

Report on the applicability of BEST-COST methodology in Health Impact Assessment

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2 Executive Summary

This Deliverable 5.2 aims to assess how the BEST-COST methodology can support quantitative Health Impact Assessment (HIA) of environmental policy interventions. Building on Deliverable 5.1, this Deliverable establishes a transparent pathway to assess and monetize the impacts of these policy interventions to the interest of public health. This pathway includes several steps, from (1) intervention selection, (2) screening, (3) mimicking impacts of interventions on population exposure, (4) measuring attributable Burden of Disease (BoD) and, (5) economic valuation. The approach is demonstrated for transport-related air pollution and road traffic noise in five BEST-COST case-study capital cities (Brussels, Lisbon, Oslo, Paris, and Tallinn), using two carefully chosen policy interventions: Low Emission Zones (LEZ) and Reduction of Heavy Vehicles (RHV).

The input data to analyse the impact of the interventions on both risk factors, air pollution and noise, were selected carefully. For air pollution, particularly $PM_{2.5}$ and NO_2, spatially resolved uEMEP/EMEP concentration data and sector-specific source contributions were used for the five selected capital cities. Estimated emission reductions were applied to the targeted source layers, while other sources were retained, and the resulting concentration fields were linked to population data for BoD calculations based on Exposure–Response Functions (ERF), baseline health data and Disability-Adjusted Life Years (DALYs). For road traffic noise, detailed CNOSSOS-EU modelling in Oslo quantified the effect of a 20% reduction in heavy vehicles. Changes across 5-dB exposure categories were then transferred to Environmental Noise Directive (END) data for cities without spatially resolved modelling.

The assessment shows that BEST-COST can operationalise the quantitative component of HIA by translating intervention-induced exposure changes into comparable estimates of avoided disease burden and potential health gain. The BEST-COST method provides a common analytical structure which can be applied across environmental stressors, or even other types of risk factors that the public health is exposed to. Especially, the *healthiar* R package created in Work Package (WP) 4 of this project facilitates scenario comparison by condensing the BoD calculations with potential subgroup analysis, thus can be applied beyond the project case studies and beyond air pollution and noise.

It should be emphasized that the general applicability of the BEST-COST method and the *healthiar* R package depends on the availability, compatibility and spatial resolution of the exposure data, the population data and baseline health data; yet more importantly, on whether an intervention can be represented credibly in an exposure model. Where local modelling of these interventions is unavailable, proportional adjustments of different exposure sources (GIS layers) and cross-city transfer methods may provide an alternative solution to achieve the impact of the interventions on the available exposure data. Such results should therefore be treated carefully with documented assumptions, sensitivity and uncertainty analysis.

Our findings support the integration of HIA in the early steps of policy design and thus may assist in the tightened cooperation among public health, environmental, transport, municipal and modelling authorities. Future projects should prioritise detailed exposure models which can implement interventions theoretically, and focus on harmonised high-resolution city, population, and socioeconomic data. By enabling consistent comparison across cities, interventions and risk factors, the BEST-COST project hope to provide added values through greater evidence comparability, more transparent cross-sectoral appraisal and stronger support for interventions that maximise health gains and reduce inequalities.

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3 Introduction

Health Impact Assessment (HIA) is a thorough assessment of the impacts of a specific policy or intervention on public health (1). This assessment can assist policy makers in having better understanding of these policies or interventions. To conduct the HIA, many health indicators, such as avoided cases, deaths or Disability-Adjusted Life Years (DALYs) can be used to describe the expected health loss, while health benefits should be understood as the decrease of these health indicators (2). Monetisation can then translate these reductions in negative health indicators into the economic value generated by the selected intervention or policy. Although monetary valuation cannot capture every ethical and social dimension of health, it makes otherwise hidden benefits more visible and allow them to be incorporated into Cost–Benefit Analyses (CBA) and other economic evaluations.

The methodology for calculating DALY, or in general, the Environmental Burden of Disease (EBoD), has advanced significantly over recent decades (2). In Deliverable 5.1 of BEST-COST, we have assessed different input data and methodological assumptions for calculating EBoD, given different input data are available, to find the most common and applicable approach. Generally, it is required to have the exposure data, the population data, the exposure-response function (ERF), and the baseline health data. Regarding air pollution, it is best, if possible, to use the air pollution exposure data based on the urban European Monitoring and Evaluation Programme (uEMEP) (3), while the population data can be retrieved from the national statistical bureau or from the European Environment Agency (EEA) (4), or other sources. The ERF can be chosen from the recommendations of WHO (5), while the baseline health data can be retrieved from the Global Burden of Disease (GBD) calculation (6). Regarding road traffic noise, if access to national detailed noise models is impossible, data reported under the Environmental Noise Directive (END) can be used (7), while the ERF can be attained from existing epidemiological studies, e.g. (8).

Especially, in Deliverable 5.1, we were able to identify and estimate the reduction in health burden resulting from two selected interventions: Low Emission Zones (LEZ) and Reduction of Heavy Vehicles (RHV). Based on this work, we will hereby discuss in more detail our processes and methods to conduct the HIA in relation to the developed BEST-COST recommendations. Therefore, this Deliverable has two main objectives:

(1) First, it aims to demonstrate how the methodological framework and best-practice recommendations, developed in BEST-COST Deliverable 5.1, can be applied within a Health Impact Assessment (HIA) to quantify the health benefits of environmental interventions. Testing Low Emission Zones (LEZ) and Reduction of Heavy Vehicles (RHV) interventions, we illustrate how changes in population exposure to air pollution and road traffic noise can be translated into changes in health burden and their associated economic value.
(2) Second, this Deliverable aims to identify the main methodological challenges associated with modelling intervention impacts and introduce practical approaches to overcome these challenges, particularly when detailed, intervention-specific exposure models or sufficient input data are unavailable. To address these objectives, we first present the main components of HIA and describe the selection of the two interventions. We then explain the methods used to estimate changes in exposure and construct post-intervention population exposure distributions, including alternative approaches and assumptions employed to address data and modelling limitations.

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4 Health Impact Assessment

4.1 Concept

Health Impact Assessment (HIA) is a structured approach for anticipating how a proposed policy, programme, plan, strategy, or project may affect population health (9). The widely used definition developed in the Gothenburg Consensus Paper describes HIA as a combination of procedures, methods, and tools through which a proposal can be assessed in terms of its potential effects on the health of a population and the distribution of those effects within the population (1). Thus, HIA is concerned not only with whether a policy produces an overall health benefit or harm, but also with who receives the benefits and who bears the remaining risks. The approach is particularly relevant to decisions made outside the healthcare sector, including decisions concerning transport, urban planning, energy, housing, environmental regulation, and climate policy, because these sectors influence important environmental and social determinants of health.

The principal purpose of HIA is to provide decision-makers with systematic and evidence-informed knowledge before, or during, the implementation of a policy (10). It aims to identify potential positive and negative health consequences, compare alternative courses of action, and formulate recommendations that maximize health benefits while preventing or reducing adverse health effects. HIA does not replace political decision-making. Instead, it makes the expected health consequences of different choices more explicit and provides a transparent basis for considering health alongside environmental, economic, technical, and political objectives. WHO therefore describes HIA as a practical approach for systematically assessing the potential health effects of policies and other proposals, with particular attention to vulnerable and disadvantaged population groups (10).

4.2 Method

An HIA may be qualitative, quantitative, or based on a combination of the two (10, 11). Qualitative HIA draws on scientific literature, expert judgement, stakeholder knowledge, interviews, workshops, and community experience to identify plausible pathways through which an intervention may affect health. Quantitative HIA estimates the magnitude of these effects using numerical information about the population, baseline health data, environmental exposure, and exposure–response functions. In environmental health applications, for example air pollution (12), quantitative HIA commonly links a change in emissions or another policy-related determinant to a change in population exposure and subsequently to changes in mortality, morbidity, or summary measures of population health. A mixed-method approach can be particularly useful because quantitative modelling can estimate the expected magnitude of selected impacts, while qualitative evidence can identify effects, implementation barriers, and distributional consequences that cannot be adequately represented in the available models.

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The Gothenburg Consensus identifies democracy, equity, sustainable development, and the ethical use of evidence as fundamental values of HIA (13). Democracy implies that affected populations should have opportunities to participate in the development and assessment of policies that may influence their health. Equity requires explicit consideration of whether health effects differ between socioeconomic, demographic, occupational, or geographical population groups. Sustainable development emphasizes both short- and long-term consequences, including effects on future generations. The ethical use of evidence requires the assessment to be systematic and transparent and to describe the quality, limitations, and uncertainty of the evidence rather than presenting modelled results as exact predictions. These principles distinguish HIA from a purely technical calculation of changes in disease burden. Although the precise terminology differs among HIA guidelines, the process usually includes screening, scoping, assessment or appraisal, development of recommendations, reporting, and monitoring and evaluation (Figure 1). These stages should be understood as an iterative rather than strictly linear process. New information identified during assessment may require the scope to be reconsidered, additional data to be collected, or assumptions to be revised. The level of detail may also vary from a rapid HIA based largely on existing evidence and expert judgement to a comprehensive HIA involving new data collection, extensive modelling, and broad stakeholder participation. The appropriate level of assessment depends on the expected importance of the policy, the likely magnitude and distribution of its health effects, the availability of evidence, the decision-making timeframe, and the resources available.

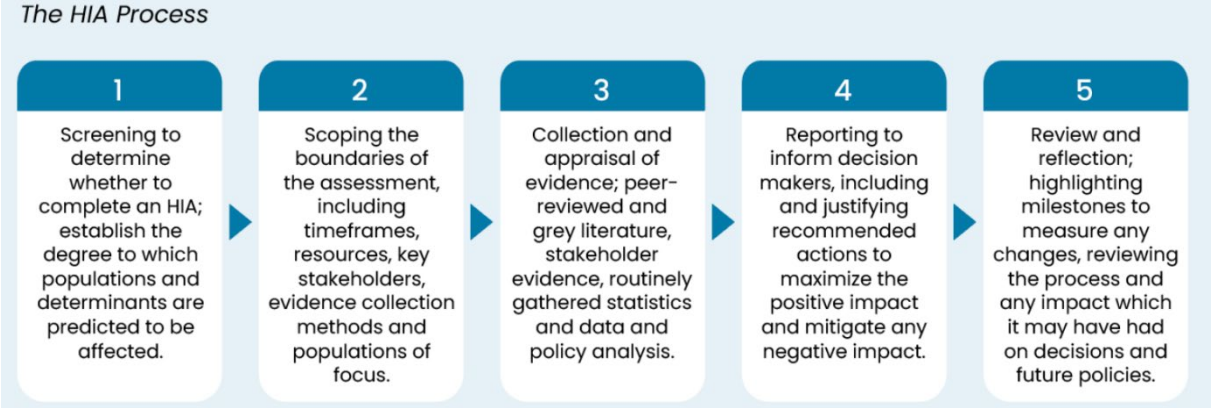


Figure 1. Health Impact Assessment (HIA) and the different stages of the HIA process. Source: https://www.heec.co.uk/resource/harnessing-health-impact-assessments-for-a-fairer-and-healthier-future/

The first stage, screening, determines whether an HIA is appropriate and likely to provide useful information for the decision under consideration (10, 11). Screening examines whether the proposed policy could plausibly produce important health effects, whether particular population groups may be disproportionately exposed or affected, whether the decision can still be modified, and whether the necessary evidence and analytical capacity are available. It also helps avoid conducting an extensive assessment where the expected health implications are negligible, already sufficiently understood, or cannot influence the decision. In this project, the screening process begins with the interventions identified in WP5 and considers whether each intervention can be connected to a relevant air-pollution or environmental-noise exposure pathway.

The second stage, scoping, defines the boundaries and analytical plan of the HIA (10, 11). This includes specifying the intervention and its alternatives, identifying the study population and geographical area, selecting the environmental exposures and health outcomes to be included,

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defining the baseline and intervention scenarios, and determining the relevant time horizon. Scoping should also identify potentially affected or vulnerable groups, the data and models required, the stakeholders who should be involved, and the principal sources of uncertainty. A conceptual pathway is particularly useful at this stage. These detailed decisions will later on help shaping the selection of variables whose data will need to be gathered for further assessment. For example, a transport intervention may change the number and types of vehicles on the road, which may alter emissions and traffic noise, affect population exposure, and subsequently influence risk of cardiovascular, respiratory, metabolic, or other health outcomes. Clearly specifying this chain helps prevent the assessment from including outcomes for which no credible causal pathway or adequate evidence exists.

The third stage, appraisal, involves collecting, evaluating, and synthesizing the available evidence (10, 11). This may include policy documents, scientific literature, environmental monitoring data, emission inventories, transport statistics, population data, baseline mortality and morbidity rates, and exposure–response functions derived from epidemiological studies. Quantitative assessment generally compares at least two scenarios: a baseline scenario representing conditions without the intervention and an intervention scenario representing conditions after the assumed policy change. The difference between the scenarios provides the basis for estimating the attributable or avoidable health burden. Where feasible, alternative implementation assumptions may also be analysed to show how results depend on the scale, timing, or effectiveness of the intervention.

The **4th and the 5th stage**, includes a.o. the reporting, reviewing and reflection. These steps though are not of quantitative method but nevertheless important as condensed information will be used by policy makers. Reporting and dissemination are central to the transparency of an HIA. The final reporting should describe the policy question, data sources, analytical methods, assumptions, excluded pathways, uncertainty, limitations, and potential conflicts between health and other policy objectives. Results should be communicated in forms appropriate to policymakers, technical experts, stakeholders, and affected communities. This is especially important for complex quantitative modelling, where apparently precise numerical estimates may conceal substantial uncertainty. Clear reporting should distinguish observed data from modelled estimates and modelled estimates from assumptions transferred from another geographical context.

To quantify and measure the changes in public health, DALY can be one of the potential indicators (14). DALY combines Years of Life Lost (YLL) due to premature mortality, and Years Lived with Disability (YLD), allowing health effects associated with different diseases and levels of severity to be expressed using a common measure. Comparing DALY between the baseline and intervention scenarios provides an estimate of the disease burden that could potentially be avoided if the intervention produced the assumed change in exposure (Figure 2). The resulting estimate should be interpreted as a model-based measure of potential impact rather than as an exact forecast of future health outcomes. Its validity depends on the quality and compatibility of the exposure data, population data, baseline disease rates, exposure–response functions, and assumptions about implementation.

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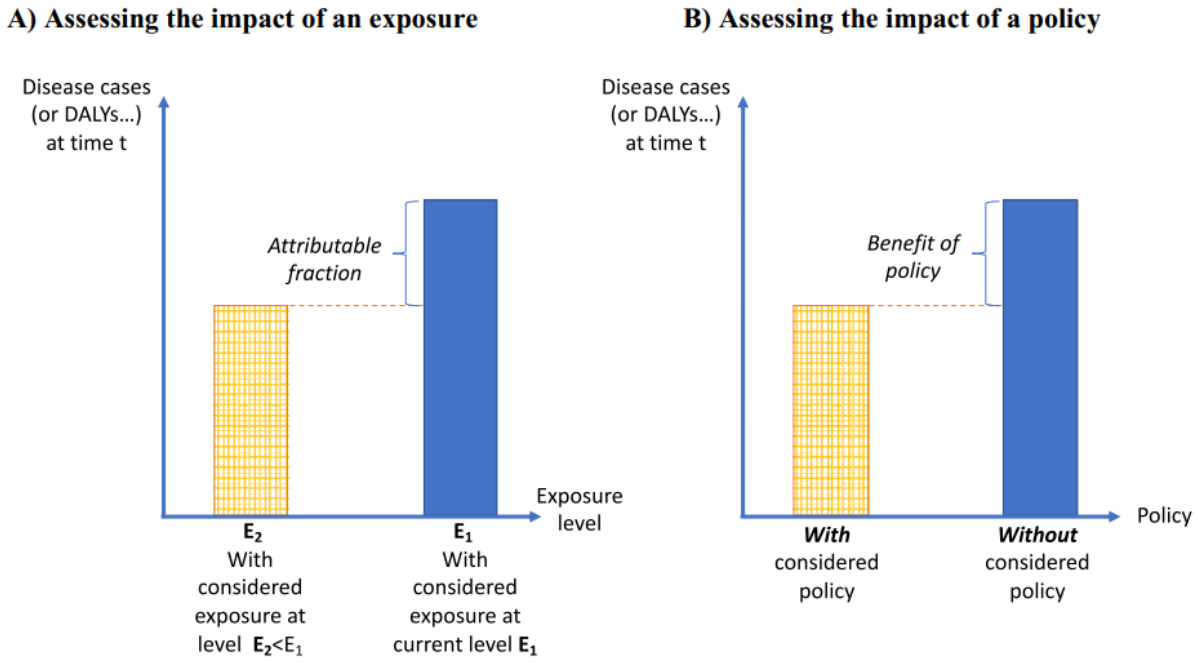


Figure 2. Illustration of the similitude of the principles of changes in exposure (A) and of a policy or program (B). When considering an exposure (A), the fraction of disease cases attributable to a specific exposure (compared to a lower and theoretically achievable level) is estimated for time t (typically assumed to correspond to the current time). When considering a policy (B), the expected health benefit of the project or policy (consisting in changing the level of one or more environmental factors) is estimated, considering the population at the current time or at a later time t, comparing it to the situation without change. Source: Rigaud et al., 2024 (11). https://link.springer.com/article/10.1186/s12940-023-01039-x

Where relevant, the averted health burden may also be expressed in monetary terms (e.g. Euros) (10, 11). Monetary valuation can support comparison between the health benefits of an intervention and its implementation or operating costs. However, monetization is an extension of the HIA rather than a substitute for reporting health outcomes. Results expressed as attributable disease cases, deaths and DALYs remain important because they show the nature and scale of the health consequences directly. Besides, monetized results depend on the selected valuation method and value assigned to e.g. a DALY or other health endpoint. Yet one should not forget the cost of interventions, as without these investment and/ operating costs, the intervention would never happen and thus there is no alternative scenario except the baseline.

After conducting the HIA, the findings will be translated into recommendations (10, 11). Recommendations should be specific, feasible, and directly connected to the identified health pathways. They may concern the design, geographical coverage, implementation intensity, timing, monitoring, or targeting of an intervention. They may also propose measures to prevent unintended effects or protect population groups that receive fewer benefits or experience disproportionate burdens (e.g. persons having a lower socio-economic status (SES)). The aim is therefore not simply to determine whether an intervention is beneficial, but to identify how it could be designed or implemented to produce greater and more equitably distributed health gains.

Monitoring and evaluation will complete the HIA cycle. Monitoring examines whether the intervention was implemented as intended and whether the expected changes in emissions, exposure, or other health determinants occurred. Evaluation considers whether the HIA influenced policy design and whether the anticipated health effects were observed after implementation. Post-implementation information can also be used to revise assumptions and improve subsequent assessments. In practice, comprehensive outcome evaluation may

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be challenging because health changes can occur over long time periods and may be influenced by several policies and contextual factors simultaneously.

The WHO methodological guidance similarly presents screening, scoping, appraisal, reporting, and monitoring as the central components of the HIA process (WHO, HIA methods and tools) (15). Throughout these stages, attention should be paid to participation, intersectoral collaboration, transparency, and equity. Collaboration is particularly important in assessments of transport-related air pollution and noise because the required knowledge is distributed across public-health agencies, environmental authorities, municipalities, transport agencies, exposure modellers, economists, and affected communities (10, 11).

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5 Applicability

To conduct a thorough HIA, we need to follow specific steps to achieve not only the interested interventions but also to measure the impacts of these interventions on the risk factors that the population are exposed to. In this section we introduce the important and necessary steps to (1) choose the intervention, (2) analyse or screen the intervention, (3) model the impacts of the intervention on the interested risk factors. We also introduce different methods we have used to overcome the challenges of lacking access to detailed modelling for both air pollution and noise in BEST-COST.

5.1 Choosing interventions

In this Deliverable, the first stage of the HIA process involves identifying policy interventions that could reduce the population's exposure to the risk factor under consideration, i.e. air pollution and noise pollution for BEST-COST (see Deliverable 5.1). To create an extensive overview of the potential interventions, they should be identified through a broad and systematic review of relevant evidence and policy sources. These may include national and municipal strategies, governmental guidelines, legislation, policy targets, technical reports, international recommendations, conference proceedings, previous HIAs, and peer-reviewed scientific literature. In our case, we outlined the critical components an intervention must have to be modelled and analysed. After discussing with our partners, two main components of an intervention were identified: (1) it needs to be mentioned in the national report and planning, and (2) it needs to have cost information, such that a CBA can be conducted later. Additionally, more than one plausible intervention should be selected for investigation. Examining only one option provides no indication of whether an alternative measure could achieve the same health objective more effectively, equitably, or at a lower cost. Due to this perspective, we have gone through many different sources, both scientific and governmental, to identify the potential interventions for this project.

Intervention selection should be guided by an explicit understanding of the policy objective. The same environmental or behavioural risk factor can often be addressed through several different mechanisms. For example, exposure to transport-related air pollution may be reduced through Low Emission Zone (LEZ), restrictions on certain vehicle categories, accelerated fleet renewal, improvements to public transport, congestion charging, lower traffic speed, or measures that support a transition to active travel. Similarly, road-traffic noise may be addressed through traffic reduction, speed management, low-noise road surfaces, restrictions on heavy vehicles, changes in tire use, noise barriers, or improved building insulation. Although these measures may contribute to the same overall objective, they will have different impact on the risk factors. Therefore, after going through many potential interventions, two have been chosen: Low Emission Zone (LEZ) and Reduction of Heavy Vehicles (RHV).

The suitability of an intervention depends strongly on the local context. An intervention shown to be effective in one city or country cannot automatically be assumed to produce the same effect elsewhere. Its effectiveness may depend on baseline exposure levels, the dominant emission sources, transport patterns, fleet composition, urban structure, population density, existing infrastructure, climatic conditions, institutional capacity, public acceptance, and the availability of complementary policies. Intervention selection should therefore consider both

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the general evidence of effectiveness and the extent to which the evidence is transferable to the population and geographical area being assessed.

The intervention must also be defined with sufficient precision to support subsequent exposure and health-impact modelling. Broad policy objectives such as “improve air quality” or “promote sustainable transport” are not, by themselves, sufficiently specific for a quantitative HIA. They must be translated into concrete measures, such as reducing passenger-car traffic by a specified percentage, excluding vehicles below a defined emission standard from a particular area, or replacing a specified proportion of older buses with low- or zero-emission alternatives. The selected intervention should therefore have a plausible and clearly articulated pathway connecting implementation to a change in the risk factor and, subsequently, to a change in population health.

In addition to expected effectiveness, several practical criteria should be considered. These include whether the intervention is technically and legally feasible, whether its geographical and temporal boundaries can be defined, whether adequate baseline data are available, and whether the intervention can be represented in an exposure model or through another defensible analytical approach. In our case, we have chosen 5 European cities: Brussels, Lisbon, Oslo, Paris, and Tallinn. We focused on capital cities instead of country level as the chosen geographical area due to the realistic essence in conducting these interventions, as it is more realistic to conduct these on the city level than the national level.

As already mentioned, more than one plausible intervention should be selected for investigation. An intervention that initially appears promising may later prove difficult to model, insufficiently effective, technically infeasible, disproportionately burdensome for certain population groups, or not cost-effective. Including several alternatives reduces the risk that the assessment will depend entirely on a single intervention and allows the HIA to support comparison among policy options.

The selected alternatives do not necessarily need to be mutually exclusive. In some cases, it may be useful to assess individual interventions separately and then examine a combined policy package. A combination of measures may produce a larger effect than any single intervention, although care is needed to avoid double counting where several measures affect the same sources or population groups. The choice of interventions should ultimately result in a manageable set of clearly defined, policy-relevant and analytically feasible scenarios that can be compared with a common baseline. Based on these criteria, we formed three possible scenarios in our HIA: (1) LEZ – air pollution, (2) RHV – air pollution, and (3), RHV – air pollution and noise. We formed these three scenarios because not only is it nearly impossible to know the impact of noise by LEZ but it is also to emphasize the importance of noise in environmental burden of disease; thus, a broadened perspective in HIA is much better than a narrow perspective.

5.2 Screening

After potential interventions have been identified, screening is conducted to determine which of them warrant a more detailed HIA. In standard HIA practice, screening is not intended to provide a complete analysis. Rather, it is a structured preliminary assessment of whether an intervention is likely to produce meaningful health effects, whether these effects can be assessed with reasonable credibility, and whether the resulting information could contribute to decision-making. Screening helps concentrate analytical resources on interventions for which an HIA is both relevant and feasible.

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The screening process begins by clarifying the intervention and the decision to which the HIA is intended to contribute. It should establish whether the intervention is hypothetical, planned, adopted, or already being implemented, and whether there remains an opportunity for the assessment to influence its design. It should also consider whether the intervention is likely to produce substantial positive or negative health effects, whether the affected population is sufficiently large, and whether particular groups (e.g. persons with lower SES) may experience disproportionate benefits or harms.

A central screening task is to identify the risk factors and health pathways that may be affected. An intervention may influence more than one exposure and may generate both direct and indirect health effects. For example, a transport intervention may reduce emissions of $PM_{2.5}$ and NO_2, but it may also alter environmental noise, the risk of road-traffic injury, physical activity, access to services, travel time, and greenhouse-gas emissions. Screening should identify the pathways that are plausible and relevant before deciding which can be included quantitatively. Pathways that cannot be modelled should not automatically be ignored; they may instead be described qualitatively and acknowledged when interpreting the overall effect of the intervention.

Screening should also establish whether the intervention is sufficiently well defined. A detailed definition is essential because it determines which parameters and data are required in later stages. The definition should specify the policy mechanism, target sources or activities, affected population, geographical coverage, implementation period, level of enforcement, and expected compliance. Where alternative levels of implementation are possible, several scenarios may be defined—for example, limited, moderate, and ambitious implementation.

One chosen intervention in WP5, Low Emission Zone (LEZ), is selected to illustrate the importance of precise intervention definition. It is necessary to define the boundary of the zone, vehicle categories covered, applicable emission standards, implementation date, operating hours, exemptions, enforcement mechanisms, and expected compliance. With five different case study cities, there are various substantially different ways to understand and implement this intervention (See Deliverable 5.1 for more detailed information). For example, in Oslo, policy may place greater emphasis on reducing the amount of private-car use and supporting further public transport than on establishing a clearly defined LEZ. In contrast, in larger cities such as Paris or Lisbon, LEZs may be more explicitly defined, with detailed restrictions on which vehicles may enter the zone.

Besides, in our case, information about vehicle characteristics is also required for this intervention. This may include the number and proportion of vehicles by type, age, fuel, weight, and emission standard, as well as their typical activity levels. Emission information is needed for each relevant category if the intervention is to be incorporated into an air-pollution model. Where noise is also assessed, information may be required about vehicle type, speed, traffic volume, road surface, tire type, and the proportion of heavy vehicles. The necessary level of detail depends on the structure and input requirements of the available model.

The temporal dimension of the intervention must also be considered carefully. This includes the implementation date, duration, phase-in period, and the year for which exposure and health effects will be estimated. A policy introduced gradually may produce smaller effects in its first years than after full implementation. For instance, in WP5, we consider the intervention to be implemented from 2023 to 2030; yet with the challenges in exposure modelling, we cannot separate clearly the gradual annual impact but can only attain the exposure data before and after the intervention is applied. Geographical scale is equally important. An intervention may be implemented within a small urban zone, across an entire municipality, or nationally. Its effects, however, may extend beyond its formal boundary. A restricted zone may displace traffic and emissions to surrounding roads, while a city-wide public-transport policy may

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influence commuting from neighbouring municipalities. Screening should therefore consider both the implementation area and the broader area in which exposure changes may occur. This helps identify possible displacement effects and prevents benefits within the intervention area from being assessed without considering increased exposure elsewhere.

The availability and suitability of exposure models should be examined at this stage. The first question is whether an appropriate model exists and can be accessed. The second is whether the intervention can be expressed using variables accepted by that model. A model may provide baseline exposure estimates but may not permit direct modification of specific emission sources, traffic characteristics, or other intervention-relevant parameters.

In BEST-COST, we chose the urban European Monitoring and Evaluation Programme (uEMEP) exposure model for air pollution as we can obtain the exposure data for all five cities (Lisbon, Oslo, Tallinn, and the metropolitan areas of Brussels and Paris), provided by the Norwegian Meteorological Institute. Where direct modelling of an intervention is impossible, alternative approaches may include applying concentration changes reported in comparable studies, modifying sector-specific components of exposure, or reallocating the population among exposure categories. These limitations will be discussed in the following section. However, in the case of noise, only Oslo has access to the detailed noise model, such that we have to apply a heuristic method (described below) to achieve the intervention effect of noise in other cities.

Values for the required parameters such as the number of different types of cars in traffic, the shares of heavy vehicle in the total car fleet, etc. may be obtained from governmental documents, municipal statistics, transport surveys, emission inventories, technical reports, scientific studies, evaluations of previous interventions, and consultation with experts. The evidence may not provide one definitive value. Different studies of the same intervention may report different effects because of differences in implementation, study design, local conditions, and population behaviour. Rather than selecting one estimate without explanation, the assessment should evaluate the relevance and quality of the available studies and consider defining a range of plausible values.

The screening stage should conclude with a documented decision for each candidate intervention. An intervention may be retained for comprehensive quantitative assessment, retained for a more limited or qualitative assessment, modified to improve analytical feasibility, or be excluded. The reasons should be stated explicitly. Possible reasons for exclusion include an implausible health pathway, negligible expected effects, insufficient policy definition, lack of applicable evidence, an inability to construct a meaningful baseline or counterfactual, or the absence of a credible method for estimating exposure changes.

Screening should be detailed enough to establish that the selected interventions are relevant and assessable, but it should not attempt to complete the full HIA prematurely. The output should be a clear intervention description with detailed explanation of the impact on the interested risk factor, together with a list of related health outcomes, a preliminary identification of required variables, and a decision about whether and how the intervention should proceed to detailed assessment. The subsequent scoping and modelling stages can then specify the analytical boundaries, parameter values, scenarios, uncertainty analyses, and reporting strategy in greater depth.

5.3 Change in exposure

5.3.1 Air pollution

After different important indicators of the intervention have been identified and measured, we want to see how these indicators will impact the risk factors. The impacts of interventions,

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thus, must be translated into changes in exposure before their health effects can be quantified. The resulting exposure data are combined with population data to construct population exposure distributions, which are subsequently used to estimate DALYs under the baseline and intervention scenarios (see Deliverable 5.1 part 1a and 2 for more detailed computations). DALY is not used only to show the averted DALYs, i.e. the health benefit of the intervention, it can also be monetised using national estimates of the cost per DALY, where available. If national DALY estimates are not available, one may derive the lacking estimate through the country's Gross Domestic Product (GDP) (14), though this method is still controversial as a loss of a DALY should not be equal to the decrease of the similar GDP value. Exposure data may be available either as spatially aggregated tabular data or as geographically resolved Geographic Information System (GIS) data. Whenever possible, spatially resolved exposure data are preferable because they allow pollutant concentrations to be matched more accurately with the population living in each location, thereby accounting for spatial variation in both exposure and population density.

A central challenge is that suitable exposure data or intervention-specific exposure models are not available for every risk factor or case-study area. For air pollution, the Norwegian Meteorological Institute (MET) provided spatially resolved modelled concentration data for Lisbon, Oslo, Tallinn, and the metropolitan areas of Brussels and Paris. The concentration estimates were generated using the uEMEP model and disaggregated into sector-specific contribution layers based on the EMEP source classification. The analysis focused particularly on contributions from traffic emissions (GNFR-F) and residential heating emissions (GNFR-C). These layers allow the contributions of sectors targeted by an intervention to be distinguished from other local and background sources of air pollution.

Source-specific concentration contributions at each receptor grid were calculated through a combination of the EMEP and uEMEP modelling systems. First, nationally reported EMEP emissions at a resolution of $0.1° \times 0.1°$ were downscaled to 250×250 m sub-grids. OpenStreetMap road-network data were used as spatial proxies for traffic emissions, while population density was used to allocate residential-heating emissions. The resulting high-resolution emissions were dispersed using the uEMEP Gaussian plume model (GPM). Local contributions were calculated from emissions within a moving $0.2° \times 0.2°$ window centred on each concentration sub-grid. EMEP additionally estimated source-specific contributions originating outside this local window but within a larger $1.2° \times 1.2°$ area, corresponding to 12×12 EMEP grid cells. Finally, where city-polygon data were used, calculated source contributions can be restricted to emissions originating within the administrative area associated with the city. In this case, all source contributions originate within the defined city polygon rather than from the wider $1.2° \times 1.2°$ region.

The baseline exposure data used for the intervention assessment differs from those used in the EBoD assessment done in Part 1 of the WP5. Part 1 uses concentration data from the European-scale modelling framework to estimate the burden of disease across the project study areas. For the intervention assessment, however, the baseline must be derived from the uEMEP/EMEP modelling setup provided by MET for Lisbon, Oslo, Tallinn, and the metropolitan areas of Brussels and Paris. These data provide high spatial resolution and sector-specific source contributions required to model changes in traffic and residential heating emissions.

Accordingly, all intervention scenarios are compared with a baseline constructed from the uEMEP/EMEP dataset for the relevant capital or metropolitan area. The resulting baseline concentration estimates, and aggregated health impacts may differ from the corresponding estimates reported in Part 1 of Deliverable 5.1. This is expected, as the two analyses use different model configuration, spatial resolutions, and approaches to source attribution. The intervention analysis is intended to estimate the change in exposure and health impact

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between the uEMEP/EMEP baseline and each intervention scenario. It is not intended to reproduce or replace the European-scale burden-of-disease estimates in Part 1 of Deliverable 5.1.

In Norway, MET has developed a tool, an interventions calculator "*Tiltakskalkulator*" (16) *which* allows users to modify selected input parameters and estimate the corresponding changes in emissions and concentrations. However, no equivalent tool is available for the other case-study countries, and the underlying air-pollution model does not contain sufficiently detailed intervention variables that can be modified directly for every scenario considered in the project. Moreover, effects estimated for Oslo cannot simply be transferred to other cities. The relationship between an intervention, emissions, and ambient concentrations is shaped by local characteristics, including building density, road-network length and configuration, traffic volume, vehicle-fleet composition, residential heating patterns, and meteorological conditions.

To address this modelling limitation, a broad literature review was conducted to identify evidence on how the selected interventions affect the relevant risk factors. The review covered scientific literature, governmental and technical reports, municipal documents, and other relevant sources (see Table 1). The resulting evidence was used to formulate the intervention assumptions and estimate the corresponding emission reductions. Further details on the chosen interventions and how their indicators were measured are provided in Deliverable 5.1, Section 6.2.

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Table 1. Summary of changes in emissions and concentrations of two chosen interventions

Interventions	Pollutants	Oslo		Brussels		Lisbon		Tallinn		Paris	
		Em.	**Con.**	**Em.**	**Con.**	**Em.**	**Con.**	**Em.**	**Con.**	**Em.**	**Con.**
Traffic reduction (All types of vehicles)	$PM_{2.5}$	2.0%	0.41%	22.30%	13.90%	NA	NA	7.0%	NA	13% (inside the LEZ perimeter) / 4% (outside the LEZ)	(Inside the LEZ) Could be up to 2µg/m3 lower near major roads
	PM_{10}	8.8%	2.32%	16.40%	13.40%	46%	30.5% (Zone 1) and 22.5% (Zone 2)	8.0%	NA	9% (inside the LEZ perimeter) / 3% (outside)	(Inside the LEZ) Could be up to 4µg/m3 lower near major roads
	NO_x/ NO_2	11.42%	4.57%	49.70%	22.80%	13%	9.4% (Zone 1) and 12.9% (Zone 2)	9.0%	NA	14%* (NOx) (inside the LEZ perimeter) / 4% (outside)	1 µg/m3 away from major roads & 2 to 19 µg/m3 near major roads
Reducing share of heavy vehicles	$PM_{2.5}$	0.001%	0.15%	0%	NA	NA	NA	0.0%	NA	0.00%	NA
	PM_{10}	1.5%	0.46%	0%	NA	NA	NA	0.0%	NA	3.40%	NA
	NO_x/ NO_2	3.9%	1.87%	16.54%	NA	NA	NA	29.0%	NA	11.30%	NA

"Em." stands for Emissions and "Con." stands for Concentrations. Data were found in different literature sources. See Deliverable 5.1 Task 2 for more detailed information.

After finding the changes in emissions and concentrations for each intervention in the relevant geographical area, this information was used to produce the exposure data after intervention by changing the values on each grid cells of the baseline exposure data. MET provided several gridded data layers, including the total concentration layer and the sector-specific layers. The sectors vary from non-exhaust concentration from road traffic to heating. The sector-specific contribution layers and corresponding sectoral emission totals thus formed the basis for modelling the intervention scenarios. Most interventions proposed by the participating cities were expressed as changes in emissions rather than as direct changes in ambient concentrations. We therefore calculated the percentage reduction in emissions associated with each intervention and applied this reduction uniformly to the corresponding sector-specific concentration contribution layer.

For each grid cell, the estimated reduction in the targeted sector's contribution layer was subtracted from the baseline total concentration. Contributions from sectors not affected by the intervention were left unchanged. The step-by-step guide of how to achieve the exposure data with intervention is as follows:

(1) Baseline concentration and emission data
For all the cities, baseline air-pollution concentration data are available at a spatial resolution of 250 × 250 m, together with the city-level total emission data. These two key data are provided by MET. Let $C_i^{baseline}$ denote the baseline total concentration in grid cell i, and let $C_{i,s}^{baseline}$ denote the baseline concentration contribution from sector s in that grid cell. The sector-specific layers identify the contribution to total ambient concentration of sources such as road traffic and residential heating.

(2) Intervention-related emission changes
We used the changes in emissions as the critical parameter for modelling the intervention scenarios. Direct applying changes in concentration would require additional conversion of the source data and could introduce uncertainties that were not fully quantifiable or controlled with available data. In agreement with MET, emission changes were therefore used to derive the corresponding changes in sector-specific concentration contributions, expressed as percentage changes in emissions and applied to the relevant sector-specific contribution layer.

(3) Application of the emission reduction to the relevant source contributions
Let p_s represent the proportional reduction in emissions from the targeted sector s. The concentration reduction in grid cell i was estimated by applying this reduction directly to the sector-specific layer:

$$\Delta C_{i,s} = p_s C_{i,s}^{baseline} \quad (1)$$

The post-intervention concentration estimate was then calculated as:

$$C_i^{scenario} = C_i^{baseline} - \Delta C_{i,s} = C_i^{baseline} - p_s C_{i,s}^{baseline} \quad (2)$$

This approach assumes that the change in a sector's contribution is proportional to the assumed change in emission from that sector. It retains the modelled spatial pattern of the source contribution while reducing its magnitude. Contributions from non-targeted sectors remain unchanged.

(4) Concentration of intervention-scenario exposure distribution data
The resulting concentration estimates for all grid cells were spatially linked to the corresponding population data to create the intervention-scenario exposure distribution.
These data were then used as inputs for the health-impact assessment of each intervention.

(5) For NO_2, the procedure includes an additional step, as the intervention scenarios were initially modelled as changes in NO_x concentrations. The resulting NO_x concentration estimates were converted to NO_2 concentrations using the empirical relationship provided and approved by MET:

$$f(NO_x) = \frac{30NO_x}{NO_x + 35} + 0.23NO_x \quad (3)$$

Thus, for each grid cell, the scenario NO_2 concentration was estimated as:

$$C_{i,NO_2}^{scenario} = f\left(C_{i,NO_x}^{scenario}\right) \quad (4)$$

The function was applied separately to the baseline and intervention-scenario NO_x concentration layer. This is necessary because the conversion is non-linear; a percentage change in NO_x does not necessarily result in the same percentage change in NO_2.

Within the BEST-COST project, the air-pollution interventions primarily target traffic emissions. Hence the traffic-related exposure layer was used to create data after interventions. The two interventions include an overall reduction in traffic activity across vehicle types (by implementing Low-Emission Zone (LEZ)) and a reduction in the share of heavy-duty vehicles. For the first intervention, LEZ was modelled in the metropolitan area of Paris. The intervention areas were defined using official boundaries supplied by the municipalities: the *Zone à Faibles Émissions* (ZFE) defined by Métropole du Grand Paris. In the remaining cities, the intervention areas were represented by the corresponding administrative city boundaries. For each city, information supplied by the cities and evidence identified in the literature were used to estimate the percentage reduction in traffic emissions within the intervention area. This percentage was applied to the traffic-related concentration contribution attributable to sources located inside the LEZ or city boundary. The approach therefore preserves the spatial distribution of the modelled traffic contribution while reducing its magnitude according to the assumed intervention effect.

The intervention targeting heavy vehicles was modelled differently. Its emission-based percentage reduction was applied to the total traffic contribution, including contributions from both within area and surrounding sources. This reflects the interconnected nature of heavy-duty freight movements: heavy vehicle traffic within a city is part of a wider regional transport network and cannot be treated as entirely isolated from traffic flows outside the administrative or LEZ boundary.

Finally, the modified concentration fields were spatially linked to population data to derive population exposure distributions for the baseline and each intervention scenario. These distributions were then used as inputs to the HIA, following the common BEST-COST HIA protocol. Applying the same population data and concentration–response functions across scenarios ensures that the estimated changes in DALYs reflect the modelled changes in exposure attributable to each intervention. For changes in exposure data of each intervention in each city, see Result section 6.3 in Deliverable 5.1.

5.3.2 Noise

Spatially resolved noise level data in GIS format were available only for Oslo. For road traffic noise, the impact of the reduction in heavy vehicle traffic was modelled by the Municipality of

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Oslo. The noise calculations were conducted according to CNOSSOS-EU and based on a three-dimensional terrain modelling, accounting for vehicle types, buildings, noise barriers, terrain features, and their acoustic properties. The noise prediction and mapping software CadnaA was used for the calculations. The noise emission of road traffic was determined based on traffic volumes, including diurnal distribution, types of vehicles, as well as signed speed limits. Detailed traffic data for 2023 were used. The impact of a of 20% reduction in heavy vehicles on all roads was modelled, which implied a reduction of the total AADT (Annual average daily traffic).

Noise levels (Lden and Lnight) were calculated at multiple façade points for all residential buildings in Oslo for 2023, at a height of 4 m above ground level. Levels of modelled residential road traffic noise at baseline and after the intervention scenario were then linked to population data from Statistics Norway. For each residential building, the building's population was evenly distributed across these façade points and assigned the corresponding calculated Lden and Lnight levels. Finally, these data were aggregated across all residential buildings to establish population exposure distributions both for baseline and for the intervention scenario.

For the other case-study cities, noise exposure information was obtained from reporting under the Environmental Noise Directive 2002/49/EC (17). Unlike the detailed GIS data available for Oslo, the END data describe population exposure as aggregated numbers of people within predefined noise-level bands. This difference in data availability made it impossible to model the spatial effects of the intervention separately in each city. Nevertheless, because the project aimed to assess a common intervention affecting both air pollution and noise, we developed a transfer approach based on the intervention effect estimated for Oslo. First, the population exposure data for Oslo under both the baseline and intervention scenarios were converted into categorical distributions using 5-dB noise intervals, consistent with the structure of the available END data. For each noise category, we then calculated the percentage change in the exposed population between the baseline and intervention scenarios (see Table 2).

Table 2. Percentage changes in population noise exposure under the 20% heavy-vehicle reduction intervention in Oslo, for application to other countries' END data

Exposure	Exposure category	Average bin	Percentage changes after intervention
Lden	45-49	47.5	1.1%
Lden	50-54	52.5	-1.2%
Lden	55-59	57.5	-2.1%
Lden	60-64	62.5	-4.3%
Lden	65-69	67.5	-5.4%
Lden	70-74	72.5	-9.4%
Lden	>75	77.5	-17.7%
Lnight	40-44	47.5	-1.2%
Lnight	45-49	52.5	-15.5%
Lnight	50-54	57.5	-4.2%
Lnight	55-59	62.5	-3.0%
Lnight	60-64	67.5	-10.0%
Lnight	65-69	72.5	-29.9%
Lnight	>70	77.5	-33,0%

These category-specific percentage changes were subsequently applied to the corresponding END exposure categories in the other cities to estimate their post-intervention population exposure distributions. This approach assumes that the intervention produces a broadly comparable proportional redistribution of the population across noise-exposure categories in

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the different cities. Although it does not capture local spatial characteristics or city-specific differences in traffic composition, urban form, road infrastructure, or detailed baseline noise conditions, it provides a consistent and transparent method for estimating intervention-related changes where detailed GIS-based noise modelling is unavailable. The resulting post-intervention exposure distributions were then used as inputs to the noise health impact assessment and compared with the respective baseline distributions to estimate changes in the noise-attributable burden of disease (see result section in D.5.1 task 2, section 4.2).

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6 The contribution of BEST-COST – Burden of Disease in Health Impact Assessment

While Health Impact Assessment (HIA) provides an overarching framework for systematically assessing the potential health consequences of policies, programmes and interventions, the BEST-COST (BC) methodology provides a quantitative approach that can support the estimation of environmental health impacts within such a framework. In many cases, though HIA has been implemented quite detailed, its findings have been expressed using measures other than disability-adjusted life years (DALYs). For example, the Aphekom project assessed the health benefits of reducing urban air pollution in terms of avoided hospital admissions, postponed deaths and gains in life expectancy, alongside their monetary valuation (18). Years of life lost and changes in life expectancy are also used in WHO's AirQ+ life-table approach to assess air-pollution impacts (19). Furthermore, some HIAs assess effects on wider determinants of health, such as employment, income and social conditions, using qualitative or mixed-method approaches without aggregating these effects into DALYs, as demonstrated by assessments of Brexit and COVID-19 restrictions in Wales (20, 21). Therefore, the BEST-COST project emphasizes the use of DALY (with carefully detailed choices of input data as described in other Deliverables) in HIA. the BEST-COST methodology offers a structured approach for translating population exposure to environmental risk factors into estimates of attributable health burden, expressed in DALYs.

A central feature of our methodology is the use of detailed exposure estimates for a defined geographical area and population. Exposure distributions for environmental stressors, such as air pollution and environmental noise, are combined with relevant exposure–response functions to estimate the attributable burden of selected health outcomes. The primary challenge is not deciding which exposure data to use but rather identifying the most suitable exposure data for different case studies. This data must also be integrable with other datasets and allow for the theoretical simulation of interventions within the exposure models. These careful choices of input data later will lead to the comparable results of health effects from the interventions, thereby providing a common metric for quantifying and comparing health loss across different health outcomes and environmental exposures.

The use of DALYs also provides a basis for considering how health impacts are distributed within the population. Although an overall estimate of population burden is useful for evaluating the total health impact of an intervention, HIA also places importance on the distribution of health impacts across socially vulnerable population groups. Where sufficiently detailed exposure, population and health data are available, the BEST-COST methodology can in principle be applied to population subgroups defined by geographical areas. This may help identify whether environmental exposures and their associated health burden are disproportionately distributed across groups characterised, for example, by different levels of socioeconomic position or other indicators of social disadvantage. Such analyses may be particularly relevant when considering environmental inequalities, as differences in exposure levels, underlying health status and susceptibility may all contribute to unequal distributions of environmental health burden. Linking estimates of exposure and attributable burden of disease to indicators of social deprivation may therefore provide an additional dimension to the assessment of health impacts and help to identify whether interventions have the potential to reduce, maintain or increase health inequalities. BEST-COST has developed a multiple deprivation index (MDI) comprising five indicators of socioeconomic position, measured at municipal level across the five case countries. The MDI has been validated against ischaemic heart disease (IHD) mortality, with associations observed at municipal level in each country, although their strength varied. BEST-COST has also extended the use of the MDI to investigate

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associations with $PM_{2.5}$ and attributable IHD burden, presented in section Task 5.1b of this report. These analyses indicate a complex relationship between air pollution and attributable disease burden when stratified by the MDI, varying with baseline exposure levels, the geographical resolution of the exposure data, particularly within larger cities, and covariation with the area-level characteristics, including demographic composition, degree of urbanisation and population size. The MDI for the five countries will be made publicly available, together with the methods needed to develop equivalent indices in other countries. The extent to which such distributional analyses can be undertaken will, however, depend on the availability and geographical resolution of exposure, population, health and deprivation data.

BEST-COST has also developed tools that support such analyses in practice. The R package *healthiar* (22) developed in WP4, implements the methodological framework for calculating BoD attributable to environmental exposures developed in WP1.3. The package requires user-provided input data and offers several calculation options, allowing the framework to be applied to exposures beyond air pollution and noise. The *compare()* function allows BoD estimates to be compared using the delta DALY approach, similar to that employed in WP5, task 5.2. The package also supports subgroup analyses by age, sex or education level, enabling assessment of how the health impacts of interventions are distributed across population groups. *healthiar* has, for example, been used to estimate BoD in an HIA of low-emission zones in Barcelona (23).

Although the BEST-COST methodology has primarily been developed and applied to air pollution and environmental noise, its underlying principles are potentially transferable to other environmental exposures, such as heat and chemicals. The general approach, combining geographically defined population exposure with appropriate exposure–response functions and baseline health data to estimate attributable health burden, can be applied to other environmental risk factors, provided that sufficiently robust epidemiological evidence and the necessary input data, including exposure data, are available. In particular, the possibility of estimating DALYs for a defined geographical population provides a common framework through which different environmental exposures may be assessed and compared.

A further methodological consideration relates to the temporal perspective of the DALY estimation used in the current BEST-COST methodology. BEST-COST adopts a hybrid approach, estimating YLDs on a prevalence basis and YLLs on an incidence basis. This approach is well suited for estimating the health burden attributable to exposure within a population during a given period, such as one year. However, the choice of incidence- or prevalence-based estimation may have different implications, depending on the health outcome and the temporal perspective of the intervention assessment. For some health outcomes and intervention scenarios, an incidence-based approach may be more appropriate for capturing the future health consequences associated with changes in exposure. The BEST-COST framework is sufficiently flexible to accommodate alternative approaches to estimating health burden where these are justified by the available evidence and the purpose and temporal perspective of the assessment.

The BEST-COST methodology also has some limitations when applied in an HIA context. One important consideration concerns the geographical definition of the assessment population. Health data and other relevant input data are often available only for predefined administrative or geographical areas, which may not correspond to the geographical scale at which an intervention takes place or at which exposure changes occur. This may limit the ability to capture highly localised impacts or interventions affecting populations across administrative boundaries. The geographical resolution of the assessment may therefore influence the extent to which changes in exposure and health burden can be accurately attributed to a specific intervention. Moreover, with our choices of intervention modelling, it is unrealistic to know the

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changes of exposure data annually when the intervention is implemented. This leads to the fact that we could not estimate yearly DALY changes, which is an issue when interventions involve multi-years investments rather than a one-year funding. Other limitations are related to the assumptions and data underlying any quantitative burden-of-disease assessment. Estimates depend on the quality and spatial resolution of exposure data (see also Deliverable 6.2 in WP6), the availability and appropriateness of exposure–response functions, the choice of counterfactual exposure levels, and the availability of geographically relevant background health data. Uncertainty in these inputs will propagate through the assessment and should therefore be considered when interpreting estimated health impacts.

Conclusively, the BEST-COST methodology can complement the broader HIA framework by providing a transparent and quantitative method for estimating environmental health impacts and potential health gains from interventions. Its strengths include the use of detailed exposure assessment, a consistent approach to quantifying health loss in DALYs, and the potential to examine both total and distributional health impacts. At the same time, its application should take account of the geographical scale of the intervention, the availability and resolution of relevant data, the temporal perspective of the assessment, and the methodological assumptions underlying the estimation of attributable burden of disease.

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7 Recommendations for future Health Impact Assessment

Future studies may require more investment in accessing exposure modelling. The limited availability of accessible exposure models capable of directly simulating specific interventions remains an important challenge for health impact assessment. Although DALYs can be estimated using a single exposure value, such as population-average exposure, this approach may obscure spatial variation in exposure and the associated health impacts. Accounting for this variation is particularly important for environmental risk factors such as air pollution and noise, whose distributions depend strongly on local conditions. Detailed, spatially explicit models are therefore needed to estimate intervention-related changes in exposure and support transparent, methodologically robust assessments of their public health consequences. Although several air pollution models have been developed in Europe, their accessibility and adaptability for intervention-specific analyses remain limited to our knowledge. Publication of model results does not necessarily provide access to the underlying code, input data, or parameters needed to simulate alternative interventions. Future projects should therefore prioritise making models, documentation, and relevant data accessible and reusable, enabling researchers and policymakers to assess and compare the potential public health impacts of different interventions. By increasing the availability of high-resolution environmental exposure datasets covering cities, harmonized city indicators can be developed.

Another point that could be developed after this project is the incorporation of socioeconomic indicators into HIA. This systematic integration would allow future analyses to examine how environmental health burdens and intervention benefits are distributed across population groups. This could be achieved by stratifying population data according to indicators such as income, educational attainment, employment status, or area-level deprivation, and linking these groups to spatially resolved exposure estimates. DALYs could then be calculated separately for each socioeconomic group, using group-specific baseline disease rates and, where supported by sufficient evidence, exposure–response relationships that account for differences in vulnerability. Reporting both total DALYs and DALYs per capita, with age standardization where appropriate, would help distinguish differences in population size and demographic structure from inequalities in health burden. Applying the same approach to intervention scenarios would make it possible to assess not only the overall health benefits but also whether these benefits are distributed equitably and whether existing health inequalities are reduced or widened. However, such analyses require sufficiently detailed and compatible socioeconomic, demographic, exposure, and health data, and care is needed when using area-level deprivation as a proxy for individual socioeconomic status. Future projects should therefore prioritise developing these data linkages and incorporating socioeconomic stratification into the assessment framework from the outset, enabling equity considerations to inform both intervention design and policy evaluation.

Future projects could also take a broader perspective regarding the environmental risk factors to which the public is exposed. Adopting a mixture-based approach in health impact assessment would provide a more comprehensive understanding of how interventions affect public health through multiple environmental and behavioural pathways. While the current work focuses on air pollution and noise, the exposome concept recognises that individuals are simultaneously exposed to a wide range of potentially harmful stressors and health-promoting factors. An intervention that changes urban transport or land use, for example, could reduce air pollution and noise while also increasing physical activity, modifying heat exposure, and improving access to green space. Assessing these pathways together would help capture

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additional health benefits as well as potential trade-offs that may be overlooked when exposures are considered separately. However, simply adding the estimated impacts of individual factors may lead to double counting where exposures are correlated or affect health through overlapping pathways, and may fail to capture interactions between them. Future research should therefore strengthen the evidence on the joint health effects of multiple exposures and develop exposure–response functions and assessment methods that distinguish overlapping, independent, and interacting effects. Although capturing the entire exposome remains an ambitious goal, progressively incorporating a broader set of relevant health determinants would support more comprehensive evaluations and help policymakers identify interventions that deliver benefits across several dimensions of public health.

Besides, uncertainty analysis should be an integral part of HIA, as presenting a plausible range of outcomes alongside central estimates can provide policymakers with a more informative basis for decision-making than deterministic calculations alone. Such analyses should be accompanied by transparent discussions of the underlying assumptions, their justification, and how alternative assumptions might affect the results and their interpretation. Although our analyses include confidence intervals, these reflect only the uncertainty captured by the risk estimates from the exposure–response functions and the monetary valuation of DALYs. They do not account for uncertainty in the exposure modelling, despite exposure estimates being a key input in the assessment of intervention-related health impacts. Consequently, the reported intervals capture only part of the overall uncertainty and may understate the range of plausible outcomes. Future projects should therefore aim to incorporate uncertainty across the full assessment pathway, from modelled changes in exposure to estimated health impacts and their monetary valuation, as uncertainty estimates for the relevant inputs become available. Complementary sensitivity analyses could examine the influence of key methodological assumptions and identify which inputs contribute most to variation in the results. Together, these approaches would help policymakers assess the robustness of the findings and understand whether conclusions about the relative benefits of different interventions remain consistent under alternative plausible conditions.

Lastly, integrating HIA early in the policy process would allow its findings to inform the design of interventions while key decisions are still open to revision. The assessment of potential health consequences during the initial planning stages can help policymakers compare alternative options, identify unintended adverse effects, and adapt proposals to maximise health benefits. This early integration can also create opportunities to consider the distribution of these benefits across population groups, ensuring that equity objectives are addressed alongside improvements in overall population health. To support this process, collaboration between policymakers, public health researchers, exposure modellers, and relevant stakeholders may need to begin when policy objectives and intervention scenarios are being defined. Such collaboration would help ensure that the scenarios assessed are relevant to the decisions being made and that the necessary data and analytical resources are available in time to inform them. HIA could then be updated as proposals develop and new evidence becomes available, providing an ongoing basis for refining interventions and establishing priorities for subsequent monitoring and evaluation.

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8 Conclusion

This deliverable demonstrates that the BEST-COST methodology can provide a transparent and reproducible quantitative component of Health Impact Assessment (HIA). By linking policy interventions to changes in environmental exposure, attributable disease burden and potential health gains, it enables comparison across health outcomes, environmental stressors and cities using DALYs. The applications to transport-related air pollution and road-traffic noise show that the approach is transferable, provided that suitable exposure, population, health and exposure–response data are available.

Where local intervention modelling is unavailable, source-layer adjustments and cross-city transfer methods can extend analytical coverage, but results should be treated as indicative and supported by transparent assumptions and uncertainty analysis. The methodology adds value at the European level by improving comparability and enabling cross-sectoral decisions that explicitly consider health and equity. Future development should prioritise intervention-ready models, harmonised high-resolution data, vulnerability indicators and post-implementation monitoring to strengthen robustness, scalability and policy impact.

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