four-step *(25)* and activity-based *(26)* models that use (multimodal) travel demand forecasting techniques (usually requiring specific technical expertise, resources and detailed travel data sets). They can also be based on user-generated input data (based on what users have available, such as travel surveys or trip counts), as HEAT does (see section 2.14).

In the second step, the avoided travel is converted into carbon emissions saved by using a set of emissions factors (in grams of CO_2e per passenger-km or grams of CO_2e per vehicle-km). Related key considerations here are behaviour and technology, including knowledge about travel demand patterns (the distribution of time and place of travel being substituted, such as commuting at peak travel times in large urban areas) and the vehicle fleet mix (propulsion technology, age and fuel type for each mode of transport in the study area). Three main approaches can be distinguished.

A fuel consumption and carbon balance method is used internationally but implies significant data requirements and detailed assessment of the energy intensity of the various transport fuels used by the study population.

A relatively simple travel activity and emissions factor method is based on changes in travel distance for different modes of transport multiplied by mode-specific average emissions factors, for which wide variation should be considered, depending on mode characteristics such as vehicle type, engine type, fuel type, transmission, vehicle age, vehicle maintenance and vehicle occupancy and vehicle use. Such approaches should also consider that average emissions factors evolve over time as more efficient and cleaner vehicles enter the fleet.

A more complex travel activity and speed-emissions factor method assumes that the amount of carbon emitted by different modes of transport depends on three key factors: (1) distance and average trip lengths; (2) average speed; and (3) mode characteristics such as vehicle type, engine type, fuel type and vehicle age. This method also considers the (changes in) observed mean speeds and vehicle types in the study area to calculate the hot emission of CO_2e per km. For cars, cold-start excess emissions (for the mileage running cold for each trip, typically the first 3–4 km from cold) are added to this. The latter is important, since most of the cycling and walking trips are short: within the cold-start distance range.

In the third step, the long-term effects of reducing carbon emissions are assessed and an economic value is applied to account for the expected effects of anthropogenic climate change (using carbon price and cost values, in euros per tonne of CO_2e). The valuation of climate change effects involves many challenges, including uncertainty about future political, socioeconomic, scientific and philosophical factors and ethical issues around the weighting of equity *(23,24)*. Nevertheless, carbon values have been estimated using integrated assessment models to assess abatement costs or damage values for more or less carbon in the atmosphere, and many jurisdictions have produced methods and values to be used specifically in policy appraisal and evaluation, which can be used for carbon valuation of cycling and walking.

Two types of estimates for the cost of carbon are mainly relevant for the transport sector *(12)*.

The damage cost estimate (the social cost of carbon) can be defined as the monetized value of the global damage caused by the incremental impact of an additional tonne of CO_2e emitted at a point in time. This value varies widely because of the uncertainty in both methods and data, the time horizon, the use of discounting and the weighting of equity.

Basing the estimated cost of abatement on emissions targets or current mitigation policies uses the marginal abatement costs per tonne of CO_2e to achieve emissions targets or current mitigation policies. Abatement costs do not represent the social cost of carbon, except under the condition that the abatement strategy is set at the optimal level, in which case the two approaches produce the same result. They do not represent the potential benefit from mitigation or the potential costs of inaction, and the cost of abatement varies with policy options and the CO_2 reduction target chosen.

The social cost of carbon approach was therefore selected for HEAT since it enable the derivation of default values across contexts independent of a specific policy option chosen (see section 3.12).

2.7 Mortality or morbidity?

Physical activity has beneficial effects on many aspects of morbidity, such as coronary heart disease, stroke, diabetes, some types of cancer, musculoskeletal health, energy balance and aspects of mental health (including anxiety and depression) and improving functional health in older people *(44)*. From a public health viewpoint, these benefits materialize more rapidly than reductions in mortality. They can also be important in motivating individuals to walk and/or cycle, as people may be more likely to increase their physical activity to improve their immediate health and well-being than to prolong their life. Thus, including morbidity leads to more comprehensive economic appraisal of the health effects of transport interventions, and addressing morbidity has been identified as the single most important improvement to be made to HEAT in future revisions. In addition, the current evidence on morbidity, both for walking and for cycling, is more limited than that on mortality. Thus, including the impact of morbidity in economic appraisal leads to greater uncertainty.

Although the 2014 and 2016 consensus meetings considered options to include morbidity into HEAT, for the time being it was recommended to focus only on all-cause mortality for HEAT for walking and for cycling. This method is likely to produce conservative estimates, since it does not account for disease-related benefits.

2.8 Age and sex

Ideally, economic analysis would be able to consider the differential effects of physical activity on children and adults and on adults of different ages. However, the vast majority of epidemiological studies have been conducted on adults, mainly because the most commonly studied disease end-points such as coronary heart disease or death are rare among children, and studies on adults are easier to carry out. Thus, the evidence base for the long-term health effects of physical activity on young people is not as large as that for adults. The advisory group concluded that the evidence for children and adolescents is insufficient and that economic appraisals should solely focus on adults for now.

Studies find that risk reduction differs by age: for example, increased activity might yield higher benefits in older age groups than in younger age groups. Differentiating risk reduction by age groups could further enhance the results of economic appraisal. However, this would require cycling and walking data by age groups, which are often not available. The availability of transport data by age group should be improved further.

Age is also very relevant for the mortality rates used. Mortality rates vary substantially by age, and thus the choice of age range for the rate used in an economic appraisal can substantially affect the calculated benefits.

The age groups to which the results may be applied and for which mortality rates were used should therefore be made explicit. If any model is subsequently applied to children or older adults, any related assumptions should also be made explicit.

The review of the epidemiological evidence on the effects of walking and cycling did not find obvious differences between the sexes in the effects on all-cause mortality *(10)* that would warrant different estimates of relative risk for men and women. A similar conclusion was drawn for the effects of air pollution *(64)* (see section 3.10).

Active transport behaviour can differ between men and women: for example, women often walk and cycle more often than men, whereas men cycle longer distances. Ideally, economic analysis should consider such gender differences. For the road crash risk for cycling, men and women differed slightly (after correction for the longer distances cycled by men) *(65)*, which ideally should also be considered for road crash risk assessment.

2.9 Static versus life-table approach

Since economic appraisal evaluates benefits over a period of time, several parameters may not stay constant over the time of the analysis. For example, the mortality rate in the population may change because of an increase in walking or cycling or other factors. The evaluated populations also represent a broad age range, and health effects may vary by age. Life-table calculations constitute a method for addressing these issues and thus increasing the precision of assessment. Recent scientific appraisal of the health benefits of cycling or walking has applied such approaches.

Nevertheless, using life-table calculations increases the complexity for target users, and the potential improvement in accuracy appears to be small compared with the remaining uncertainties in various other parameters of such appraisals or the effects of including or excluding older age groups.

2.10 Walking and cycling data

The quality of economic appraisal highly depends on the validity and reliability of the walking and cycling data used. In many countries, systematic long-term surveys of cycling and walking are not yet available or do not provide local-level data, which are often needed for appraising local transport interventions or infrastructure.

Data from local surveys must be ensured to be representative of the population assessed. The studies should be carried out over a sufficient period of time and across sufficient locations to adjust for known seasonal and spatial variation in cycling or walking; otherwise the data have to be adjusted using realistic assumptions to reflect long-term averages as much as possible.

2.11 Time needed to reach the full level of walking or cycling

Transport interventions can take various lengths of time to influence a specific type of behaviour. For example, a certain new cycle path might result in immediate uptake, whereas increasing use on another might take a year or more. Transport appraisal should enable different assumptions about the speed or level of uptake of cycling or walking after such interventions.

2.12 Activity substitution

Most of the literature on health effects relates to total physical activity, usually a composite index expressing overall energy expenditure (often measured as kilocalories per week) or time spent active, including a wide range of non-transport activity such as leisure-time and occupational activity. Assessing the health effects of transport interventions must consider the potential substitution of one form of activity for another, which could occur in two ways.

- Does an observed increase in the rates of walking and cycling necessarily mean that total physical activity has increased? For example, people may have stopped jogging when they started cycling or walking to work. Although some evidence shows little or no substitution *(66,67)*, no definite conclusions can be drawn yet *(68)*. Studies based on self-reports from trail users show stronger effects *(69)*, and the effect is more likely to occur for recreational activity. No final conclusions can be drawn yet. Nevertheless, intervention studies should consider, for example, that a new cycle path might lead to a user's new journey actually being shorter than before.
- The results of studies on walking or cycling could be confounded by other forms of physical activity, such as leisure-time activities. This could lead to an overestimation of the health effects of walking or cycling if the people who cycle or walk were actually previously more active through other forms of physical activity.

It is recommended that economic analysis account for activity substitution as far as possible. This means not assuming that any increase in cycling or walking automatically leads to a corresponding increase in total physical activity and using studies that correct for non-transport-related forms of physical activity.

2.13 Costs applied

Conducting economic appraisal of walking and cycling requires agreeing on a method of valuation of health (or life). This can be done in several ways.

Transport appraisal often uses a standard VSL derived using willingness to pay. The willingness to pay shows how much a representative sample of the population would be willing to pay (in monetary terms), for example for a policy that would reduce their annual risk of dying from 3 in 10 000 to 2 in 10 000. Thus, this estimates the overall economic value to society of reduced premature mortality.

The cost of illness applies the costs for each specific disease, such as the costs to the national health service or loss of earnings.

The years of life lost (or gained) enables more comprehensive assessment of health effects, since it considers the life expectancy of the participants.

Quality-adjusted life-years is derived from the years of life spent in ill health multiplied by a factor representing the relative undesirability of the illness state.

Disability-adjusted life-years measures the overall disease burden, expressed as the number of years lost from ill health, disability or early death.

Different audiences prefer different economic end-points. Health experts prefer years of life lost or health care costs, but transport appraisal, the main target use of HEAT, uses VSL more commonly.

A method based on a comprehensive review *(18)* has found an average VSL of €2.132 million for the WHO European Region (for 2015) (see section 3.15.1). This is substantially higher than earlier commonly used values in Europe, such as the €1.574 million proposed by the UNITE study *(70)*, which was used in early versions of HEAT *(4)*, and somewhat lower than the €2.487 million used in the previous version *(5)*. Thus, internationally, VSL differs substantially *(16,70,71)*; it is therefore recommended to use either a local VSL or, if this is not available, a current, internationally agreed VSL.

Other methods, such as an approach based on quality-adjusted life-years or the value of a life-year, could be adopted if data were available to permit more comprehensive assessment and to broaden the appeal for a health audience. However, such metrics require assessing the effects of walking and cycling on morbidity (see section 2.6).

2.14 Discounting

Since economic benefits occurring in the future are generally considered less valuable than those occurring in the present, economists apply a discount rate to future benefits. Common discount rates are usually available from governments. In many cases, a more comprehensive cost–benefit analysis of transport interventions or infrastructure projects will include the economic appraisal of health effects related to walking and cycling as one component. The final result of the comprehensive assessment would then be discounted to enable the net present value to be calculated.

2.15 Sensitivity analysis

Carrying out economic appraisal of the health effects of transport behaviour is a complex undertaking and invariably involves several assumptions and expert judgements, as outlined above.

It is strongly recommended that the uncertainties around an assessment be made explicit and that the calculations be carried out with high and low estimates of the main variables to improve the understanding of the possible range of the final results.

3 How HEAT works: introduction

Based on the considerations on the scientific guidance set out in Chapter 2, a practical tool for walking and for cycling known as HEAT has been developed *(8)*.

3.1 General principles

The international advisory groups agreed on the following core principles for HEAT. The tool should be:

- scientifically robust and based on the best available evidence;
- as user-friendly as possible:
  - minimal data input requirements
  - availability of default values
  - clear prompts and questions
  - design and flow of the tool geared to maximize usability;
- fully transparent with regard to assumptions and approaches taken;
- based in general on a conservative approach;
- adaptable to local contexts; and
- modular.

3.2 Who is HEAT for?

HEAT is designed to enable users without expertise in impact assessment to assess the economics of the health effect of walking or cycling. The tool is based on the best available evidence and transparent assumptions. It is intended to be simple to use by a wide variety of professionals at both the national and local levels. These include primarily transport and urban planners, traffic engineers and special interest groups working on transport, walking, cycling or the environment.

The tool is also of interest to health economists, physical activity experts and health promotion experts. However, because it uses transport-specific methods such as VSL, the results of HEAT in its current form might need to be accompanied by additional information and explanations for such audiences.

3.3 What can HEAT be used for?

HEAT estimates the value of reduced mortality that results from specified amounts of walking or cycling, answering the following question.

If *x* people regularly walk or cycle an amount of *y*, what is the economic value of the health benefits resulting from the reduction in mortality caused by their physical activity?

In addition, HEAT can now also consider the health effects of road crashes and air pollution and the effects on carbon emissions.

The tool can be used for several types of assessment, for example:

- assessing current (or past) levels of cycling or walking, such as showing the value of cycling or walking in a city or country;
- assessing changes over time, such as comparing before-and-after situations or scenario A versus scenario B (such as with or without measures taken); and
- evaluating new or existing projects, including calculating benefit–cost ratios.

HEAT can be used as a stand-alone tool or to provide input into more comprehensive economic appraisal exercises or prospective health impact assessment.

3.4 What should HEAT not be used for?

Before HEAT is used, the following should be considered carefully to ensure that HEAT is applicable.

HEAT is to be applied for assessment on a population level: groups of people and not individuals.

HEAT is designed for habitual behaviour, such as cycling or walking for commuting or regular leisure-time activities. Do not use it for the evaluating one-day events or competitions, such as walking or cycling days, since they are unlikely to reflect long-term average behaviour.

HEAT is designed for adult populations. HEAT calculations are based on mortality rates for the age ranges of 20–74 years for walking and 20–64 years for cycling. HEAT should not be applied to populations of children or adolescents, since the scientific evidence used by HEAT does not include these age groups. The upper age boundaries have been set by consensus to avoid inflating health benefits from misrepresenting active travel behaviour among older age groups that have higher mortality risks. If the assessed population is considerably younger or older than average, the user can specify a lower or higher age range.

The tool is not suited for populations with very high average levels of walking or cycling. HEAT applies evidence from studies in the general population and not in subpopulations with very high average levels of physical activity, such as bicycle couriers or mail personnel. Although the exact shape of the dose–response curve is uncertain, benefits from physical activity seem to start to slow above levels equivalent to perhaps 1.5 hours of cycling and 2 hours of brisk walking per day. The tool is therefore not suited for populations with average levels of cycling of about 1.5 hours per day or more or of walking of about 2 hours per day or more, which exceed the activity levels common in an average adult population.

The HEAT air pollution module should not be used for environments with very high levels of air pollution. Most of the studies on the health effects of cycling and walking and of air pollution used for HEAT have been carried out in environments with low or medium levels of air pollution (concentrations of fine particulate matter up to about 50 $\mu g/m^3$; see section 3.9). They are therefore unsuited for application to environments representing an exposure for cyclists or pedestrians of particulate matter of considerably more than 50 $\mu g/m^3$. Negative effects from air pollution seem to start to level off at higher concentrations, and the effects of such levels of exposure on cyclists and pedestrians have not yet been well studied.

The accuracy of the HEAT calculations should be understood as estimates of the order of magnitude of the expected effect rather than as precise estimates.

Knowledge of the health effects of walking and cycling is evolving rapidly. These projects represent first important steps towards agreed harmonized methods. In developing this tool, on several occasions the international advisory group made expert judgements based on the best available information and evidence. Users should bear in mind the approximate nature of the results, much like for many other types of economic assessment of health effects. Further improvements will be made as new knowledge becomes available.

3.5 How does HEAT work?

HEAT aims to promote the integration of the economic value to society of reduced premature mortality from cycling and walking into the economic appraisal of transport and urban planning and interventions. Users can calculate the mortality benefits only or choose to consider the effects of air pollution and road crashes or to estimate the effects of replacing motorized trips by walking or cycling on carbon emissions.

Fig. 2 shows the key steps of HEAT.

The following chapters give more information on the approaches taken to produce the HEAT results and on the four HEAT impact assessment modules.

3.6 Health impact assessment and comparative risk assessment approaches in HEAT

Health impact assessment is a combination of procedures, methods, and tools used to evaluate the potential health effects of a policy, programme or project. Using a combination of qualitative, quantitative and participatory techniques, health impact assessment aims to produce recommendations that will help decision-makers and other stakeholders make choices about alternatives and improvements to prevent disease and injury and to actively promote health.

HEAT is a health impact assessment model: a quantitative tool to calculate the health effects of regular cycling and/or walking (and the related carbon emissions). Health impact calculations aim to quantify the benefits and risks of a certain level of specific types of exposure or a change thereof in a specific population over a defined period of time.

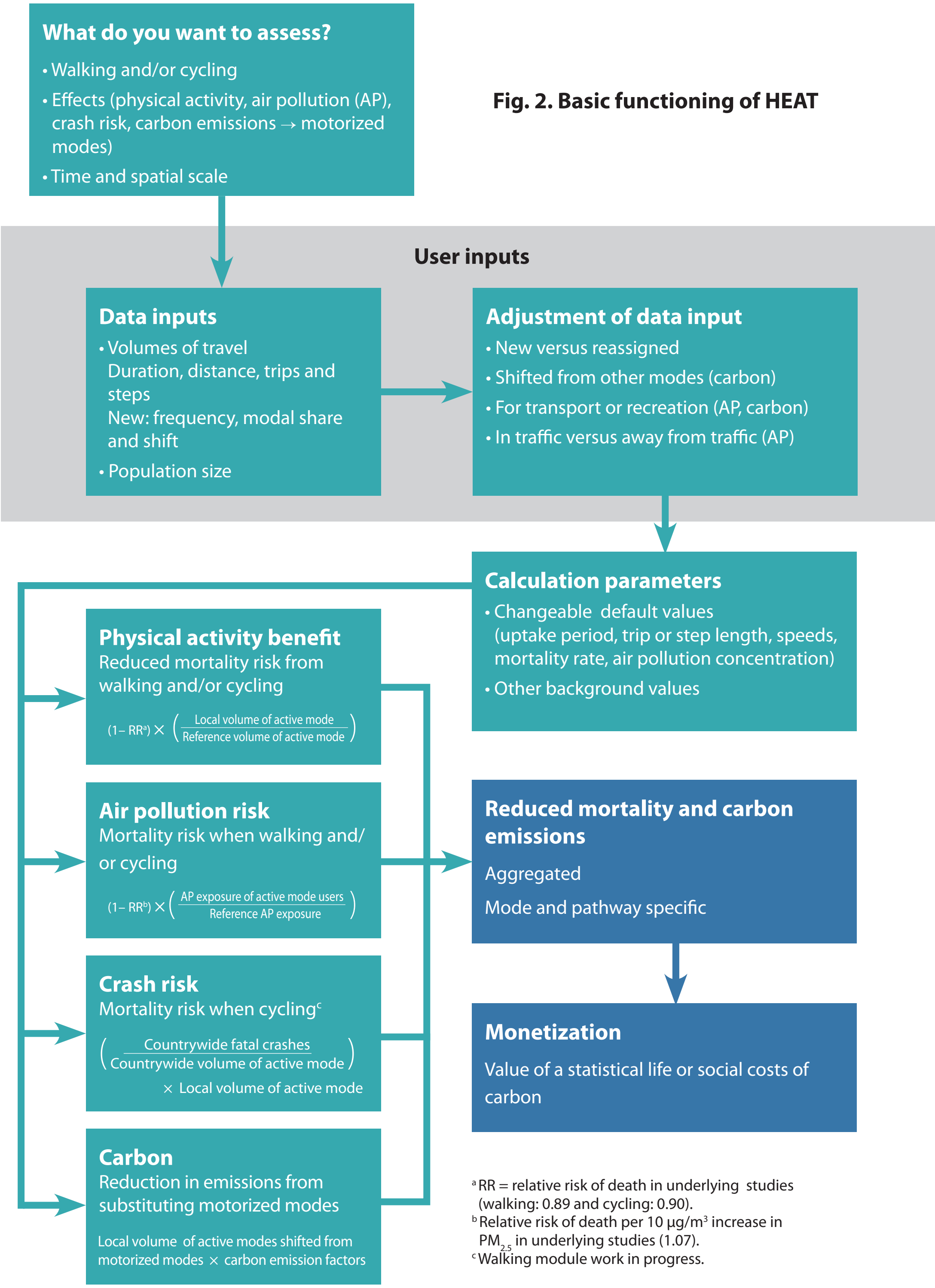
The basic calculation quantifies the number of deaths occurring in a population over a given period of time by multiplying a mortality rate by the population size and the assessment time.

For example, in Denmark, among people 20–74 years old, the mortality rate is 500 per 100 000 population per year. During 10 years, among the 4 million people in that age range, 200 000 are expected to die: 500 per 100 000 × 4 000 000 × 10.

HEAT applies the comparative risk assessment approach, in which the risk of interest (mortality or premature deaths) is compared between two cases: the reference case and a comparison case (also sometimes referred to as the counterfactual case). The impact of interest is the difference in mortality between the two cases. For HEAT, this difference is a result of a contrast in physical activity from regular walking or cycling between the two cases (Fig. 3).

To calculate this impact, HEAT uses well-established relationships from epidemiological

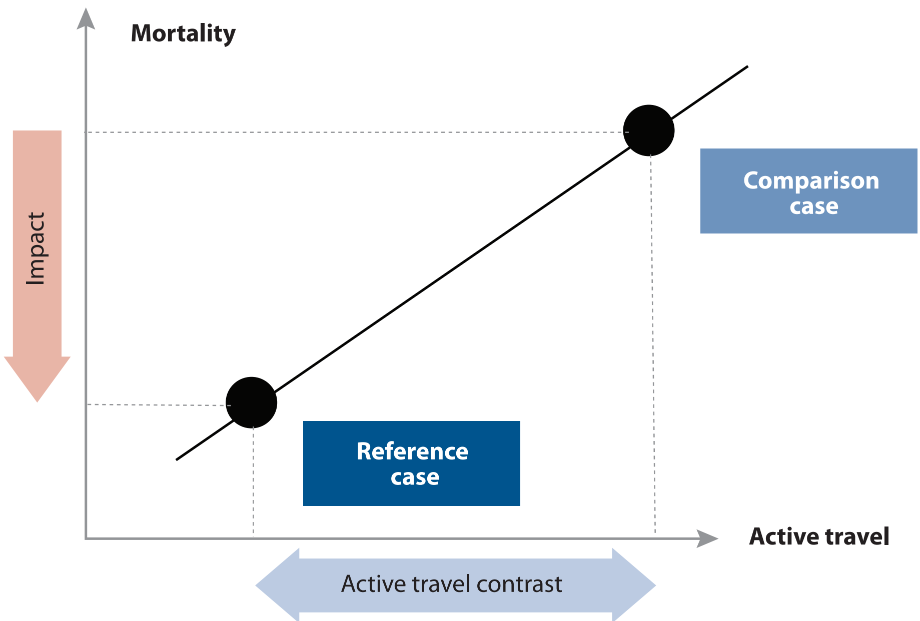
Fig. 2. Basic functioning of HEAT



[a] RR = relative risk of death in underlying studies (walking: 0.89 and cycling: 0.90).
[b] Relative risk of death per 10 µg/m^3 increase in $PM_{2.5}$ in underlying studies (1.07).
[c] Walking module work in progress.

Green boxes: new features of the 2017 HEAT 4.0 version; blue boxes: features of the 2015 HEAT version.

Fig. 3. Comparative risk assessment approach in HEAT



research between an exposure (amount of walking or cycling) and a health outcome (in HEAT: mortality from any cause: all-cause mortality). These effects are quantified as relative risks, comparing the risk (such as the risk of dying) among people who are exposed (walk or cycle regularly) to the risk among people who are not exposed (who do not walk or cycle or walk or cycle less).

The relative risk (taken from the literature) is scaled to the local levels of walking or cycling. Because relative risk estimates refer to long-term exposure, the local data provided by the user in HEAT assessment must also represent estimates of long-term walking or cycling behaviour.

The number of expected deaths in the population walking and/or cycling is calculated using the same method as above but now multiplied by the relative risk (scaled to reflect the assessed level of walking or cycling).

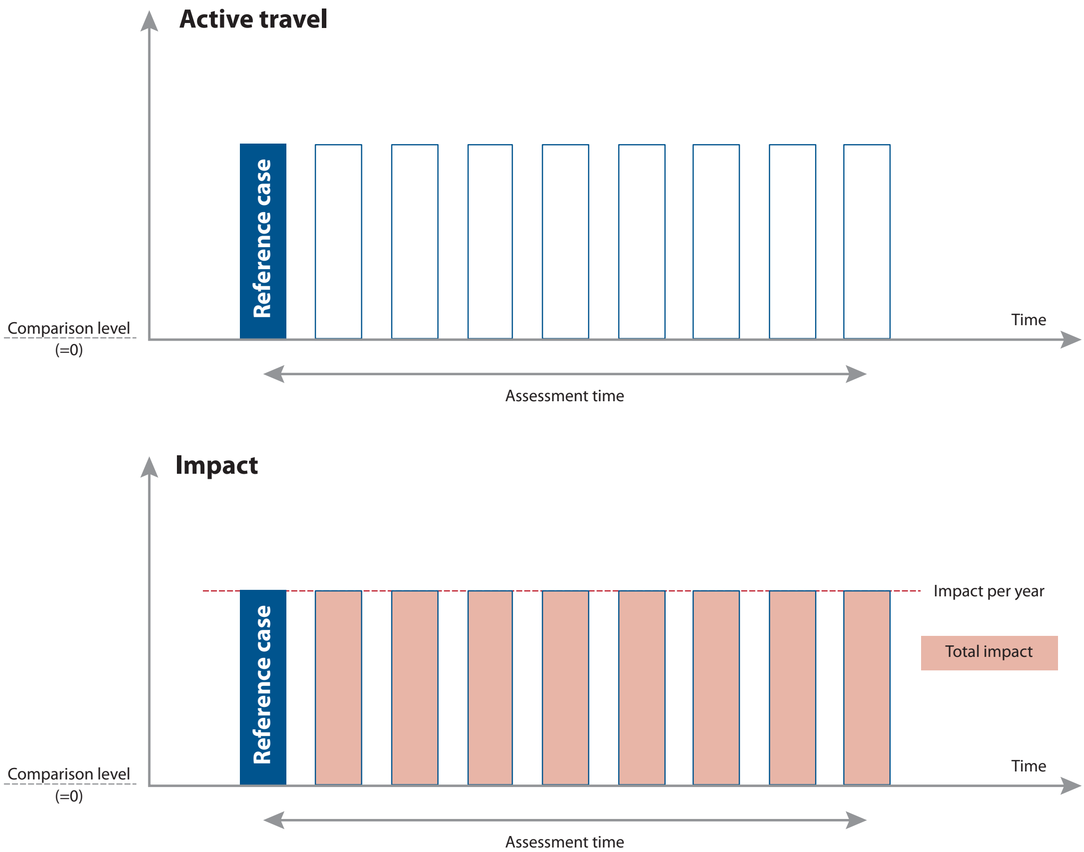
In a single-case assessment in HEAT, the user only specifies walking or cycling for the reference case, which is then compared to an implicit comparison case of no walking or no cycling.

In a two-case assessment, the user specifies walking and/or cycling levels for both cases.

The average impact, the number of prevented premature deaths, at the population level is the difference between the calculation in the reference case and the comparison case, again reflecting population size and assessment time (Fig. 4).

In single-case assessment, the tool assumes a steady-state situation: the assessed level of active travel is assumed to having been prevalent for several years, and subjects experience the full health effects from long-term active travel.

Fig. 4. Single-case assessment in HEAT



In two-case assessment, the calculations consider an uptake time until full levels of active travel are achieved (user specified) and a build-up time of five years until the health effects manifest in full (Fig. 5).

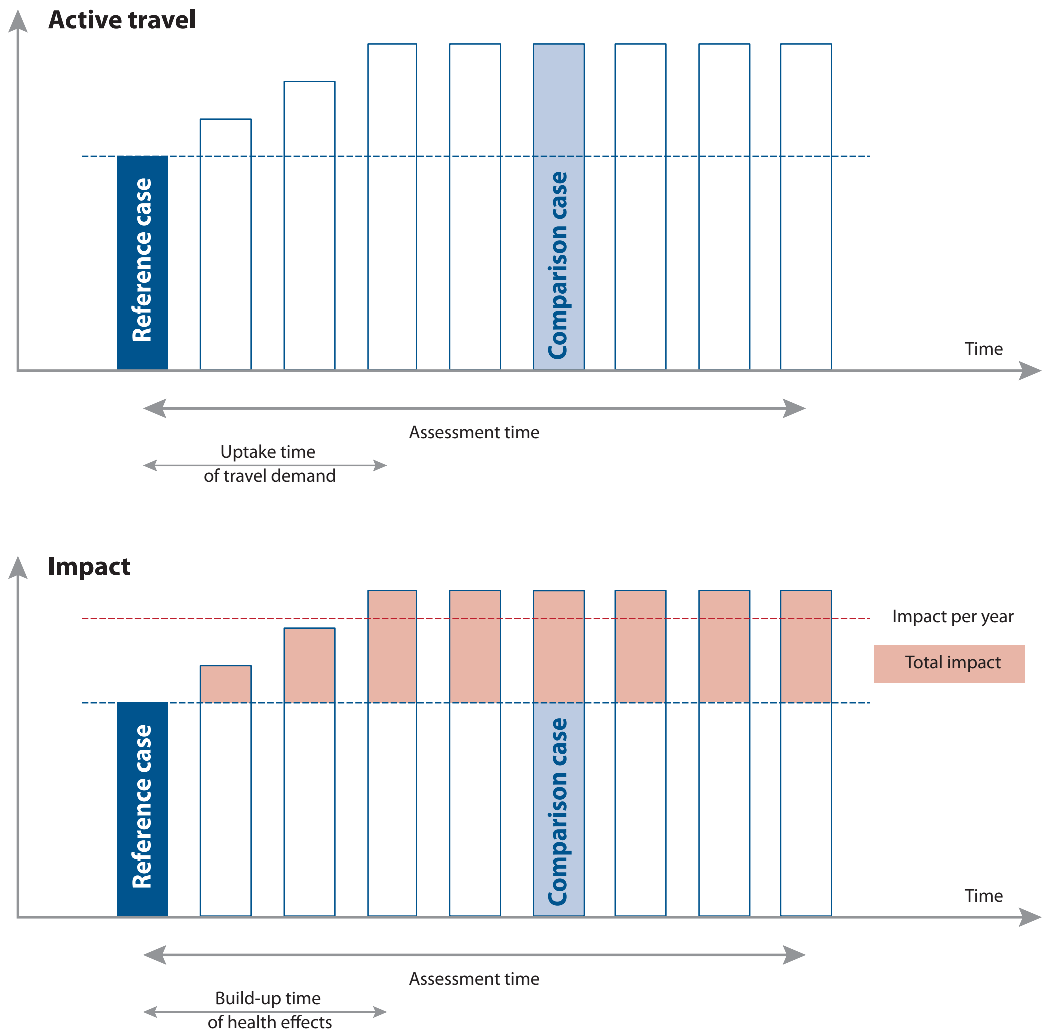
The HEAT impact calculations for physical activity and air pollution apply a population-attributable fraction formula. This formula is used to relate the mortality rate for the general population (MR_{pop}) to the two groups compared in comparative risk assessment: the exposed group (reference group) (e) and unexposed group (comparison group) (u). In HEAT, exposure refers to the assessed amount of cycling or walking.

The MR_{pop} is the weighted average of the mortality rate in the exposed (MR_e) and unexposed (MR_u) populations. MR_{pop} depends on the contrast in mortality risk between the two groups as well as the size of the two groups.

$$MR_{pop} = MR_u \times P_u + MR_e \times P_e$$

Epidemiological studies estimate the contrast in mortality risk and express it as a relative risk (RR): for example, $RR_{cycling} = 0.9$ for *x* minutes of cycling

Fig. 5. Two-case assessment in HEAT



per day compared with 0 minutes of cycling per day.

$$RR = MR_e/MR_u$$

The size of the exposed and unexposed groups is typically expressed as the proportion of exposed subjects (P_e). In the HEAT context, this quantifies the size of the assessed population cycling or walking relative to the size of the total population on which the MR_{pop} is based (all inhabitants of a country 20–64 or 20–74 years old, respectively). In most use cases, the proportion of people exposed is quite small, such as in city-level or sub-city-level assessment (in which the population assessed is much smaller than the country's population), and in assessments in which walking or cycling levels are not very high (with little influence on the overall mortality risk). By default, the tool therefore assumes the proportion of exposed people to be close to zero (0.001), which means that the influence of the assessed walking or cycling on the country-level mortality rate (MR_{pop}) is negligible. Users may change this for use cases in which this does not apply, such as country-level assessments in which walking and cycling levels are very high. In these cases, mode share or an equivalent figure can be used as an approximation of the proportion exposed.

The mathematical formulas used by HEAT were derived based on these considerations. To calculate effects in terms of premature deaths (avoided), MR_u and MR_e are estimated based on MR_{pop}, RR and P_e ~=0.

$$MR_{pop} = MR_u \times P_u + MR_e \times P_e$$

$$RR = MR_e/MR_u$$

$$P_u = 1 - P_e$$

$$MR_u = MR_{pop} / [1 - (P_e \times (1 - RR))] \sim= MR_{pop}$$

$$MR_e = MR_{pop} \times RR / [1 - (P_e \times (1 - RR))] \sim= MR_{pop} \times RR$$

MR_u and MR_e are then multiplied by the assessed population to derive the number of deaths in the exposed group (the population assessed in HEAT) and unexposed group (the hypothetical counterfactual of the same population not being exposed: not cycling or walking). The difference between the two groups reflects the number of deaths attributed to the exposure or the impact of the exposure. If the impact is smaller among exposed people, the exposure prevents deaths, such as physical activity.

$$D_u = MR_u \times \text{population}$$

$$D_e = MR_e \times \text{population}$$

$$D_{attributed} = D_e - D_u$$

In a two-case comparison, the same assessment is calculated twice for different levels of exposure. The deaths attributed then reflect the difference between the two assessments.

See section 3.5 for more information on how the various HEAT modules calculate impact assessment.

3.7 What data are needed?

To use HEAT, the following data are needed:

- an estimate of the size of the study population, which might come from route user surveys, population surveys or roadside counts or could be estimates from a scenario; the population size must reflect the age range being assessed, such as excluding people younger than 20 years, which HEAT does not consider; and

- an estimate of the average amount of walking or cycling in the study population, which can again come from surveys or estimates and can be entered in several ways but must be provided as an average per person per day:

  - duration: average time (minutes or hours) walked or cycled per person, such as 30 minutes walked on average per day;

  - distance: average distance walked or cycled per person, such as 10 km cycled on average per day;

  - trips: average per person or total observed across a population, such as 250 bicycle trips per year;

  - steps: average number of steps taken per person, such as 9000 steps per day;

– mode share (in trips, duration or distance): mode share is a percentage of total travel (all modes): for example, 20% of all trips are walking;

– frequency, referring to such questions as "How often do you use your bike?" or "How often do you walk?" (such as 20% if users cycle 1–3 days per week); and

– percentage change: for example, compared with scenario A, in scenario B 20% of the population cycles *x* minutes more.

The average amount of walking or cycling must be based on the same type of population, such as pedestrians or cyclists only or the general population, perhaps including people who do not walk or cycle.

HEAT enables users to insert their data on modes of transport in various units or formats. The tool then converts these to standard units, such as minutes and kilometres per day. The default values are used to inform these conversions as necessary (such as the average trip distance).

The following conversions apply.

- To convert volume data between duration and distance, average speeds by mode of transport are assumed (see section 3.13).

- To convert steps into distance, the number of steps is multiplied by an average default step length (see section 3.13).

- To convert number of trips into distance, average trips distances by mode of transport are used (see section 3.13).

- To convert modal share, the percentage share is multiplied by the total volume (trips, distance or duration) and then the conversions as described above are applied, as necessary.

- The following frequency categories are available: daily or almost daily, 1–3 days per week, 1–3 days per month, less than once per month and never. To convert frequency categories into distances, first the number of days walked or cycled per year is derived, using the category midpoints. Thus, "daily or almost daily" is assigned 5.5 days per week (midpoint between 7 and 4 days in a week) and multiplied by 52; "1–3 days per week" is assigned 2 days per week; "1–3 days per month" is assigned 2 days per month and multiplied by 12; "less than once per month" is 6 days per year; and "never" is assigned zero. The days per year are then divided by 365 and multiplied by an average daily distance by mode , which is estimated by multiplying a number of trips per person per day in all modes (three) by the average trip distance by mode (see above).

If users are interested in assessing the effects on carbon emissions, they can also enter data on motorized modes of transport or can use default values if no local data are available (see section 3.12).

HEAT provides several default values; these have been derived from the literature and agreed on as part of the expert consensus process. They should be used unless more relevant data are available that more accurately reflect the situation being assessed. More information is available in section 3.13 and at the HEAT website *(8)*.

3.8 Input data on the volume of cycling or walking

Input data for the model may come from a number of sources, including:

- route user surveys;
- population-level travel behaviour surveys;
- destination-based behaviour travel surveys (such as commuter behaviour); and
- traffic counts.

Alternatively, informed estimates may serve as surrogates for empirical data, such as in scenario calculations. In all cases, it is important to use the most reliable data possible and to validate these with secondary sources when available.

Ultimately, the quality of economic appraisal depends entirely on the accuracy of the walking and cycling data used. A few considerations will help to make the best use of the available data and avoid mistakes.

3.8.1 Use of short-term counts and surveys

The main concern with short-term counts is that they do not accurately capture variation in walking or cycling over time: time of the day, day of the week, season or weather. If counts are done on a sunny day, larger numbers may be seen than on a rainy day. Cycling also typically declines in the winter months compared with spring and summer in many countries. Since HEAT assumes that the entered data reflect long-term average levels of walking or cycling, data from short-term counts may distort the results.

This issue will affect single-site evaluations (such as a footpath or a bridge), in which counts are conducted at the site itself, or community-wide evaluations based on surveys conducted only during a certain time of the year.

Short-term counts may also be adjusted for temporal variation to better reflect long-term levels of walking or cycling.

Not affected by this issue are assessments based on large surveys conducted on a rolling basis, such as national travel surveys or automated continuous counts.

3.8.2 Use of data from a few locations

Spatial variation, especially in walking, may affect evaluations based on counts at a single location or a few locations. The choice of location may strongly influence the count numbers, which may not be representative of the wider level of walking (or cycling). The results need to be interpreted carefully and should in general not be extrapolated beyond the locations where actual data were collected.

Not affected by this issue are evaluations based on surveys that sample subjects randomly from a defined area (such as large household surveys) and, to a lesser extent, count-based evaluations on linear facilities such as trails.

3.8.3 Use of trip or count data

In HEAT, trip or count data need to be combined with an estimate of average trip length to calculate the volume of walking or cycling. An example is provided by counts conducted on a bridge, in which how far people walk or cycle beyond the bridge remains unknown. Average trip distance may be estimated from user surveys on a specific facility or from travel surveys.

3.8.4 Use of pedometer data

If assessment is based on pedometer data, it should be ensured that the number of steps used is predominantly composed of intentional brisk walking. Some pedometers have a function that excludes steps that are not deliberate walking. Another approach could be to include only intentional walking steps at a rate of about 100 steps per minute *(72)* or to assume the proportion of total steps falling into this category.

3.9 Physical activity assessment in HEAT

To derive an estimate of the health benefits from physical activity from regular walking or cycling, the tool uses estimates of the relative risk of death from any cause among regular cyclists or walkers compared with people who do not cycle or walk regularly.

The tool is based on a relative risk from a meta-analysis of published studies. For more details on the relative risks used in HEAT for cycling and walking, see section 3.9.1.

The tool uses these relative risks and applies them to the amount of walking or cycling entered by the user, assuming a linear relationship between walking or cycling and mortality. To illustrate this, the relative risk from the meta-analysis used for the updated version of HEAT for cycling is 0.90 for regular commuter cycling for 100 minutes per week for 52 weeks of the year (equivalent to 87 hours of cycling per year). Thus, in any given year, a population of regular cyclists receives a protective benefit of 10% (1.00 minus 0.90): that is, overall they are 10% less likely to die from all causes combined than a population of non-cyclists. If the user enters a cycling volume equivalent to 29 hours per year (one third as much), the protective benefit of this amount of cycling will be about 3%. If the user enters 174 hours (twice the time cycled in the reference population), the resulting protective benefit is 20%. This is twice the protective benefit of the reference population.

The same approach is taken for walking, in which the risk reduction is 0.89 for regular walking of 168 minutes per week for 52 weeks of the year (equivalent to 146 hours of walking per year). HEAT then uses population-level mortality data to estimate the number of adults normally expected to die in any given year in the target population. Then it calculates the reduction in expected deaths among the people in this population who cycle or walk at the level specified by the user, using the adjusted relative risk.

Unless a steady-state situation is being assessed, it is important to recognize that there will be a time lag between increases in physical activity and measurable benefits to health. Based on expert consensus, it was agreed that five years was a reasonable assumption to use for such additional physical activity to reach full effect, with an increment of 20% in benefits each year.

3.9.1 Scope and limitations

Although literature suggests that the dose–response relationship between physical activity and mortality is most likely non-linear *(73,74)*, the meta-analysis carried out for HEAT *(10)* also showed that differences between various dose–response curves were modest (see section 3.6). For HEAT, a linear relationship was chosen to avoid additional data requirements on baseline activity levels (which would be needed using a non-linear dose–response function) and because a linear approximation is often adequate within the foreseen range of activity for HEAT (see below).

To avoid inflated values at the upper end of the range, the risk reduction available from HEAT is capped. Inspection of the data points of the new meta-analyses suggested that, after about 45% risk reduction for cycling and 30% for walking, the risk reduction starts to slow (and most of the evidence relates to exposure below these levels). A large cohort study found through purposive review *(75)* also confirmed these limits. On this basis, the advisory group recommended using these caps in the updated HEAT. Thus, HEAT will apply a maximum 45% risk reduction (corresponding to 447 minutes per week) in the risk of mortality for cycling and a maximum 30% risk reduction (corresponding to 460 minutes per week) for walking (Table 1).

3.9.2 Formula

The basic functioning of the physical activity module of HEAT uses the following formula:

1 – RR × (local volume of walking or cycling/ reference volume of walking or cycling)

Where:
RR = relative risk of death in underlying studies (walking: 0.89; cycling: 0.90).

The reference volume of cycling per person is calculated based on 100 minutes per week for

Table 1. Caps for the benefits from physical activity in HEAT

Mode	Applicable age range	Relative risk	Reference volume	Benefits capped at
Walking	20–74 years	0.89 (CI 0.83–0.96)	168 minutes/week	30% (460 minutes/week)
Cycling	20–64 years	0.90 (CI 0.87–0.94)	100 minutes/week	45% (447 minutes/week)

CI: confidence interval.

52 weeks per year at an estimated speed of 14 km/hour.

The reference volume of walking is based on 168 minutes per week at 4.8 km/hour.

The relative risk is then used to calculate number of deaths prevented based on mortality rate, applying a population-attributable fraction formula. For details, see section 3.6.

3.9.3 Relative risk estimate used

The strongest evidence at the time of the first project on the mortality effects of cycling was the relative risk data from two combined Copenhagen cohort studies *(5,76,77)*. This study included about 7000 20- to 60-year-old participants followed up for an average of 14.5 years. It found a relative risk of all-cause mortality among regular commuter cyclists of 0.72 (95% CI 0.57–0.91) compared with non-cycling commuters for 180 minutes of commuter cycling per week.

In 2013, a new systematic review on the reduced relative risk of all-cause mortality from regular cycling or walking was carried out *(10)*.

To be included in this review, a study was required:

- to be a prospective cohort study;
- to report the level of regular walking or cycling, such as duration, distance or metabolic equivalents (MET);
- to report all-cause mortality rates or risk reductions as outcome; and
- to report results independent of (that is, adjusted for) other physical activity.

A total of 8901 titles were identified, and 431 full texts were screened. Seven cycling studies

(carried out in China, Denmark, Germany and the United Kingdom) and 14 walking studies (from China, Denmark, Germany, Japan, United Kingdom and the United States) met the inclusion criteria. A meta-analysis was carried out, combining the results of these studies. Since the available studies used a range of types of exposure, conducting the meta-analysis required estimated for each study the reduced risk at a common exposure level. For this purpose, the various types of cycling and walking exposure used in the studies were converted into MET-hours per week (assuming a linear dose–response relationship and an average intensity of 6.8 METs for cycling and 4.0 METs for walking, if not otherwise stated). The common exposure level was set at 11.25 MET-hours per week. This value was derived from the global physical activity recommendations as corresponding to the recommended level of at least 150 minutes of moderate-intensity physical activity per week *(20)* using 4.5 METs as an average for moderate-intensity physical activity. Using 6.8 METs as an average intensity for cycling, this exposure represents about 100 minutes of cycling per week and 170 minutes of walking per week, using an average intensity of 4.0 METs.

The international advisory group recommended that, for HEAT, a linear dose–response curve based on a relative risk of 0.90 for cycling and 0.89 for walking should be used, applying a constant absolute risk reduction *(78)*. The sensitivity of the results to various possible shapes of dose–response relationships was tested. The differences between the various curves were modest, and the difference in the final risk estimate was no more than 6%.

3.10 Air pollution assessment in HEAT

A method used for quantitative risk assessment of air pollution and modes of transport *(25,79)* was agreed to serve as the basis for assessing the effects of air pollution on cyclists and pedestrians in HEAT *(7,80,81)*. This method uses $PM_{2.5}$ as the air pollution measure, based on background $PM_{2.5}$ concentrations. Based on the selected country and/or city, HEAT will propose a $PM_{2.5}$ concentration retrieved from the WHO Global Urban Ambient Air Pollution Database (city values) *(82)* or the Global Health Observatory data repository (country values) *(83)*; users can review this value. If no value is available from the databases or the user prefers to enter a local value, a $PM_{2.5}$ value can be entered (or a $PM_{2.5}$ value can be derived using an internationally accepted conversion factor of 0.6 *(84)* to transform more widely available PM_{10} measurements into estimates of $PM_{2.5}$ *(81)*, where necessary).

The equivalent change of air pollution intake resulting from cycling or walking compared with a reference scenario is calculated using a ventilation rate (1.37 m^3/hour for walking and 2.55 m^3/hour for cycling) *(80,81)*, duration of exposure and $PM_{2.5}$ concentrations in the mode of transport. The calculated intake is added to the intake during the rest of the day.

HEAT considers two aspects when calculating the difference in air pollution exposure resulting from a specific level of cycling or walking:

- the location of the cycling or walking to derive the appropriate level of air pollution exposure: (a) mainly on or near a road with motorized traffic (and therefore at an air pollution concentration that is considered equal to the background concentration multiplied by an agreed conversion factor for cycling or walking (see below)); (b) mainly in a park or away from roads with motorized traffic (and therefore at a concentration of air pollution that could be considered equal to the background concentration); and

- the main purpose of the cycling and walking to derive the appropriate reference case: (a) mainly for leisure where the comparison scenario HEAT is using is "staying at home" (with a concentration of air pollution that is considered to be equal to background concentration and a ventilation rate of 0.61 m^3/hour); (b) mainly for commuting where the comparison scenario for HEAT is "using a car" (with a concentration of air pollution equal to the background concentration multiplied by an agreed conversion factor (see below) and a ventilation rate of 0.61 m^3/hour *(80,81)*).

Mode-specific $PM_{2.5}$ concentrations are derived from the background concentrations using conversion factors. The applied factors of 2.0 for cycling, 1.6 for walking and 2.5 for using a car[3] (versus background) were derived for HEAT from a purposive review of studies that estimated $PM_{2.5}$ concentrations while cycling or walking compared with concentrations in other modes of transport *(11)*.

The international advisory group agreed to use a meta-analysis including 14 international cohort studies for use in HEAT, which summarized the relative risk between all-cause mortality and each increment of 10 µg/m^3 of $PM_{2.5}$ as 1.07 (1.04–1.09) *(81)*. There will be a time lag between exposure to air pollution and negative health effects. Based on expert consensus, a time lag of five years – similar to that used for the health effects from physical activity (see section 3.9) – will be used for air pollution effects to build up on mortality as a reasonable and most likely conservative assumption, with an increment of 20% in benefits each year.

3.10.1 Scope and limitations

The use of non-linear integrated dose–response functions has been suggested to reflect indications that the relationship between air pollutants and health risk seem to become flat at higher pollution levels *(81)*. However, HEAT is being proposed predominantly for applications in the European Region, where the extreme exposure sometimes found in other parts of the world is rare. The experts therefore adopted a linear dose–response function as being appropriate within the HEAT framework *(7)*.

To avoid inflated values at the upper end of the range, the risk increase from exposure to particulate matter within HEAT is capped. A previously used cap of 50 µg/m^3 *(85)* was agreed for use for HEAT, which is also in accordance with the evidence on the air pollution exposure in the locations in which the studies took place on which HEAT is based *(10)*. Although HEAT still applies to locations with somewhat higher levels of air pollution, in this case no further health effects will be applied beyond 50 µg/m^3. No lower cap is used for HEAT, as recent evidence shows that health effects also occur at very low concentrations of air pollution *(86)*.

Finally, HEAT only includes air pollution effects among cyclists and pedestrians and does not consider the (often substantial *(21,79)*) effects of reducing air pollution for the whole population by replacing motorized transport by cycling and walking.

3.10.2 Relative risk estimates used

HEAT uses the relative risk from a meta-analysis including 14 international cohort studies from Austria, Canada, Denmark, France, Finland, Germany, Greece, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States *(83)*. It quantifies the relative risk for mortality from all causes for each increment of 10 µg/m^3 of $PM_{2.5}$ as 1.07 (CI 1.04–1.09). This translates into a 7% increase in risk of dying per each additional increase in long-term exposure to 10 µg/m^3 $PM_{2.5}$. In other words,

[3]The literature review *(11)* focused on studies contrasting active versus passive modes of transport; the car versus background ratio used in HEAT stems from the studies included in this review and should be seen as an approximation.

people exposed to $PM_{2.5}$ levels that are 10 µg/m³ higher have a 7% increased risk of dying (at any point in time) than people who are exposed to 10 µg/m³ less, assuming they do not differ in age, smoking status or any other relevant characteristic.

If multiple papers on a study existed, only the most recent one was used, which had longer follow-up. The only studies included in the quantitative meta-analysis were those that directly estimated $PM_{2.5}$ exposure. For all-cause mortality from $PM_{2.5}$ exposure, the initial analysis *(64)* included 11 studies and was later updated to include three more studies *(83)*, which only had a minor effect on the relative risk estimate.

The authors also found little evidence for a stronger association among women than among men. People with less education and obese subjects had a larger estimated effect for mortality related to fine particulate matter, although more recent studies have weaker evidence for differences related to education *(64)*.

3.10.3 Combining physical activity and air pollution exposure

The published relative risks for mortality and physically activity from walking and cycling used by HEAT are taken from studies in settings in which participants were exposed to (different levels of) air pollution. As such, the relative risks for physical activity include a small population-average degree of influence of air pollution while walking or cycling. When HEAT users select solely assessing the effects of physical activity, this is not specifically adjusted for, implicitly assuming that air pollution levels are comparable between the assessed setting and the settings in which the studies were conducted.

However, if the user selects both the physical activity and the air pollution assessment, then HEAT adjusts the relative risk for physical activity benefits from walking and cycling to exclude the effects of air pollution, using relative risk estimates adjusted to what they would be if the physical activity studies had been conducted in non-polluted environments. The effects of the additional air pollution exposure from walking or cycling are calculated separately (and shown in the detailed HEAT results in section 3.16).

To derive the adjusted relative risks, the exposure to air pollution ($PM_{2.5}$) in each of the cycling and walking study settings was estimated using international databases and assuming a 50% higher historical exposure to consider the general improvement of air pollution between the time the underlying studies were conducted (between 1964 and the early 2000s) and the year 2011 for which air pollution exposure was available *(7)*. The effect of this exposure while walking or cycling on the original relative risks from the physical activity studies *(10)* was calculated, using a published exposure–response function between $PM_{2.5}$ and all-cause mortality *(64)*, default ventilation rates (see section 3.13) and the published durations of exposure *(35)*.

The following is an overview of the relative risks used in assessing physical activity.

For cycling:

- unadjusted: RR = 0.903 (0.866–0.943); and
- adjusted for air pollution: RR = 0.899 (0.861–0.939).

For walking:

- unadjusted: RR = 0.886 (0.806–0.973); and
- adjusted for air pollution: RR = 0.883 (0.803–0.970).

Note that the vice versa argument could be made for the influence of active travel on the published relative risks of air pollution from studies in which subjects engaged in walking or cycling. It is fair to assume that this influence would be negligible because of the small contribution of the additional inhaled dose of air pollution while walking or cycling to the total exposure of the entire study population.

3.11 Assessing road crashes in HEAT

HEAT assesses the effects of road crash through a basic approach *(35)*: a generic estimate of road crash risk is multiplied by the local data on cycling provided by the tool user (implementations for walking and driving are planned). The generic estimate of road crash risk for cycling is derived based on national statistics, dividing the total number of fatal cycling crashes by the total number of kilometres cycled for each country (see data sources below).

3.11.1 Safety improvements over time

In assessments that compare two cases (such as before and after or scenario A versus B), the user has the option to specify a change in road crash risk (such as a 10% decrease) *(34)*. HEAT then applies a linear interpolation of the road crash risk over time (see section 3.6).

3.11.2 Scope and limitations

Since the availability of city-level data is limited, this module is primarily offered for assessment at the national level; the corresponding default national fatality rate is currently provided if a city-level assessment is selected. Users can use this approximated value or choose to overwrite it if they have a suitable local background road crash risk they can use. Offering assessment based on city-level background road crash rates is foreseen as more data become available.

Since road crash risks can vary greatly at a subcity level, such as between types of roads or facilities, deriving accurate crash risk estimates at such scales remains challenging. Because of its simplified approach to estimating road crash impact, HEAT will probably not provide this level of assessment.

HEAT further does not consider differences or changes in exposure to motorized traffic. Such assessment, as proposed by Elvik et al. *(27)* and others, may be offered in a later version.

Currently HEAT also does not consider injuries from road crashes. The HEAT advisory group acknowledged that not including the health effects and costs of injuries would mean that HEAT would not yet fully consider all negative health effects from road crashes *(35)*. However, it was recognized that the currently available data sources and the lack of internationally standardized approaches to definitions and to collecting information on road injuries do not yet allow non-fatal outcomes to be included. Such assessment may be offered later.

3.11.3 Formula

$$F_{local} = FR_{generic} \times D_{local}$$

Where:

F_{local} = cycling fatalities expected due to local cycling.

$FR_{generic}$ = generic national fatality risk estimate calculated by dividing the national number of cyclists killed in road crashes per year by the national estimate of total cycling in km per year.

D_{local} = local cycling distance in km based on data provided by the HEAT user.

3.11.4 Crash risk data

The generic estimates of road crash risk were calculated using fatality and exposure data derived from various sources. Fatality data were compiled from the international data sets of the International Transport Forum *(87)* and the World Health Organization *(88)*. Because of the lack of international databases for exposure, data were compiled from several national sources (details are provided on the HEAT website *(8)*). For the countries not included in these databases, cycling exposure was estimated using assumptions on mobility demand (three all-mode trips per person per day) and trip distance (3 km per cycle trip), population data *(88)* and extrapolations of data on modal share *(89)*.

The sources used differ in quality, and combining them implies different levels of reliability of the resulting generic estimates of fatality risk. The next section provides more information.

3.11.5 Development of background road crash rates

The generic estimates of fatality risk were calculated by dividing the national number of cyclists killed in road crashes per year (numerator) by national estimates of total cycling in km per year (denominator). Both fatality and exposure data were derived from different sources with different data quality.

Fatality data from the international data set of the International Transport Forum *(87)* were given priority over data from WHO *(88)* (Fig. 6), since this dataset comprises observations for time series over multiple years. A five-year average (2011–2015) was calculated for HEAT to reduce the effect of the usual variation of fatality data from one year to another. However, the International Transport Forum data set does not include information for all countries considered in HEAT. For these countries, fatality data from WHO *(88)* were used. This data set contains data from many countries but only for one year (mostly 2013) and can include observations as well as model estimates when observations are not available. The number of fatalities for the transport mode was calculated by multiplying all-mode fatalities by the share of fatalities for each mode.

Because of the scarcity of international databases for exposure data (km travelled by bicycle per year), data were compiled from several national sources. If data were available for different years, more recent data (from 2015) were given priority. If exposure data were available for more than one year, averages (optimally from 2011–2015) were calculated. In some cases, national exposure data were incomplete and required additional calculations using assumptions. For countries with no available exposure data from national sources, cycling exposure was estimated by multiplying the population *(88)* by the number of all-mode trips per person and day (assumption), the distance per cycle trip (assumption) and modal share by world region extrapolated from city data *(89)* (Fig. 6).

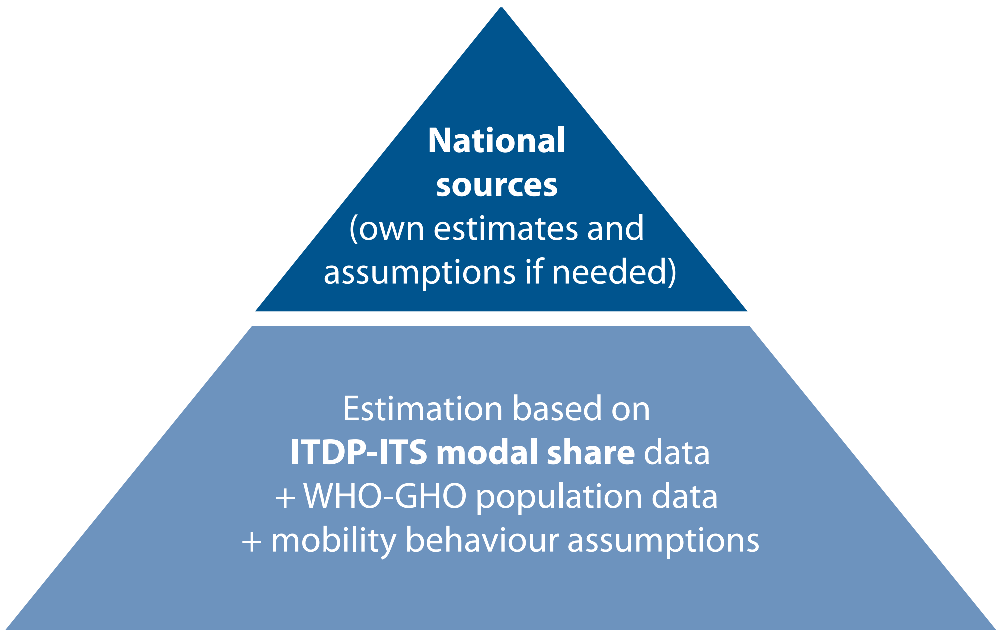
The following assumptions were applied.

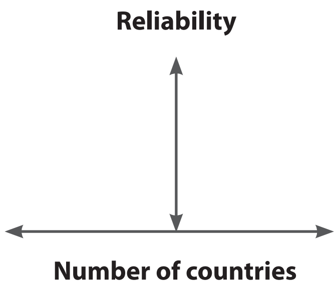
- Three daily trips per person per day. According to Diaz Olvera et al. *(90)*, all-mode mobility demand ranges from 3.0 to 4.6 in low- and middle-income countries in sub-Saharan Africa, which is similar to those found in higher-income countries such as France. The lowest value of the range is used in HEAT to obtain conservative estimates.

- Three kilometres per bicycle trip. According to the EU project WALCYNG for Europe, the average cycling trip distances range from 3 to 4 km *(91)*. Again, HEAT uses the lowest value of the range to obtain conservative estimates.

The above-mentioned sources are of different quality, and combining them implies different levels of reliability of the resulting fatality risk

Fig. 6. Sources used for exposure data for the HEAT background road crash rates





E = population × MD × BMS × BTL

E = exposure: km travelled by bicycle per year

Population: WHO data

MD = mobility demand (three all-mode trips per day, assumption)

BMS = bicycle modal share: bicycle trips per total trips (ITDP-ITS extrapolations by world region)

BTL = bicycle trip length (3 km per bicycle trip, assumption)

ITDP-ITS = Institute for Transportation and Development Policy and Institute of Transportation Studies

WHO-GHO = WHO Global Health Observatory

estimates. Five levels of reliability were considered based on the data quality of the datasets used for fatalities (numerator of the fatality risk estimate) and exposure (denominator):

- very high: numerator from International Transport Forum fatality data and denominator from national sources;
- high: numerator from International Transport Forum fatality data and denominator from national sources that imply some calculations or assumptions;
- medium: numerator from International Transport Forum fatality data and denominator estimated based on modal share extrapolation by the Institute for Transportation and Development Policy;
- low: numerator from observed WHO Global Health Observatory fatality data and denominator estimated based on modal share extrapolation by the Institute for Transportation and Development Policy; and
- very low: numerator from modelled WHO Global Health Observatory fatality data and denominator estimated based on modal share extrapolation by the Institute for Transportation and Development Policy.

3.12 Assessing carbon emissions in HEAT

3.12.1 Overview

The assessment of carbon emissions in HEAT consists of three main assessment steps *(35)*:

- assessing true mode shift from motorized travel to walking or cycling (or vice versa);
- assessing the carbon emissions from substituted motorized travel; and
- assessing the economic value of the social impact of changes in carbon emissions.

HEAT can assess the modal shift from motorized travel in assessments that compare two cases (see section 3.6): for example, reference versus comparison, before versus after an intervention and with policy measures versus without policy measures. After entering a volume of walking and/or cycling, users are asked to adjust their data (see section 3.14) to consider the shares of walking and/or cycling that:

- have been reassigned (shifted from other routes or destinations) or are entirely new because of induced (or generated) demand, both of which are not considered for the carbon assessment; for example, if 5% of new cycling was a shift from a parallel route and 5% was newly induced travel, the cycling activity relevant to the carbon assessment is 90% of the volume initially entered by the user;
- are mainly for transport (versus for recreation); assuming that any walking and/or cycling for recreation will not have been shifted from or carried out by motorized travel, the carbon assessment does not consider the volume of recreational active travel; and
- were shifted from other motorized modes; for these modal shifts, changeable default diversion rates are provided (see section 3.12.2).

Single-case assessment (which assumes a steady-state situation) by definition excludes reassigned and induced walking and/or cycling. In this case, the proportions shifted from other modes are used to derive the amount of motorized travel that hypothetical would have been carried out otherwise (for no walking and/or cycling). The same approach applies to two-case assessment in which the user has selected the option of "no data" on motorized modes (input data section).

The second step converts these changes in travel activity into carbon emissions that are potentially avoided (single-case assessment) or saved (two-case assessment). For this calculation step, the HEAT approach includes:

- **operational emissions** (section 3.12.3), including country- and year-specific background values on average trip lengths, fuel splits, vehicle fleet composition, ambient temperature, cold-start excess emissions and a changeable default value on prevailing traffic conditions in the study area;
- **energy supply emissions** (section 3.12.4), including country- and year-specific background values on well-to-tank emissions for various transport fuels such as gasoline, diesel and electricity; and
- **vehicle life-cycle emissions** (section 3.12.5), using a standard life-cycle inventory approach applying embedded carbon emission factors for the materials and energy used in vehicle manufacturing.

In the third step, the resulting saved carbon emissions are monetized using the social cost of carbon approach (see section 3.15.2). Changeable default values are provided disaggregated by country and the year economic assessment starts.

3.12.2 Modal shift and diversion rates (step 1)

The carbon tool excludes new trips that do not displace trips made previously by motorized modes from the assessment of carbon emissions from motorized travel. This has been implemented by parameterizing diversion rates *(38)* for walking and cycling for transport, with values between 0 and 100% for the shares of new cycling (or walking) estimated to be shifted from motorized travel and walking (or cycling). The motorized modes considered include cars (as driver or passenger), local buses, urban rail (including tram and underground) and motorcycles (not shown separately in Fig. 7 for space reasons). For two-case assessment, the user is asked to consider excluding any induced (entirely new trips not replacing motorized travel) or reassigned (route shift) travel activity. The diversion rates are applied to the volume of walking and/or cycling entered by the user.

The dashed boxes are only really relevant for assessments of before versus after comparisons.

Assume an infrastructure intervention has led to an increase in connectivity, making it easier and safer to travel via the new route. New cycling trips are being recorded along that route (such as by using trip counters or user intercept surveys). Some of the new trips were made previously using different modes (modal shift), and some were on a parallel route that perhaps was not as convenient or safe to use (route shift or route reassignment). Some even did not exist at all before the intervention (newly generated or induced demand that was suppressed before). The carbon module focuses on the former (modal shift) and does not consider the latter (route shift and newly induced trips).

For the diversion rates of the remaining volume of walking or cycling, HEAT provides recommended values based on a conservative assessment of the evidence found in the appraisal guidance *(38)*, project evaluation *(92–96)* and impact scenario *(96–98)* literature. For instance, United Kingdom transport appraisal guidance (WebTAG) *(38)* and Mulley et al. *(99)* reported car substitution rates of 25%

Fig. 7. HEAT assessment of carbon emissions: modal shift using travel activity and diversion rates

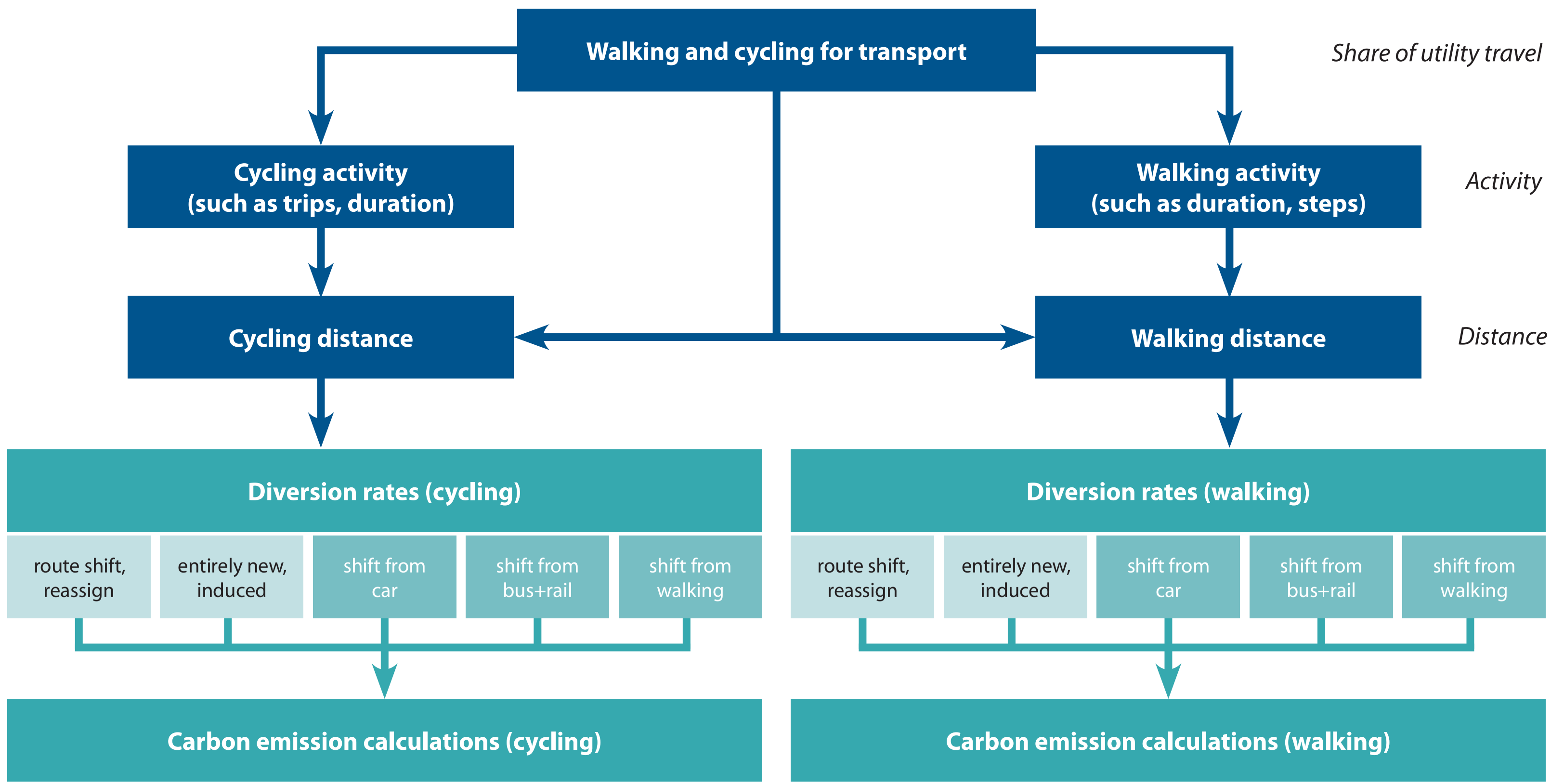


Table 2. Changeable default values for modal shift and diversion rates

From	To cycling (%)	To walking (%)
Car or van: as driver or passenger	30	20
Local bus	40	50
Urban rail: light rail, trams, metro (if relevant)	10	10
Walking	20	Not applicable
Cycling	Not applicable	20

to 30%. The European Cyclists' Federation *(100)* suggested using car 32%, bus 42% and walking 26%, based on the modal substitution rates observed for bicycle trips with bicycle share schemes.

Table 2 shows the HEAT-recommended default values for diversion rates from other transport modes to cycling or walking.

3.12.3 Operational emissions (step 2)

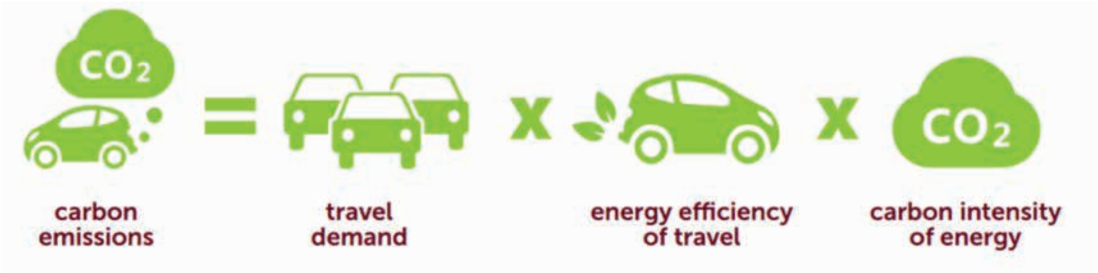
Operational carbon emissions are derived by breaking carbon emissions down into changes in travel demand (passenger-km, by mode – see step 1 in section 3.12), differences in energy efficiency (megajoules per passenger-km, by mode and fuel type) and differences in carbon intensity (CO_2e/MJ, by mode and fuel type); (that is, a typical decomposition approach (Fig. 8).

HEAT considers the effects of three contextual factors on carbon emission factors:

- distance and average trip lengths;
- average speed, representing various traffic conditions in the study area; and
- mode characteristics such as vehicle type and fuel type.

For cars, HEAT considers average traffic speeds, vehicle fleet composition and the effect of

Fig. 8. Composition of operational carbon emissions



real-world driving (adding 21.6% to the carbon emissions derived from official laboratory test data; value based on the conversion factors used in the United Kingdom *(101)*) in the study area to calculate the "hot" emission of CO_2e emitted per km, based on published relationships between fuel consumption, average speed and conversion to carbon emissions using a standard carbon balance method. For motorcycle, bus and rail, only fuel type shares are considered, with average emission factors based on the conversion factors used in the United Kingdom *(101)*. Buses are mainly powered by diesel power trains; motorcycles are 100% gasoline; and urban rail is assumed to be all electric. For cars, cold-start excess emissions (for the cold driving for each trip, typically the first 3.4 km after starting) are added to this. This can be specified as follows:

$$E_t = \sum\nolimits_{mode} ef_{hot,t}(mode, speed, fuel, size) * pkm_t(mode) + E_{cold}(temp, trip\ length, trips)$$

Where:
E_t = pollutant emissions (such as CO_2e); *t* = scenario (such as without and with the intervention), $ef_{hot,t}(mode)$ = hot emission factor for *mode* in scenario t; $pkm_t(mode)$ = passenger-km for *mode* in scenario *t*; E_{cold} = cold-start excess emissions (for cars only); *temp* = ambient temperature; *trip length* = average trip length.

The first term includes the dependence of emission factors on speed as follows (based on the European Environment Agency's COPERT model *(37)*):

$$ef_{hot} = \frac{a + c * V + e * V^2}{1 + b * V + d * V^2}$$

Where:
V= average speed and coefficients *a* to *e* are empirically derived for each fuel and hard-coded in the HEAT module.

Hot emissions dominate total emissions, but cold-start emissions should not be neglected, since they constitute a significant share of total emissions for shorter trip lengths (typically 15–20%). E_{cold} is typically derived for each vehicle technology *k* as:

$$E_{cold,k} = \beta_k * pkm_k * ef_{hot,k} * (\frac{ef_{cold,k}}{ef_{hot,k}} - 1)$$

$$\frac{ef_{cold,k}}{ef_{hot,k}} = l - m * temp$$

Where:
β = fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature, pkm_k = passenger-km, e_{cold} / e_{hot} = cold/hot emission quotient for vehicles of technology *k*, *temp* = ambient temperature. *l* = 1.47, *m* = 0.009 (gasoline); *l* = 1.34, *m* = 0.008 (diesel) based on the European Environment Agency *(37)*.

The β parameter depends on ambient temperature and average trip length *(37)*. In HEAT, β was derived by dividing the average trip length of the substituted car trip by an average cold-start distance of 3.4 km, with $\beta \leq 1$.

Vehicle fuel type shares and average occupancy rates are based on international databases, including the GAINS (greenhouse gas–air pollution interactions and synergies) model projections (scenario WPE_2014_CLE of the Council Working Party on Environment (WPE) based on current legislation (CLE)) of the International Institute for Applied Systems Analysis for years up to 2050 *(102–106)*. Future projections of carbon emission factors are thus based on available scenario data, not forecasts, and any projections beyond the 10-year time frame should therefore be treated with caution.

For cars, the user can choose between five generic traffic conditions based on typical road speeds observed in European countries, including: Vienna 46 km/h, Newcastle 42 km/h ("nearly free-flow conditions"); Prague 37 km/h, Barcelona 35 km/h, Paris 31 km/h, Edinburgh 30 km/h, Rome 30 km/h ("some heavy traffic and peak-time congestion"), London 19 km/h and Brussels 22 km/h ("heavy congestion and wider peaks") *(107,108)*. The five categories are:

- European average, urban (32 km/h) – changeable default value;
- little or no congestion, urban (free flow) (45 km/h);
- some peak-time congestion (commute, school run), urban (35 km/h);

Table 3. Derived average hot and cold emission factors (tailpipe, tank-to-wheel), showing values derived for the United Kingdom in 2015 (HEAT uses country- and year-specific factors)

Example: United Kingdom, 2015	**Average traffic conditions**				
Average hot emissions factors (grams of CO_2e per passenger-km)	European average, urban	Little or no congestion (free flow)	Some peak-time congestion	Heavy congestion most days	European average, rural
Car (as driver or passenger[a,b]	129.1	112.3	124.0	161.5	104.8
Local bus[a,b]	101.7	NA	NA	NA	NA
Urban rail, trams, metro (100% electric)[b]	0	NA	NA	NA	NA
Motorcycle[a,b]	79.3	NA	NA	NA	NA
E-bike or bike	0	NA	NA	NA	NA
Average cold-start emissions per trip (grams of CO_2e per passenger-trip)[c]					
Car (as driver or passenger[a,b]	150.4	130.8	144.4	188.1	122.0

[a]Considers weighted fuel and engine type shares for each mode, such as for cars in the United Kingdom in 2015 (56% gasoline, 43% diesel, 1% electric), bus (100% diesel), motorcycle (100% gasoline). [b]Car occupancy rate of 1.56 (all trip purposes), 12.21 (local buses), 40 (average urban rail, tram and metro), 1.05 (average motorcycle). [c]With a cold:hot ratio of 1.33 and cold trip distance of 3.51 km, derived from ambient temperature of 9.4°C and average trip length of 14 km. NA: not applicable.

Sources: hot and cold emissions factor coefficients: COPERT IV *(37)*; EMEP/EEA *(109)*; vehicle fleets: UK Government conversion factors for company reporting, full 2016 dataset *(101)*; European motor vehicle parc 2014: vehicles in use (2009–2014) *(102)*; UK new car market starts 2016 on a high with best January in 11 years *(110)*; Transport statistics Great Britain: 2015 edition *(111)*.

Table 4. Derived average energy supply emissions factors (well-to-tank) per passenger-km, showing values derived for the United Kingdom in 2015 (HEAT uses country- and year-specific factors)

Example: United Kingdom, 2015	**Average traffic conditions**				
Average energy supply emissions factors (grams of CO_2e per passenger-km)	European average, urban	Little or no congestion (free flow)	Some peak-time congestion	Heavy congestion most days	European average, rural
Car (as driver or passenger[a,b]	28.4	24.7	27.3	35.5	23.0
Local bus[a,b]	22.5	NA	NA	NA	NA
Urban rail, trams, metro (100% electric)[b]	67.2	NA	NA	NA	NA
Motorcycle[a,b]	17.3	NA	NA	NA	NA
E-bike	5.4	NA	NA	NA	NA

[a]Weighted by fuel and engine type shares for each mode, such as for cars in the United Kingdom in 2015 (56% gasoline, 43% diesel, 1% electric), bus (100% diesel), motorcycle (100% gasoline). [b]Car occupancy rate of 1.56 (all trip purposes), 12.21 (local buses), 40 (average urban rail, tram and metro), 1.05 (average motorcycle). NA: not applicable.

Main sources: well-to-tank emissions factors: UK Government conversion factors for company reporting, full 2016 dataset *(101)*; JEC well-to-wheels analysis *(113)*; electricity emissions factors: Electricity-specific emission factors for grid electricity *(114)*; vehicle fuel shares: IIASA, IIASA GAINS model, scenario WPE_2014_CLE: the updated "current legislation" (after the bilateral consultations in 2014) of the PRIMES 2013 REFERENCE activity projection *(106)*.

- heavy congestion most days (AM, PM and inter-peak), urban (20 km/h); and
- European average, rural (60 km/h).

HEAT uses country- and year-specific emission factors. Table 3 provides an example for the United Kingdom in 2015.

3.12.4 Energy supply carbon emissions

Carbon emissions from energy supply include upstream emissions from the extraction, production, generation and distribution of energy supply. The adopted approach uses well-to-tank emission factors for various energy supply pathways for transport fuels (gasoline, diesel, electricity, etc.) *(112)*, taken from published and well respected sources including the JEC Well-to-Wheels study *(113)* and its use in developing national recommended values such as the United Kingdom Department for the Environment, Food and Rural Affairs and Department for Energy and Climate Change *(101)*. For E-bikes, cars, buses and urban rail, this is based on different values for the JEC well-to-wheels study of gasoline (0.654 kg of CO_2e per kg of fuel), diesel (0.688 kg of CO_2e per kg of fuel) and delivered electricity[4] (for example, this was 0.517 kg of CO_2e for the United Kingdom in 2015). As with operational emissions, an additional 21.6% was added to account for real-world driving conditions. Since electricity

[4] This includes emissions from electricity generation and its transport and distribution and from the generation well-to-tank and transport and distribution well-to-tank stages.

factors vary significantly between countries (up to three orders of magnitude, reflecting the use of high shares of renewable sources versus high shares of fossil fuels), HEAT uses country-specific factors based on the widest possible country comparison from an authoritative source *(114)*.

Table 4 provides an example for the United Kingdom in 2015.

3.12.5 Life-cycle carbon emissions

HEAT is considering only carbon emissions from the manufacture of vehicles (the clear majority of vehicle life-cycle carbon emissions, apart from operational ones), with aggregate carbon values per vehicle type (cars, motorcycles, bikes and public transport vehicles) derived assuming typical lifetime mileages, mass body weights, material decomposition and material-specific emission and energy use factors.

Table 5. Assumptions and average CO_2e emissions from vehicle manufacture

Mode	Total vehicle weight (tonnes)	Tonnes of CO_2e per vehicle	Lifetime mileage (km)	Grams of CO_2e per passenger-kilometre
Bicycle	0.017	0.10	20 000	4.9
E-bike/pedelec[a]	0.024	0.19	20 000	9.3
Motorcycles	0.15	0.54	50 000	10.3
Average car (~1% electric vehicles)	1.295	4.7	150 000	19.9
Average bus	11	39.5	1 000 000	4.0
Urban rail	66	237.1	1 500 000	3.2

[a]The battery and motor add 7 kg in weight; assumed 2.5 grams of CO_2e per km for the battery based on Odeh et al. *(112)*.

Table 5 shows the key inputs, assumptions and derived carbon emissions factors per passenger-km for the United Kingdom. HEAT uses country-specific factors, reflecting local differences in occupancy rates for the various motorized modes *(115)*.

3.13 Default and background values for HEAT calculations

Whenever possible, HEAT provides generic data based on the best available evidence or expert judgement. HEAT has two types of generic values:

- default values provided for HEAT assessment but that the users can overwrite if they prefer to use other values, such as from their specific local context; and

- background values considered to represent the best possible scientific consensus (such as estimates based on numerous epidemiological studies) that the user cannot change.

This section provides an overview of the main default values (Tables 6–8) and background values (Tables 9–12), with their source, used either for general calculations (such as to derive volume data for the calculations) or in the HEAT modules.

3.13.1 Default values

Table 6. General default values used by HEAT

Description	Value	Unit	Sources
Average number of trips per day using all likely modes	3	trips (all modes) per person per day	*(91,116)*
Average walking speed	5.3	km/h	*(10)*
Average cycling speed	14.0	km/h	*(10)*
Average distance per walking trip	1.3	km/trip	*(117,118)*
Average distance per bicycle trip	4.1	km/trip	*(117,118)*
Time frame for calculating the mean annual benefit	10	years	HEAT advisory group decision
Average length of walking steps	72	cm	*(5)*
Discount rate	5	%	HEAT advisory group decision

In addition, default values are provided for each country for the mortality rates *(119)*, values of a statistical life *(18)* (see section 3.14) and the social costs of carbon *(120,121)* (see section 3.14).

The HEAT **physical activity** module uses only non-changeable background values (see section 3.14).

The HEAT **air pollution** module provides default $PM_{2.5}$ concentrations by country and city as available from the WHO Global Health Observatory data repository *(88)*.

HEAT also provides default fatality rates for each country (and, for future versions, by city) and by mode for road crash assessment (see section 3.1.11).

Table 7. Default values for road crash assessment in HEAT

Description	Value	Unit	Sources
Average number of trips per day using all likely modes	3	trips (all modes) per person per day	*(91,116)*
Reduction in road crash rate over time (non-linear adjustment)	0	%	HEAT advisory group decision

Table 8. Default values for HEAT carbon emission assessment

Description	Value	Unit	Sources
Average distance per walking trip	1.3	km/trip	*(117,118)*
Average distance per bicycle trip	4.1	km/trip	*(117,118)*
Average distance per car trip	15.6	km/trip	*(117,118)*
Average public transport speed	22.7	km/h	*(117,118)*
Average car speed	42.0	km/h	*(117,118)*
Average motorbike speed	29.8	km/h	*(117,118)*
Average bus speed	15.4	km/h	*(117,118)*
Average light rail speed	16.1	km/h	*(117,118)*
Average train speed	37.4	km/h	*(117,118)*
Average road traffic speed for European standards in urban areas	32	km/h	*(122–124)*
Average road traffic speed for nearly free flow at all times in urban areas	45	km/h	*(122–124)*
Average road traffic speed for minor congestion mainly at peak times in urban areas	35	km/h	*(122–124)*
Average road traffic speed for heavy congestion throughout the day, urban areas	20	km/h	*(122–124)*
Average road traffic speed for European average standards in rural areas	60	km/h	*(122–124)*
Share of walking trips shifted from bike	20	%	*(38,95,100)*
Share of walking trips shifted from car	20	%	*(38,95,100)*
Share of walking trips shifted from public transport (50% bus + 10% rail)	60	%	*(38,95,100)*
Share of walking trips shifted from bike	20	%	*(38,95,100)*
Share of cycling trips shifted from car	30	%	*(38,95,100)*
Share of cycling trips shifted from public transport (40% bus + 10% rail)	50	%	*(38,95,100)*

3.13.2 Background values

Tables 9–12 show the general background values for HEAT assessment for physical activity, air pollution and carbon emission. This subsection also explains the values used for the background road crash rates.

Table 9. General background values used in HEAT assessment

Description	Value	Unit	Sources
Time needed to obtain full health effects in single-case assessment	0	years	HEAT advisory group decision
Time needed to obtain full health effects in two-case assessment	5	years	HEAT advisory group decision

Table 10. Background values used in HEAT physical activity assessment

Description	Value	Unit	Sources
Capped risk reduction for walking	30	%	*(13)*
Capped risk reduction for cycling	45	%	*(13)*
Relative risk for cycling	0.903	ratio	*(10)*
Relative risk for walking	0.886	ratio	*(10)*
Reference duration of cycling	100	minutes per person per week	*(10)*
Reference duration of walking	168	minutes per person per week	*(10)*
Relative risk for cycling without air pollution effect	0.899	ratio	*(7)*
Relative risk for walking without air pollution effect	0.883	ratio	*(7)*

Table 11. Background values used in HEAT air pollution assessment

Description	Value	Unit	Sources
Relative risk for $PM_{2.5}$	1.07	ratio	*(51)*
Reference concentration for $PM_{2.5}$	10	$\mu m/m^3$	*(51)*

Table 11. (continued)

Description	Value	Unit	Sources
Conversion rate for particulate matter exposure: walking	1.6	ratio	*(11)*
Conversion rate for particulate matter exposure: cycling	2	ratio	*(11)*
Conversion rate for particulate matter exposure: car	2.5	ratio	*(11)*
Conversion rate for particulate matter exposure: public transport	1.9	ratio	*(11)*
Ventilation for walking	1.37	m^3/hour	*(125,126)*
Ventilation for cycling	2.55	m^3/hour	*(125,126)*
Ventilation for car	0.61	m^3/hour	*(125,126)*
Ventilation for public transport	0.61	m^3/hour	*(125,126)*
Ventilation for sleep	0.27	m^3/hour	*(125,126)*
Ventilation for rest	0.61	m^3/hour	*(125,126)*
Activity duration for sleeping	480	minutes per person per day	*(125,126)*

For calculating background **road crash** rates, the HEAT road crash module uses population data from the WHO Global Health Observatory *(88)* (for each country and, for future editions, by city) are being used. For more information, see section 3.1.11 and the HEAT website *(8)*.

Table 12. Background values used in HEAT carbon emission assessment

Description	Value	Unit	Sources
Share of bus trips compared to rail trips	50	%	*(127)*
Average CO_2e emissions per vehicle-km for bike	4.93	g of CO_2e per vehicle-km	*(128,129)*
Average CO_2e emissions per vehicle-km for E-bike	9.31	g of CO_2e per vehicle-km	*(128,129)*
Average CO_2e emissions per vehicle-km for car by country	31.01	g of CO_2e per vehicle-km	*(100,130)*

Table 12. (continued)

Description	Value	Unit	Sources
Average CO_2e emissions per vehicle-km for bus by country	39.51	g of CO_2e per vehicle-km	*(100)*
Average CO_2e emissions per vehicle-km for rail	158.03	g of CO_2e per vehicle-km	*(100)*
Average CO_2e emissions per vehicle-km for motorcycle	10.78	g of CO_2e per vehicle-km	*(130)*
Number of walking trips per year	372	trips per year	*(131)*
Number of cycling trips per year	248	trips per year	*(131)*

3.14 Data adjustments within HEAT

Input data on active modes of transport provided by the user may not be adequate or sufficient for all calculations of impact. HEAT therefore offers several options to adjust the data or provide additional information to inform the calculation, depending on the characteristics of the assessment. If the user does not provide such information, default settings apply.

Data adjustment options in HEAT may include the following (depending on the type of assessment):

- proportion excluded
- temporal and spatial adjustment
- uptake time for active travel demand
- proportion of new trips
- proportion of reassigned trips
- proportion of shifted trips
- proportion in traffic
- proportion for transport
- traffic conditions
- change in crash risk
- substitution of physical activity.

3.14.1 General adjustments of data on active travel

3.14.1.1 Proportion excluded because of unrelated factors (two-case assessment only)

When the impact of an intervention is assessed, not all the cycling or walking observed may be directly attributable to the intervention. For example, cycling may have become more fashionable over time, or gasoline or public transport prices may have changed and affected active transport behaviour. Walking or cycling arising from such external effects should not be included in the assessment of the infrastructure or project.

The precise effects of an intervention and unrelated factors can rarely be disentangled. Estimate the proportion you would exclude from the assessment (such as –30%) to the best of your knowledge. The HEAT website provides more guidance *(8)*.

The default setting is 0%.

3.14.1.2 Temporal and spatial adjustment

HEAT requires long-term average input on active travel (such as annual means). Active travel is highly affected by such factors as season, weather and time of day. Short-term counting, for example, is typically carried out in summer or fall and often during rush hour. If active travel data is from a short-term survey or count, it likely under- or overestimates the long-term average. This can be adjusted here (such as + 20% or – 30%). Data from continuous counters can be helpful in assessing the potential need for adjusting for time.

Similarly, the location where count data or intercept surveys are collected may not represent average volumes for the complete facility of interest (such as a bike path, trail, or network). This slider can be used to apply a spatial adjustment (such as + 20% or – 30%). Data from multiple locations are usually needed to inform spatial adjustment, but crude guesses may be adequate in some cases. Accurate spatial adjustment would require a spatial modelling approach.

The default setting is 0%.

3.14.1.3 Uptake time for active travel demand (two-case assessments only)

Here users can specify a take-up time (in years) until the maximum volume of active travel is reached. This allows adjusting for the estimated time to reach the full level of walking or cycling entered, such as after an intervention has been implemented. For example, if a new footpath is built, and an estimated 5 years will elapse for usage to reach a steady state, this figure should be changed to 5. For steady-state situations, with no build-up time considered, this should be set to zero.

The default setting is 1 year.

3.14.1.4 Investment costs (two-case assessment only)

This input field allows the user to provide an estimated cost for the investment that led to the assessed active travel. HEAT will compare this to the monetized value of the effects and calculate a benefit–cost ratio.

3.14.2 Information characterizing the contrast between the reference and comparison cases

HEAT assessment is based on comparing the reference and comparison cases (see section 3.6). In a two-case comparison, the user provides travel data for both cases. In single-case assessment, users do not provide input data for the comparison case, leaving a greater information gap for the HEAT assessment. To improve the calculations for certain types of assessment (use cases), HEAT allows the comparison to be informed using some additional questions. HEAT automatically only presents the questions needed for assessment.

A first set of questions asks "if, where and how the trips in the reference case would occur in the comparison case". The three questions specifically request the proportion of new trips, reassigned trips and shifted trips.

3.14.2.1 Proportion of new trips (two-case assessment, carbon emissions only)

New trips are trips that did not take place in the comparison case: they were neither shifted from another mode nor reassigned from another route. This information is captured through other entry options for physical activity, air pollution and road crash assessment. For carbon emission assessment for which no motorized input data are available, this additional information is needed to adjust the cold-start emissions, which are calculated based on the number of trips by active mode per year (see section 3.12.3).

The default setting is 0%.

3.14.2.2 Proportion of reassigned trips (two-case assessment, sub-city level only)

Reassigned trips are trips that merely follow a different route to now take place using new infrastructure (such as a new footpath or a cycling network). These reassigned trips will not be considered in the assessment because they do not reflect a net increase in active travel.

This adjustment will only be applied to sub-city-level assessments, since trips cannot be reassigned for countrywide or citywide assessment.

The default setting is 0%.

3.14.2.3 Proportion of trips shifted from another mode (single-case assessment, carbon emissions only)

Shifted trips are active mode trips that replace a trip by another mode in the comparison case. Users are first asked to provide the total proportion shifted (such as 80%).

The default setting is 0%.

Thereafter users can specify the other mode of active travel from which was shifted. The sum of the modal shift percentages cannot add up to more than 100% (see more information on carbon emissions assessment in section 3.12).

These sliders are set to default values (see section 3.13), which will apply if no adjustment is made.

3.14.3 Other adjustments

Motorized traffic influences both carbon emissions and exposure to air pollution. Three questions capture the relevant information.

3.14.3.1 Proportion of active travel carried out in traffic (air pollution assessment only)

This question asks what proportion of active travel (in the reference case) takes place in traffic (versus away from major roads, in parks etc.) and adjusts accordingly the air pollution levels to which the cyclists or pedestrians being assessed are exposed (see section 3.10).

The default setting is 50%.

3.14.3.2 Proportion of travel carried out for transport (air pollution and carbon emission assessment only)

This information is used to correctly assign air pollution concentrations in the comparison case. Trips for transport are assumed to replace modes of transport (time in traffic environments with higher air pollution concentrations), whereas recreational trips replace time at home (at background air pollution concentrations). Transport-related means to get to and from places, to pursue a specific purpose at the destination (such as work, shop, visit friends or play tennis). Recreation means that the main purpose of the trip is exercise or recreation. Please specify the proportion of the travel entered that is for transport purposes (versus for recreation). Section 3.10 provides more information on air pollution assessment.

For carbon assessment, only active travel for the purpose of transport is considered, presuming that it replaces other modes of transport. Recreational trips are presumed not to replace other modes of transport.

Section 3.12 provides more information on carbon emission assessment.

The default setting is 50%.

3.14.3.3 Traffic conditions (carbon emission assessment only)

For carbon emission assessment, users are also asked to specify the local traffic conditions, referring to the times when people walk or cycle. Traffic conditions affect carbon emission rates. Users can select between European average (urban and rural), free flow (little or no congestion, 45 km/h mean traffic speed), some peak-time congestion (morning commute, school run, afternoon commute, 35 km/h mean traffic speed) or heavy congestion on most days (20 km/h mean traffic speed).

The default setting is the European urban average.

3.14.3.4 Change in road crash risk (two-case assessment, road crashes only)

The road crash risk for active modes of transport depends, among many other factors, on the volume of walking or cycling (also called safety in numbers). To consider a change in road crash risk between the two comparison cases, specify it here as a percentage change relative to the reference case. Leaving this blank will apply the same road crash risk to both cases. The changes in road crash risk may result from an increase in active modes, improved infrastructure or any other reason.

The default setting is 0%.

3.14.3.5 Substitution effect (two-case assessment, physical activity only)

In some cases, some of the observed cycling or walking may substitute for other physical activity, such as sport previously done in leisure time. This proportion does not contribute to a net gain in physical activity and should be excluded from the assessment.

The default setting is 0%.

3.15 Economic valuation of the results

3.15.1 Value of a statistical life

The value of a statistical life (VSL) is derived using a method called willingness to pay. It aggregates individuals' willingness to pay to secure a marginal reduction in the risk of premature death in relation to the years this person can expect to live according to the statistical life expectancy.

According to economic theory, the willingness to pay captures perceptions of risks and potential costs borne by the individual person rather than society, including lost consumption, immaterial costs (such as suffering) and the share of health costs paid directly by the victims. Thus, it should account for multiple domains, including consumption, inability to work, the health-care costs the individual pays (and not insurers) and their own pain and suffering. Thus, it represents the societal economic value of reduced premature mortality and is often used in transport appraisal.

The VSL is not the value of an identified person's life but rather an aggregation of individual values for small changes in risk of death: for example, how much a representative sample of the population would be willing to pay (in monetary terms) for a policy that would reduce their annual risk of prematurely dying from 3 in 10 000 to 2 in 10 000.

The default values were calculated based on a comprehensive review of VSL studies by the OECD *(132)*. Studies were only included if they were based on a representative population sample of at least 200 subjects and provided information on the size of the risk change in question. A total of 261 values from 28 studies

were selected to calculate the base VSL for adults in OECD countries of US$ 3.0 million, with a range from US$ 1.5 million to US$ 4.5 million (in 2005 US dollars). The international advisory group concluded that the OECD report represented the best currently available evidence.

The following formula was applied to derive the country-specific values in local currency for the year 2015, applying adjustments to account for income differences across countries, inflation and income growth over time and conversion of the currency from US dollars to local currency using exchange rates adjusted for purchasing power parity (PPP).

$$VSL_{\text{country, 2015 (local currency)}} = VSL_{\text{OECD, 2005, USD}}$$

$$\times (Y_{\text{country, 2005}}/Y_{\text{OECD, 2005}})^{0.8} \times PPP_{2005}$$

$$\times (1 + \%\Delta P_{2005\text{–}2015}) \times (1 + \%\Delta Y_{2005\text{–}2015})^{0.8}$$

$VSL_{\text{OECD, 2005, USD}}$ = base value for OECD of US$ 3.013 million from OECD study (±50%) *(132)*

$Y_{\text{country, 2005}}$ = real gross domestic product (GDP) per capita at purchasing power parity in 2005 of the respective country *(133)*

$Y_{\text{OECD, 2005}}$ = average real GDP per capita at purchasing power parity in 2005 of OECD countries, which equals US$ 30 801(in 2005) *(133)*

0.8 = income elasticity of VSL according to the OECD study *(132)*

PPP_{2005} = exchange rate adjusted for purchasing power parity in 2005 (local currency per US$) *(133)*

$(1 + \%\Delta P_{2005\text{–}2015})$ = inflation adjustment with consumer price index of the respective country between 2005 and 2015

$(1 + \%\Delta Y_{2005\text{–}2015})$ = income adjustment with growth in real GDP per capita in the respective country between 2005 and 2015

Using exchange rates, the country-specific values in local currencies were also transformed into euros. With these euro values and using the population-weighted averages of the country-specific VSL, average values for the 27 EU countries from 2007 to 2013 (EU27) and the 28 current EU countries including Croatia (EU28) and the 53 countries of the WHO European Region were calculated for 2015 (only available for 2005 for Azerbaijan, Belarus and Tajikistan and based on the values for other countries for six more countries).[5]

The European default values (for 2015) of €2.132 million (WHO European Region), €2.891 million (EU27 countries) or €2.877 million (EU28 countries including Croatia) can also be used.

3.15.2 Social costs of carbon

The social costs of carbon can be defined as the monetized value of the worldwide damage caused by the incremental impact of an additional tonne of carbon dioxide equivalent (CO_2e) emitted at a specific point in time.

Carbon values based on the social costs of carbon method essentially put a price on carbon. The damage costs are estimated using integrated assessment models such as the Dynamic Integrated Climate-Economy model (DICE) *(134,135)*, Climate Framework for Uncertainty, Negotiation and Distribution (FUND) *(136)* and Policy Analysis of the Greenhouse Effect (PAGE) model *(137)*. The

[5] No national default VSL could be derived for nine countries (see section 3.15). For Andorra, the value for Spain is used as default; for Liechtenstein, Switzerland; for Monaco, France; and for San Marino, Italy. For Turkmenistan, the value is based on data for Georgia, and for Uzbekistan, Kyrgyzstan. The values for 2005 (based on approximations using countries with the most similar GDP per capita level in the vicinity) are shown as default values for Azerbaijan (using data for Georgia), Belarus (using data for the Russian Federation) and Tajikistan (using data for Kyrgyzstan).

values of the social costs of carbon vary widely: for example, one meta-analysis of 211 estimates from 47 studies *(138)* found a wide distribution of carbon values, from –€1 to €451 per tonne of CO_2e. Key issues in measuring the social costs of carbon are the extent of uncertainty in methods and data, time horizon, the use of discounting, geographical scope (such as global versus regional) and equity weighting. The carbon values used in policy assessment vary by country and increase over time.

The international advisory group agreed to use country-specific carbon values based on the social costs of carbon approach in HEAT, since this is used in project appraisal independently of national emission targets and mitigation policies *(120)*.

Changeable default values for the social costs of carbon are provided by country and year, based on international evidence, regional averages *(120,121)* or country-specific values (if they exist). The values for the social costs of carbon for countries or contexts not covered in existing evidence or policy guidance have been allocated to the European Commission recommended values: US$ 44 in 2015, rising to US$ 66 by 2030.

The users may override these and use their own recommended economic appraisal values instead (see section 3.13).

3.15.3 Discounting

Since economic benefits occurring in the future are considered less valuable in economic terms than those occurring in the present, economists apply a discount rate to future benefits. HEAT uses a rate of 5% per year as the default value, which can be changed by the user if a different common discount rate is being used in the country. If the HEAT results are being integrated into a wider economic transport assessment that applies discounting, then the HEAT rate should be set at 0.

3.16 Assumptions

Knowledge on the health effects of walking and cycling is constantly evolving. The HEAT project is an ongoing consensus-based effort to translate relevant research into harmonized methods. Although HEAT relies on the best available scientific evidence, on several occasions the methods required the advisory groups (see the acknowledgements) to make expert judgements. The most important assumptions underlying the HEAT impact assessment approach are described below.

3.16.1 General remarks

The variables HEAT uses are estimates, and the results are therefore liable to some degree of error. HEAT applies several default values (see section 3.13) but allows the users to overwrite these if they prefer to use other values, such as from their specific local context. Values considered to represent the best possible scientific consensus (such as estimates based on numerous epidemiological studies) are referred to as background values (see section 3.13) and cannot be changed by the user.

To get a better sense of the possible range of the results, users are strongly advised to rerun their assessment, entering higher and lower values for variables for which estimates have been provided.

Remember that HEAT approximates the health effects of walking and/or cycling on the population level. The results cannot be applied to predict health effects among individuals, since individual health depends on many additional factors (genes, lifestyle, etc.).

This section focuses on the key assumptions.

3.16.2 Physical activity

The relative risk data from the meta-analysis, which includes studies from China, Europe, Japan and the United States (see section 3.9.2), can be applied to populations in other settings.

The tool applies a linear relationship between walking or cycling duration (assuming a constant average speed) and the mortality rate. Thus, each dose of walking or cycling leads to the same risk reduction, up to a maximum of about 60 minutes of cycling or walking per day (447 minutes of cycling and 460 minutes of walking per week).

The populations assessed do not disproportionately comprise sedentary or very active individuals. This could lead to a certain overestimation of benefits in highly active populations or a certain underestimation of benefits in less active ones.

Any walking assessed is of at least moderate pace: about 4.8 km/hour (3 miles/hour), which is the minimum walking pace necessary to require a level of energy expenditure considered beneficial for health; for cycling, this level is usually achieved even at low speeds.

No thresholds of active travel duration have to be reached to achieve health benefits.

The relative risks of reduction in all-cause mortality from walking and cycling are the same in men and women.

The relative risks of reduction in all-cause mortality from walking and cycling are the same across adult age groups (20–74 and 20–64 years, respectively).

A five-year build-up time is needed for health benefits from regular physical activity to manifest in full, based on expert consensus. In single-case assessment, a steady-state situation is assumed (active travel, and physical activity therefore took place in previous years already) and no build-up time for the health effects is applied.

3.16.3 Air pollution

The mortality rate and air pollution exposure are related linearly. Thus, each dose of air pollution (expressed as concentrations of particulate matter) leads to the same risk reduction, up to a maximum of 50 µg/m^3 (equivalent to the maximum levels of air pollution common in the European Region).

The relative risk from the meta-analysis on the health effects of $PM_{2.5}$ (see section 3.10), including studies from Austria, France, Canada, Denmark, Germany, Greece, Finland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States, can be applied to other countries with comparable levels and compositions of air pollution.

No minimum air pollution thresholds have to be reached for health effects.

Men and women have approximately the same increase in relative risk.

A five-year build-up time is needed for health effects from chronic air pollution exposure to manifest in full, based on expert consensus. In single-case assessment, a steady-state situation is assumed (active travel, and exposure to air pollution therefore took place in previous years already) and no build-up time for the health effects is applied.

3.16.4 Road crashes

Generic background road crash rates of sufficient quality and reliability for national assessment can be derived by combining data from national (and in some cases international) databases, dividing the number of traffic fatalities (by mode of travel) by the exposure (volume of active travel) within the administrative boundaries (see section 3.11).

National road crash rates (total number of pedestrian or cyclist fatalities divided by the total km walked or cycled, respectively) can be used as proxies for road crash risks in city-level assessments if no city-specific road crash rates are available.

3.16.5 Carbon emissions

Changes in travel activity by motorized modes (passenger-km by mode), changes in carbon emissions (mass of CO_2e) and the underlying carbon emission factors (mass of CO_2e per passenger-km per mode) are related linearly.

To derive emissions factors for cars, the European Environment Agency's COPERT method *(37)* is the most appropriate approach, computing energy consumption (MJ per vehicle-km) using non-linear speed-emission curves, multiplied by the carbon content of that energy (mass of CO_2e per MJ), taking into account the share of biofuels in the transport fuel mix and the carbon content of electricity (for electric vehicles). Emission factors per passenger-km are best derived using a linear relationship of emissions per vehicle-km and average vehicle occupancy rates by mode of travel (varying by country and year of assessment). Typical average occupancy rates are 1.6 passengers per vehicle for cars, 12.2 for local buses, 40 for urban rail and 1.05 for motorbikes.

The effect of real-world driving can be sufficiently approximated by adding 21.6% to official laboratory-based carbon emission factors, considering cold-start emissions, which add to hot emissions during the initial cold phase for each trip (about the first 3.4 km depending on country).

Future vehicle fuel type shares and average occupancy rates have been approximated based on international databases, including the IIASA's GAINS model reference projection for 2014 *(106)*.

- For cars, five generic traffic conditions can be derived that reflect most European contexts:
  - European average, urban (32 km/h);
  - little or no congestion, urban (free flow) (45 km/h);
  - some peak-time congestion (commute, school run), urban (35 km/h);
  - heavy congestion most days (AM, PM and inter-peak), urban (20 km/h); and
  - European average, rural (60 km/h).
- Well-to-tank carbon emissions and the fuel or energy used for energy and vehicle production are related linearly, including upstream electricity generation and fossil-fuel production.
- Changes in emissions (mass of CO_2e) and the social cost of carbon (US dollars per tonne of CO_2e) are related linearly. The social cost of carbon values for countries or contexts not covered in existing evidence or policy guidance can be allocated the values recommended by the European Commission (US$ 44 in 2015, rising to US$ 66 by 2030).

4 Step-by-step user manual

4.1 How to access HEAT

HEAT is available on the WHO Regional Office for Europe website at www.euro.who.int/HEAT *(8)* or directly from the HEAT website at www.heatwalkingcycling.org.

4.2 How to use HEAT in five steps

4.2.1 General features of HEAT

Depending on the characteristics of an assessment, a varying number of questions will apply to a specific HEAT assessment. A maximum of 21 questions will be asked; depending on the route you take, you will skip some questions. On the left side of the screen, the menu of pages helps you to orient yourself on where you are in the assessment process.

Click on "next" or "back" to move between pages. You can also go back to a previous question to check or change entries by clicking on the section in the menu to which this question belongs (see also below) in the menu on the left side of the screen. Then again use the "next" button to advance through the rest of the assessment; only sections affected by the change made will require new input; otherwise the entries made beforehand are shown.

Hovering with the mouse over a "?" icon next to an entry option will show additional information, hints and tips on this item. The HEAT website also has a section with frequently asked questions and further hints and tips, and the website also offers additional information on each section of HEAT *(8)*.

The following section describes the five steps of HEAT assessment in more detail.

4.2.2 Step 1: defining your assessment

First, consider the scope for the use of HEAT to ensure that it is applicable for an assessment (see section 3.4).

Then you are asked to provide some information about the intended assessment (such as of a project evaluation or comparing two scenarios). This information will determine the specific use case and the related methods and assumptions HEAT applies for assessment. This includes the following seven questions.

- Which active travel mode are you assessing: cycling, walking or both?
- At what geographical scale are you assessing the effects: national, city or sub-city level (the last is not available for assessing road crashes; see section 3.11)?

- Defining the comparison: if you have data for just one specific situation, you will use single-case assessment, comparing the reference case specified by the values you enter with a hypothetical comparison case of no walking or cycling. If you have data on two situations, such as before and after an intervention or are comparing alternative scenarios A and B, then you will use two-case assessment, entering data on both the reference case and the comparison case.

- Time scale: you can enter the year of the reference case, and also the year of the comparison case for two-case assessment (such as 5 or 10 years later). If you leave it blank, HEAT uses the current year as the default entry for the reference case. For two-case assessment, HEAT uses 10 years later as the reference case for the comparison case (see the next item). You can change both default entries later in the assessment (see step 3 below).

- Assessment time: over how many years do you want the benefits calculated. For single-case assessment, HEAT calculates effects for 10 years by default; in two-case comparison, HEAT calculates effects for the time difference between the years of the reference and the comparison case by default; you can change both in step 3.

- Which effects do you want to consider in assessment: benefits of physical activity, risks of being exposed to air pollution and/or to the risk of road crashes while cycling or walking or reduction in carbon emissions through trips shifted from motorized modes to walking or cycling?

- If you have selected effects on carbon emissions, you will be asked an additional question on how the assessment should consider motorized travel modes. You can choose to provide no data, or data on basic categories (driving and public transport) or refined categories of motorized modes (currently car (driver or passenger), motorcycle, local bus, light rail or train). If you have no data on motorized modes, HEAT uses default values for two-case assessment (see section 3.13). For single-case assessment, you can provide input on the (assumed or assessed) shift from other modes to walking and/or cycling later in the assessment (see subsections 3.12.1 and 3.12.2 and step 3 below) or you may choose to use default values as well.

Based on the entries you make in this first step, HEAT selects default mortality rates, VSL and/or social costs of carbon values, parameters related to carbon emissions (all at the country level), air pollution levels and road crash rates.

For air pollution assessment at the city or sub-city level, select your city from the drop-down menu. If your city is not listed, you may want to select the city listed from a country that is most similar to yours in terms of traffic volumes and composition, heavy industry, topographical setting and climate. Alternatively, you may choose to un-select "sub-/city-level assessment" and use the national background $PM_{2.5}$ level for your country instead. For city-level and sub–city level assessment of physical activity benefits and carbon emissions, HEAT uses national default values. For city-level road crash or carbon emission assessment, HEAT uses the national default values for road crash risk and carbon parameters. Road crash risk cannot be assessed at the sub-city level. With either option, you will be able to overwrite the assigned default values when you review the calculation parameters in step 4 of the assessment (see below).

4.2.3 Step 2: entering your data

All HEAT assessments require you to enter two main parameters: the amount of walking and/

or cycling and the number of people in the population. You do this in three steps.

- Enter the amount of walking and/or cycling done in the study area per person per day. You can enter this as duration (minutes or hours), distance (kilometres or miles), trips, steps, modal share, frequency or percentage change (for two-case assessment only; see sections 3.7 and 3.8).

- Next, you select the type of population from which the walking and/or cycling data were derived. You can select general population (such as if the data come from a national travel survey, a representative large-scale study or an online survey available to a general population) or specific mode users (cyclists or pedestrians only: for example, if the data were collected through counts or intercept surveys). This selection is important for correctly interpreting the entered volumes of walking and cycling. For example, a more typical average of 4 km cycled per person per day in a population of regular cyclists could mean an average of 0.5 km per person per day cycled in a general population (which includes a mix of cyclists cycling 4 km per day and non-cyclists cycling 0 km per day).

- The number of people in a population to which the walking or cycling data refer, considering that HEAT calculations are meant to be used for an age range of 20–74 years for walking and 20–64 years for cycling (see section 3.4). If younger or older people predominantly carry out the walking or cycling assessed, you can select the age ranges of 20–44 or 45–64 years (or 45–74 years for walking assessment) accordingly. The population figure should reflect the total population and not just the size of a study sample that may have been surveyed to estimate volume. For example, for a national travel survey that is representative of the whole population, use the total population (20–64 or 20–74 years old, respectively) here rather than the sample size of the travel survey. It is important to ensure that you enter the correct population figure, since this can substantially affect the results. Since it is also important that the type of population selected in the previous step (see above) matches the number of people in the population entered, HEAT preselects the type of population here; use the "back" button to go back to the previous step if you want to change your selection.

Warning messages will appear if the levels of walking or cycling entered exceed the suggested scope of HEAT (see section 3.4) and would theoretically lead to very high reductions in the mortality rate. Specifically, if you enter an equivalent of cycling or walking of more than 1 hour per day, you will be requested to consider whether the volume of walking or cycling you entered truly represents long-term behaviour in an average adult population, since this is what HEAT is designed for. To avoid inflated values, the risk reduction available from the HEAT physical activity module is capped at 45% for cycling and 30% for walking (see section 3.9).

4.2.4 Step 3: providing information for adjusting data

In this step, you are asked to provide additional information on the mode(s) being assessed. This information is needed to adjust the data for the selected calculations of impact. HEAT automatically only presents the questions needed for assessment.

Depending on the selected impact pathways and assessment types, HEAT can make several or all of the following adjustments (for more information, see section 3.14):

- the proportion of entered volume of walking or cycling to be excluded because of factors unrelated to the assessed project or intervention (two-case assessment only); the default setting is 0%;

- temporal and spatial adjustment of walking or cycling data entered to consider any under- or overestimation from such factors as seasonal or spatial variation; the default setting is 0%;

- the uptake time for active travel demand, specifying how many years it takes for usage of a new infrastructure to reach a steady state (two-case assessment only); the default setting is 1 year;

- the proportion of new trips that did not take place before the intervention (two-case assessment, carbon emissions only); the default setting is 0%;

- the proportion of reassigned trips that merely follow a different route to now take place on a new infrastructure and are thus not considered in the assessment (two-case assessment, sub-city level only); the default setting is 0%;

- the proportion of trips shifted from another mode; this information is asked for to characterize the contrast between the reference and comparison cases for carbon assessments; these sliders are set to default values, which will apply if no adjustments are made;

- the proportion of active travel carried out in traffic versus away from major roads, in parks etc. (air pollution assessment only); the default setting is 50%;

- the proportion of travel carried out for transport purposes (air pollution and carbon emission assessment only) to correctly assign air pollution levels and to exclude recreational trips for carbon emission assessment, since they are presumed not to replace other modes of transport; the default setting is 50%;

- traffic conditions (carbon emission assessment only), allowing you to select one of five options; the default setting is the urban European average (32 km/h). Alternatively, you can choose to enter a locally available value or one of the other default values (little or no congestion, urban (free flow) (45 km/h); some peak-time congestion (commute, school run), urban (35 km/h); heavy congestion most days (AM, PM and inter-peak), urban (20 km/h) or European average, rural (60 km/h));

- change in road crash risk over time (two-case assessment, road crashes only); the default setting is 0%; and

- substitution of physical activity, to specify whether some of the active travel replaces other forms of physical activity, such as previous leisure-time exercise; the default setting is 0%.

In addition, in this step, you can enter the cost of investment that led to the assessed active travel to calculate a benefit–cost ratio. The cost must include all relevant investment. For example, assessing the benefit–cost ratio of a promotion campaign for cycling requires including the cost of the cycling infrastructure used by the target audience, which may be paid for by the local administration.

4.2.5 Step 4: reviewing the calculation parameters

In this step, the HEAT will provide an overview table of all default and background values and data entries for you to review and to change, as appropriate. The expert advisory group has set the parameters for the HEAT assessment according to the best information currently available,

including background values that cannot be changed (see section 3.13). You can change the default values if reliable local data are available, bearing in mind that changing parameters can significantly affect the final results.[6] In particular, use local values for the following two parameters where available.

- For the VSL, the standard value of a statistical life used in the country of study should be entered (in euros). This will form the basis of the calculated economic value and will strongly influence the economic results. The default values are set based on the country selected in step 1[7] (see section 3.15.1). If a different value is used in your local transport appraisal context, replace the default value here.

- The annual death rate of the working-age population (deaths per 100 000 people per year in the respective age group) can be derived from published mortality data for people of working age for the study country. The default value is set at the last available national value from the WHO European detailed mortality database *(119)*. Use the most recently available national or local crude annual death rate (for the selected age range) whenever possible.

For the discount rate, you can enter the rate to be used for calculating future benefits. HEAT uses

[6] For the default air pollution background value, a $PM_{2.5}$ value can be derived using an internationally accepted conversion factor of 0.6 *(84)* to transform more widely available PM_{10} measurements into estimates of $PM_{2.5}$ *(81)* when necessary.

[7] No national default VSL could be derived for nine countries (see section 3.15). For Andorra, the value for Spain is used as default; for Liechtenstein, Switzerland; for Monaco, France; and for San Marino, Italy. For Turkmenistan, the value is based on data for Georgia, and for Uzbekistan, Kyrgyzstan. The values for 2005 (based on approximations using countries with the most similar GDP per capita level in the vicinity) are shown as default values for Azerbaijan (using data for Georgia), Belarus (using data for the Russian Federation) and Tajikistan (using data for Kyrgyzstan).

5% as the default value. Common discount rates are usually available from government agencies.

4.2.6 Step 5: results and the related economic value

The HEAT results are shown in two steps:

- the results summary, summing up the health and economic benefits and negative effects as well as carbon emission effects across all selected pathways (as selected by the user), as well as a brief summary of the data inputs made; and
- the detailed results per mode (walking and/or cycling) and pathway (physical activity, air pollution, road crashes and carbon, as selected by the user).

The results summary first displays the amount of walking or cycling the user has entered and the number of people in the the assessed population.

The tool produces an overall estimate of the following outputs (summing up positive and negative effects across health-related pathways and of reductions in carbon emissions, as selected by the user):

- the number of premature deaths prevented (per year and across the full assessment period);
- tonnes of emissions of CO_2 equivalents avoided (per year and across the full assessment period);
- sum of the economic value of effects on mortality (from physical activity, air pollution and/or road crashes, as selected by the user; per year and across the full assessment period as well as discounted, if so selected), using VSL (see section 3.15.1);
- the economic value of the effects of carbon emissions (per year and across the full assessment period as well as discounted, if so selected), using the social costs of carbon (see section 3.15.2); and
- the total economic value of effects, summing up the economic benefits from the three health as well as carbon emission calculations, as selected by the user (per year and across the full assessment period as well as discounted, if so selected).

In an overview table, users can select the detailed results they want displayed (per mode (walking and/or cycling) and pathway (physical activity, air pollution, road crashes and carbon emissions). According to the selection made, the detailed results are then displayed for each of the selected modes and pathways, including the same information as the result summary described above.

The results are also available as overview graphs, with total results and with results per mode and per pathway.

4.2.7 Limitations and sensitivity analysis

Many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error. Remember that the HEAT tools provide you with an approximation of the level of health, carbon emission and economic benefits. Several assumptions apply, as explained in section 3.16. To get a better sense of the possible range of the results, you are strongly advised to rerun the model, entering slightly different values for variables for which you have provided a best guess, such as entering high and low estimates for such variables.

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ISBN 9789289052788

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