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Review of noise policies and economic evaluations relevant to ICBEN for the period 2021-2022

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ABSTRACT

This paper builds upon previous reviews of noise policies and economics prepared on behalf of ICBEN Team 9, focusing on the period 2021 to 2022. In line with ICBEN's remit, particular attention has been given on policies and economic evaluations that are directly relevant to the biological effects of noise. In particular, it focuses on the bi-directional relationship between the scientific evidence on the health effects of noise and policy; and how the evidence can inform better economic valuations of the effects of noise. A literature search was carried out in PubMed, Scopus, and the proceedings of ICBEN 2021. This was complemented by a targeted search in Google and a query among ICBEN Team 9 members to identify additional relevant literature. The findings of this review suggest that noise and health research is having an increasingly important role in influencing policy. Reviews of flagship noise policies developed specifically to improve health outcomes highlight the significant challenges of reducing the public health burden attributable to noise. Therefore, there needs to be more emphasis on research that demonstrates how this health burden can be reduced. Such research needs to take a holistic perspective on noise exposure reduction, non-acoustic factors, health equity and competing economic, social and environmental priorities. Due to the wide scope of this subject area this paper should not be considered a systematic or comprehensive review.

Keywords (3-6): Noise, Health, Policy, Economics, Health Risk Assessment

INTRODUCTION

The International Commission on Biological Effects of Noise (ICBEN) currently has nine working groups (known as Teams) each formed to study and to communicate information about a particular aspect relevant to the biological effects of noise. Six Teams are focused on specific effects, one is on specific characteristics of the noise, and one is on combined effects of noise and other agents. The ninth Team, which was responsible for this review, has the name "Noise policy and economics". Previous overview papers in this area

summarised developments in noise policies from around the world. Such reviews provide a useful insight whether noise is moving up or down the political agenda in different geographical regions (and any comparisons between countries and continents should be interpreted with caution).

Historically noise policies were developed primarily to a) prevent hearing impairment, especially in occupationally settings, b) protect sleep during the night-time period, and c) put safeguards to manage annoyance (sometimes referred to as nuisance or amenity). Whilst our understanding within these three areas continues to develop and evolve, over the past decade there has been a step change in the availability of good quality longitudinal epidemiological evidence on the non-auditory health effects of noise. There has also been a growing interest in consolidating this evidence via systematic reviews, partly triggered by the publication of the 2018 Environmental Noise Guidelines for the European Region [1]. This review explores if and how this maturing evidence base is having an impact on policy and economics across the world.

Policy development is an inherently complex process. Whilst a specific policy may be driven by a specific need (for example the need to manage the adverse impacts of noise), it also needs to balance other economic, social and environmental considerations, including maximising co-benefits and avoiding or minimising unintended consequences. Therefore, noise and health research findings are one of many inputs into the policy development process. An alternative route of research findings into policy development is through health risk assessments, and/or the economic valuation of the noise impacts. Once policies are enacted, they may have built-in milestones that facilitate their evaluation at set intervals. For this review we included studies that evaluated the effectiveness of policies aimed at reducing the health burden attributable to noise. Finally, all these steps are likely to identify evidence gaps that could inform the process of commissioning new noise and health research. Figure *1* shows a graphical representation of this cyclic process, including the areas considered within the scope of this review.

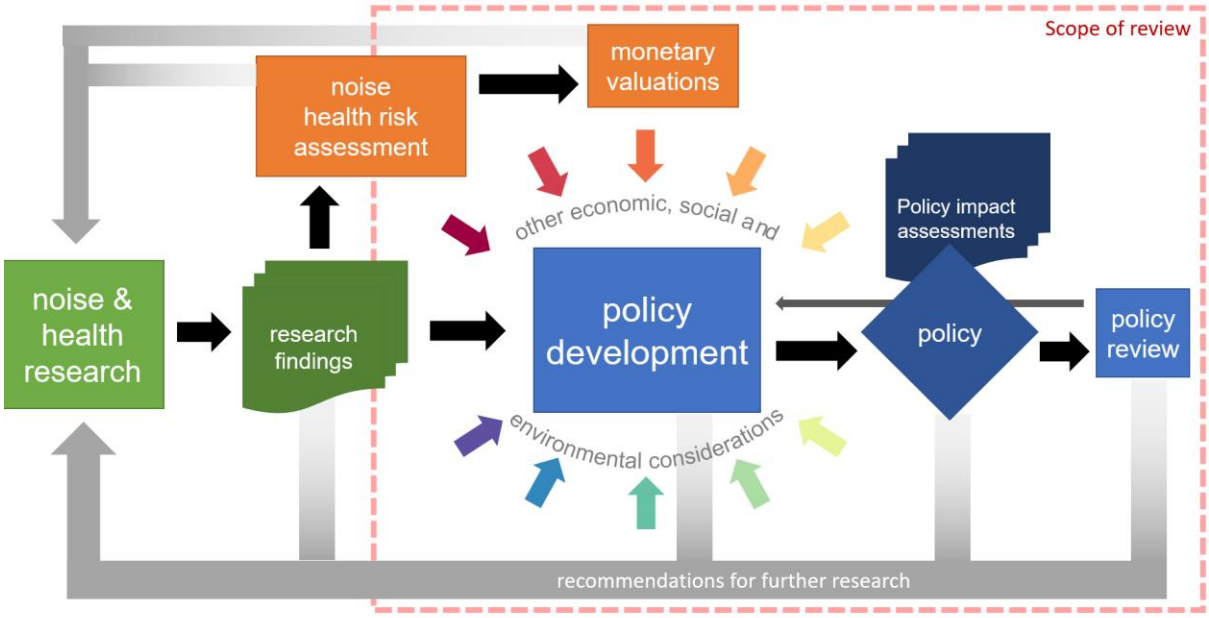

Figure 1 Simplified flow diagram showing the process how noise and health research can feed into the policy development process. The dashed rectangle depicts the focus and scope of this review.

MATERIALS AND METHODS

Knowledge and evidence in this area are spread over a wide range of literature (published and unpublished). Whilst specific aspects of the policy development process (such as risk assessments) may be published in the academic literature (scientific journals), other aspects may only be documented in reports that are not widely publicised. Such reports (a.k.a. "grey literature") is often difficult to locate efficiently (compared to a targeted search in an indexed database). Furthermore, such reports are likely to be written in the official language(s) of the relevant country/region. Searches carried out in the English language are therefore inherently biased in favour of countries and organisations that consider English as an official language.

For this review we took a three-pronged approach consisting of a scientific database search, a web search, and reaching out to peers with an interest in the area of policy and economics.

Search strategy

We split our search strategy into three:

1. A literature search of scientific articles in two indexed databases: Pubmed and Scopus. The search terms were structured around three building blocks: [noise source] AND [health / wellbeing / quality of life] AND [policy/economics]. The searches were carried out in March 2023, and were restricted to articles published in the years 2021-2022. The full search terms can be found in Appendix 1. Because articles published in ICBEN proceedings are not indexed by PubMed or Scopus, we manually added the six articles published under the section "Noise Policy and Economics" in the proceedings to the *13th ICBEN Congress on Noise as a Public Health Problem (2021)*.
2. A request to current ICBEN Team 9 members for documents that describe:
    a. policies that are directly relevant to the biological effects of noise
    b. policies that have been significantly influenced by the scientific evidence on the health effects of noise
    c. policies that may influence the future direction of noise and health research
    d. guidance for the economic valuation of the direct/indirect health effects of noise.
3. A targeted search in Google using the search terms "noise policy and health" for the period 2021-22.

Screening and Inclusion criteria

Five inclusion criteria were defined in line with the scope of this review (as described in the Introduction section. Articles/documents were included if one or more of the main aims were on:

A. How noise and health research findings have directly informed policy development and/or policy impact assessments; OR
B. How quantification of health impacts has directly informed policy development and/or policy impact assessments; OR
C. How health impacts attributable to noise have been translated into monetary values to inform policy and/or decision making; OR
D. Monitoring the progress and feasibility of policy goals aimed at reducing the health impact of noise; OR
E. Recommendations for further noise and health research that came out from a specific policy and/or policy impact assessments.

Titles and abstracts were screened independently by both BF and SJ. A mediation meeting was subsequently held to discuss and resolve differences.

RESULTS

After removal of duplicates, the searches yielded 275 (246 from Pubmed and Scopus, six from ICBEN 2021, 18 from ICBEN Team 9 members and five from a Google Search). Following screening by title and abstract, 52 documents were included for full text review. A PRISMA flowchart can be found in Appendix 2.

Whilst screening on title and abstract, four complimentary themes emerged which, whilst falling outside the strict definition of this review, may be of interest to practitioners and policy advisors interested in the area of noise and public health. These complimentary themes were:

1. Reviews of noise policies
2. Assessment of population exposure against health guidelines
3. Studies investigating changes in the sound environment due to Covid-19 lockdowns
4. Health risk assessments.

Articles and reports that fell under these four complementary themes are summarised in Table 1 to Table 4 in the subsections below. Articles and reports that were considered within the scope of this review are discussed in more detail in the Discussion section.

Reviews of noise policies

This review focuses on how the scientific evidence on sound and health is influencing, and being influenced by noise policies. Nevertheless it is equally important for ICBEN to carry on mapping the evolution of noise policies from around the world. Our search identified 11 papers/reports and one online repository (Table 1) that describe noise policies for specific geographical regions, noise sources and/or settings.

Table 1 List of articles/reports that provide overviews of noise policies.

Paper/report	Geographical areas	Sources of noise	Setting
Faulkner and Murphy 2021 [2]	Ireland	Non-specific	Non-specific
Laplace et al. 2022 [3]	Canada	Environmental noise	Non-specific
Lockhande et al. 2022 [4]	International	Firecrackers (fireworks)	Non-specific
Perna et al. 2022 [5]	Australia, Europe & North America	Road traffic noise	Non-specific
Vukić et al. 2022 [6]	Europe and Croatia	Airborne noise from ships	Cities next to ports
Yokoyama and Kobayashi 2022 [7]	Asia-Pacific region	Occupational noise	Workplace
European Commission 2021 [8]	European Union	Environmental noise	Non-specific
European Commission 2021 [9]	European Union	Tyre noise	Non-specific
Peeters and Nusselder 2022 [10]	Europe	Non-specific	Quiet areas, soundscaping and urban planning
World Road Association [11]	International	Road traffic noise	Non-specific
Schwela 2021 [12]	Low- and middle-income countries	Non-specific	Non-specific
Schwela 2022 [13]	International	Non-specific	Non-specific

Assessment of population exposure against health-based guidelines

16 studies (Table 2) compared population noise exposure against health-based guidelines published nationally or internationally (for example by the World Health Organization).

Table 2 List of articles identified in the literature search that compared population exposure with health-based guidelines.

Paper/report	Geographical areas	Sources of noise	Setting/population
Akintunde et al. 2022 [14]	Nigeria	Non-specific	University
Arani et al. 2022 [15]	Mashhad, Iran	Road traffic	Tourist, pilgrimage and business areas
Bellomo et al. 2021 [16]	Michigan, US	Activities in places of worship	Places of worship
Bogale et al. 2022 [17]	Dessie City, Ethiopia	Non-specific	Residential, health facility, commercial, and mixed sites
Camargo et al. 2021 [18]	Brazil	Forest machinery	Forests
Çİçek & Sümer 2021 [19]	Artvin Province, Turkey	Machinery	Black tea processing factories
Clark et al. 2022 [20]	Accra, Ghana	Non-specific	Non-specific
Escobar-Castro et al. 2022 [21]	Barranquilla, Colombia	Leisure noise	University students
Henneberry et al. 2021 [22]	Non-specific	Occupational	Dental hygienists
Limardo et al. 2021 [23]	Space	Equipment on International Space Station	Astronauts
Luzzi & Vasilyev 2022 [24]	Russia	Industrial (occupational) noise	Operators
Puyana-Romero et al. 2022 [25]	Ecuador	Road traffic	General population
Radun et al. 2022 [26]	Finland	Wind turbines and road traffic	Population living near wind turbines
Ranpise & Tandel 2022 [27]	Surat City, India	Urban road traffic	Non-specific
Rutkowski & Korzeb 2021 [28]	Offshore environments	Floating storage and offloading vessels	Workers
Stone & Moro 2022 [29]	Canada	Occupational	Workers at aquaculture facilities

Covid-19

In many areas across the world, the Covid-19 pandemic triggered full or partial lockdowns, where population mobility within and across national borders was significantly restricted. This resulted in a significant and unprecedented change in the noise from transport infrastructure, and consequently in the urban sound environment. These changes constituted “natural experiments” that can offer a useful insight on the implications of (arguably drastic) operational restrictions on transport infrastructure. Our search identified 11 articles (Table 3) focusing specifically on changes in the sound environment associated with Covid-19.

Table 3 List of articles identified in the literature search on the impact of Covid-19 lockdowns on the sound environment.

Reference	Title
Aletta & Van Renterghem 2021 [30]	Associations between personal attitudes towards covid-19 and public space soundscape assessment: An example from Antwerp, Belgium
Amoatey et al. 2022 [31]	Impact of COVID-19 pandemic on aircraft noise levels, annoyance, and health effects in an urban area in Oman

Bonet-Solà et al. 2021 [32]	The soundscape of the covid-19 lockdown: Barcelona noise monitoring network case study
Dance & McIntyre 2021 [33]	The Quiet Project - UK Acoustic Community's response to COVID19 during the easing of lockdown
González et al 2021 [34]	A case study of noise pollution levels during the restrictions period due to COVID-19
Hahad et al 2022 [35]	Reduced Aircraft Noise Pollution During COVID-19 Lockdown Is Beneficial to Public Cardiovascular Health: a Perspective on the Reduction of Transportation-Associated Pollution
Hasegawa & Lau 2022 [36]	A qualitative and quantitative synthesis of the impacts of COVID-19 on soundscapes: A systematic review and meta-analysis
Lenzi et al. 2021 [37]	Soundscape in Times of Change: Case Study of a City Neighbourhood During the COVID-19 Lockdown
Mostafa et al. 2021 [38]	The impact of COVID 19 on air pollution levels and other environmental indicators - A case study of Egypt
Ramphal et al. 2022 [39]	Noise complaint patterns in New York City from January 2010 through February 2021: Socioeconomic disparities and COVID-19 exacerbations
Seidler & Weihofen 2021 [40]	Commentary: Post-COVID-19 mobility and traffic noise-induced health effects

Health Risk Assessment

A health risk assessment (HRA) is the scientific evaluation of potential adverse health effects resulting from human exposure to a particular hazard – in this case, environmental or occupational noise. The main purpose of the assessment is to estimate and communicate the health impact of exposure to noise or changes in noise in different socioeconomic, environmental and policy circumstances [1]. Therefore HRAs can make an important contribution to policy development, and/or are often an intermediate step towards the economic quantification of noise impacts.

The literature search identified 20 papers (Table 4) presenting either methodological considerations of conducting an HRA, or actual assessments (e.g. burden of disease or health impact assessments). Whilst these papers were considered outside the strict definition of this review's scope (i.e. their focus was not on how the HRA informed a specific policy, and the findings were not translated into monetary terms), they may be of interest to those planning to carry out HRAs to inform policy. It is worth noting that our search terms were not developed specifically to identify HRAs, and as a result Table 4 should not be considered as a complete list of noise HRAs published between 2021-22. For example, we are aware of a number of HRAs that were published at Internoise 2022 that were not picked up by our search, including one methodological paper [41] and one BoD assessment for Nordic countries [42].

Table 4 List of articles identified in the literature search on noise health risk assessment that were deemed to fall outside this review's scope. BoD = Burden of Disease. HIA = Health Impact Assessment.

Paper/report	Geographical areas	Sources of noise	Type
Clark et al. 2022 [43]	Accra. Ghana	Environmental	Spatial modelling, inequalities, comparisons vs WHO Guidelines
d'Avila Villela 2021 [44]	Non-specific	Road traffic	Uncertainty evaluation
Farooqi et al. 2021 [45]	Punjab, Pakistan	non-specific	Health burden determined via survey
Gisela et al. 2021 [46]	Ecuador	occupational	Hearing risk assessment
Golmohammadi et al. 2022 [47]	Non-specific	Occupational	occupational exposure limits for noise-induced non-auditory effects
Hegewald et al 2021 [48]	Hesse, Germany	Road traffic	BoD assessment
Khomenko et al. 2022 [49]	European cities	Road traffic	HIA

Manohare et al. 2022 [50]	Non-specific	Road traffic	applicability of health risk prediction models in heterogeneous traffic conditions.
Marquis-Favre et al. 2021 [51]	Non-specific	Transport	Total annoyance from combined sources
Röösli et al. 2022 [52]	Non-specific	Environmental	Methodological issues in BoD and HIA
Seidler et al. 2021 [53]	Rhine-Main, Germany	Transport	HIA of interventions
Shamsipour et al. 2022 [54]	Tehran, Iran	Road traffic	BoD assessment
Tomás & Elorriaga 2021 [55]	Spain	Occupational	Level of compliance with national and EU regulations
Veber et al. 2022 [56]	Tallinn & Tartu, Estonia	Transport	HIA
Yli-Tuomi et al. 2022 [57]	Helsinki, Finland	Road traffic	Influence of exposure estimation method on estimated health impacts
Zaitseva et al. 2021 [58]	Russia	Transport	HIA based on floor of residence
Zaitseva et al. 2022 [59]	Russia	Environmental	HRA methodology
Zare et al. 2022 [60]	Kerman, Iran	Occupational	Analytic Hierarchy Process
Zhang et al. 2021 [61]	Zhejiang Province, China	Occupational	Role of the Kurtosis Metric in Evaluating the Risk of Occupational Hearing Loss
Zhou et al. 2021 [62]	Global	Occupational	Socio-economic disparity in the global burden of occupational noise-induced hearing loss:

The remaining articles/reports fell outside the review's scope because of the following reasons:

- Primary research on noise and health, including reviews and meta-analyses;
- Dealing with noise exposure measurement/modelling/control; or
- Unrelated topic.

On screening on full text, one document was identified as a book (*Environmental Noise Pollution: Noise Mapping, Public Health, and Policy* [63]) that provides an in-depth overview of this subject area. The book examines environmental noise pollution, its health implications, noise modelling, the role of strategic noise mapping for problem assessment, major sources of environmental noise pollution, noise mitigation approaches, and related procedural and policy implications.

DISCUSSION

In this section we provide a high-level summary of the reports and scientific articles that were classified as within the scope of this review. Scientific articles are grouped by five themes that are aligned with the five inclusion criteria presented in the Methods section. Reports that were classified under Themes A (role of research to influence policy) and D (monitoring the progress and feasibility of policy goals) are combined together as they were considered complimentary to each other.

Reports on Theme A: how noise and health research can influence policy; and Theme D: monitoring progress of policies

In 2022, the WHO released their Global standard for safe listening venues & events [64]. It estimates that over one billion young people are at risk of hearing loss due to sound exposure in recreational settings. It provides a common understanding of safe listening in entertainment venues and events, including recommendations on limits, monitoring, venue acoustics, hearing protection, quiet zones and training or information.

The American Public Health Association released an updated policy statement, “Noise as a Public Health Hazard” [65]. Based on research on widespread harmful effects of chronic noise in addition to those of occupational noise, it calls for national noise standards, enforcement, education, outreach, and action on noise as a public health hazard.

To inform the Swiss Federal Council on noise policy, the Swiss Federal Commission for Noise Abatement [66] has developed recommendations for the adaptation of limit values for road, rail and aircraft noise. Recommendations are based on the analysis of currently available scientific evidence on exposure-response relationships for the health effects of noise, as well as on the legal basis and experience on the enforcement of the existing limits. Several adjustments towards stricter limit values are recommended, varying depending on aspects such as noise source and time period.

After the release of the WHO Environmental Noise Guidelines for the European region, many national governments tried to interpret the consequences to their own noise policy. The Dutch government commissioned a report to gain more information on aircraft noise legislation and policy in surrounding countries in relation to the WHO recommendations on aircraft noise [67]. It was observed that limit and target values in the countries studied are all higher than values recommended by the WHO. While some countries are planning changes or improvements in the regulation, this is attributed to other reasons rather than the WHO recommendations, such as better legislative structure, calculation methods, or regular reviews and updates. The recommended levels are regarded by some policy makers as a helpful target to aim for in the long term. However, there is also concern that in the short term they may raise unrealistic expectations with the general public, with little prospective for governments and airports to actually being able to meet these.

In a 2022 update of a compendium containing an environmental noise chapter, WHO gives guidance on how to best reach the recommended levels by the Environmental Noise Guidelines [1], with relevant policies and actions for various sources of noise [68].

The European Aviation Safety Agency [69] published their European Aviation Environmental Report, in which an overview is given on the developments regarding the environmental performance of the aviation sector. In this report, the number of people exposed to aircraft noise within 55 dB L_{den} and 50 dB L_{night} contours are shown to have reduced in 2020 and 2021 with respect to 2005 (after an increase in 2019), and are hypothesized to go up again but stay below 2005 levels in the scenarios calculated for 2050. The report is meant to inform discussions on the reduction of environmental impact of the aviation sector, for instance in the light of the European Green Deal.

A report by the US Federal Aviation Administration [70] and a paper from ICBEN 2021 [71] give an overview of FAA aircraft noise policy and summarize research activities sponsored by the FAA meant to inform future aircraft noise policy. Research efforts include the effects of aircraft noise on individuals and communities; noise modeling or metrics, and reduction, abatement or mitigation of aviation noise. The public was invited to comment on the scope and applicability.

Following the adoption of the EU Zero Pollution action plan, the European Commission Joint Research Centre [72] published the first of a two-yearly Zero Pollution Outlook. This report reflects on the progress made towards the policy ambitions of the action plan and offers scientific advice to inform decision-makers regarding the actions needed to successfully implement it. Underlying this report is a study by the European Topic Centre on Human Health [73], exploring a conservative and an optimistic scenario for projected growth in population and transport. For noise, results suggest it is unlikely that the target of a 30% reduction in the number of people chronically disturbed by transport noise in 2030 will be

met without further regulatory or legislative changes. To achieve more progress, a combination of measures will be needed, including measures at the source, better urban and transport planning, and significant reductions in road traffic in cities.
The web report 'Zero Pollution monitoring assessment' by the European Environmental Agency [74] also assesses progress towards the zero pollution targets and provides an outlook on the likelihood of achieving the targets. With regard to noise, it concludes that noise from transport continues to harm health, with little progress made towards reducing noise levels. A specific briefing on the achievability of the target for noise [75] summarizes the results from EC/JRC (2022) and ETH/HE (2022).
To assess the potential health benefits to be achieved by noise measures and regulations, the European Commission commissioned the 'Phenomena' study [76]. The project concluded that a health burden reduction of around 20% for road traffic noise and over 37% for railway and aircraft noise could be achieved with a combination of different noise measures, including revised and strengthened EU policies, particularly on quieter vehicles.
A report by Eurostat [77] monitors the progress towards the Sustainable Development Goals (SDG's) in an EU context. One of the SDG's is good health and wellbeing, which includes reducing the exposure to noise. According to this report, the percentage of people in the EU who report to be affected by noise from neighbours or from the street has fallen from 20.6% in 2010 to 17.2% in 2020, albeit with large difference between Member States. It was further reported, based on calculations from the EEA in 2019, that 78.2 million people in EU urban areas were exposed to noise from road traffic of 55 dB L_{den} or higher, 10.3 million to excessive noise from railways, 3.0 million from airports and 0.8 million from industry.

Scientific articles

Theme A The role of noise and health research in influencing policy making

[78] question what is "policy" by citing Ambühl: "…*research provides the basis for decision-making and possible solutions. Decision-making, implementation, and negotiation are a matter of policy*." Accordingly they considered the following disciplines under "policy" for road traffic noise: roadway engineers, acoustical engineers, acoustic specialists, expert witnesses, environmental protection agencies and municipalities. Whilst it is debatable whether these technical disciplines fall under the "policy" category, these professionals make daily decisions that directly affect the noise exposure of the population, and ultimately any attributable health impacts. [79] argue that health professionals have an important role in educating the public about the dangers of noise and advocate to make the world a quieter, healthier place for all. They draw attention to the American Public Health Association (APHA) updated policy statement on noise: Noise as a Public Health Hazard, which uses an updated definition of noise, "unwanted and/or harmful sound," rather than the older definition, "unwanted or undesired sound" (see also *Reports on Theme A*).

[80] describe two challenges when applying exposure response relationships (ERRs) in health risk assessments to inform policy:

a. The merit of choosing an aggregated ERR versus a locally-derived curve. The WHO ENG 2018 [1] recommend that for annoyance data and ERRs derived in a local context should be used whenever possible. Denmark, Japan and Switzerland developed national initiatives for this purpose, however this appears to be the exception rather than the norm. In the absence of such "local" data, one may question whether generalized ERRs should include all international studies that meet certain quality criteria, or whether it would be better to "pick and choose" studies to match a specific situation and context. However, defining a robust set of criteria *a priori* for this purpose is likely to be very challenging.
b. How often should ERRs be updated. On the one hand, policy and decisions on new transport infrastructure should be based on sound, up-to-date evidence. On the other

hand, infrastructure development needs a degree of policy stability, especially if any operating restrictions are linked to predicted health impacts. Changes to the ERRs can also impact project cost-benefit analyses, with repercussions on the business case for specific interventions.

[81] discusses the health impacts of aviation noise from the perspective of a community group that represents communities living around UK's busiest airport – London Heathrow. Seven recommendations are made:

1. A proper debate about the economic, environmental, health and social impacts of aviation noise on overflown communities.
2. Lowering UK 'annoyance' thresholds for aviation and factoring them into cost benefit analysis and wider appraisal methodologies.
3. A commitment by all governments to develop specific long-term targets to protect the public from the health impacts of aircraft noise.
4. Improving our understanding of the implications of the health impacts of concentrated flight paths on overflown communities.
5. Creating a more robust mechanism for assessing and translating academic evidence into policy.
6. A more active strategy to identify gaps in the evidence and commission research to address them.
7. Adopting a precautionary approach when there is emerging evidence of harm, but insufficient firm research to make definitive policy decisions.

[82] discusses the legislative challenges of urban residential (neighbour) noise. In most countries, neighbour noise is legislated under nuisance rather than noise regulations. The author argues that legally enforced behavioural constraints should not be the only area of reform, and that buildings should be designed for the "worst-case scenario" (pre-empting the most disagreeable conditions rather than assuming considerate and amicable neighbours), factoring in individual differences in personality, anxiety profile, sensory processing sensitivity, perceived quality of life, and other relevant predictors. The author hypothesises that those experiencing higher levels of discomfort may engage in certain behaviours that could negate some of the positive environmental effects of urban density (such as increased travel as a means of escaping an urban environment that has developed unsustainably). For neighbourhood noise, [83] note that many noise management systems around the world are based upon estimated thresholds of annoyance. However despite this "community" focus, noise management often focuses on the grievances and health of individuals, rather than the overall health of the community as a social unit linked to a sense of place. The authors also point out the challenges in some countries associated with the fragmentation of noise policy between different levels of government, which acts as a major barrier to the strategic management of noise, especially in complex settings such as urban spaces and activated precincts

A number of papers looked at how evidence reviews and risk assessments are used to inform policy. [84] describe an evidence review of industrial noise for the Ministry of Environment of Chile. [85] describe a risk assessment to inform the establishment of an aerodrome territory and operating conditions for the Voronezh civil aviation airfield in Russia. [78] discuss the importance of vehicle horns as a significant source of noise in certain countries (and therefore the potential dangers of copying policies across regions and cultures). [86] discuss the challenges of setting limits for airports with commercial and military operations to avoid hearing damage to passengers walking from the car park to the terminal building, passengers and crew boarding/deboarding aircraft, employees working in the noise zone and medical transport transfer personnel.

[87] make the case for integrated risk assessments for urban planning. Sustainable urban transport and active travel policies have the potential to positively and negatively impact

health through changes in physical activity, air quality, noise, road safety, green spaces, social interaction and access to healthcare services. They assess the inclusion of health provisions and methodologies in urban mobility policy and planning documents of four European cities (Paris, Rome, Lisbon and London) using a multi-level perspective. They also make a number of recommendations, including considering potential unintended impacts of interventions that may widen inequalities. [88] notes that whilst several European countries are implementing considerable railway noise mitigation programs (e.g. noise barriers, retrofitting the freight fleet with composite brake blocks, and sound insulation in homes), both European and many national policies are pushing to further reduce exposure. Oertli argues that this additional noise mitigation has cost and feasibility implications for railways, and that noise mitigation efforts must not undermine railway competitiveness. Railways are a sustainable means of transport and contribute to the achievement of climate goals. The author makes the case for focusing research efforts on the whole system including asset management, such as construction intervals, safety issues, track inspection requirements as well as life cycle costs. Evaluation of noise interventions is also necessary to determine if resources spent on noise mitigation are the most cost-effective method to achieve desired health goals.

[89] highlight an initiative from Denmark bringing together public sector, companies, research institutions and citizens to reduce traffic noise and improve quality of life. 11 municipalities and the Capital region of Denmark joined forced in a partnership “Silent City” working on several levels with political influence, opinion-making, competence development and the establishment of a Living Lab – where technologies can be demonstrated in real life. The article describes several practical achievements of this partnership since 2015. The importance of collaboration is also raised by [83] when making the case for holistic noise management incorporating soundscape approaches. Soundscape studies exist at the intersection (or perhaps overlap) of multiple established disciplines, including but not limited to acoustics, engineering, psychology, policy, planning, design, architecture, and composition. The aims of soundscape management are likely to be aligned with the aims of existing regional strategic plans encouraging outcomes such as the provision of greenspace, activated streetscapes, and liveable precincts with human-centred design.

[90] discuss the importance of health equity in policy making, and set out five propositions to achieve better environmental health equity through noise action planning:

1. Noise action planning should consider differences in vulnerability
2. Distributional effects of noise action plans should be evaluated.
3. The assessment of the total noise exposure is necessary to estimate the extent of inequalities in environmental exposures.
4. Public information and consultation should involve empowerment and innovative methods to enable effective and just civic engagement.

In a second paper [91] advocate the use of non-acoustic factors as leverage to promote health equity and environmental justice through three fields of potential action: (1) developing a theoretical and methodological groundwork and multi/ interdisciplinary training of students and professionals, (2) introducing comprehensible information and inclusive participation methods, and (3) creating supportive institutional and governance frameworks.

Two studies looked at emerging technologies. [92] present a modelling framework for setting recommendations for drone operations to minimise community noise impact, based on specific health-based noise targets. [93] discuss the role of participatory technologies such as mobile phone (crowd) sensing (MPS) to add value to both noise and health research and its translation into policy, by facilitating more representative exposure data and noise maps, correlating noise observations to physiological and social behaviour, informing decision-makers on the importance of enacting policies that combine health protection, and increasing welfare and territorial sustainability.

Theme B The role of health risk assessment to influence policy making

[94] perform a comprehensive life cycle assessment (LCA) for two types of road surfaces: traditional stone-mastic asphalt (SMA) and low-noise semi-dense asphalt (SDA), Traditional LCA methods were used for assessing the greenhouse gas emissions, non-renewable cumulative energy demand and health impacts of non-noise processes. The health impacts for noise emissions consisted of high annoyance and high sleep disturbance, using dose-response curves from the Swiss SiRENE study. SDA caused around 70 % higher greenhouse gases and energy demand than SMA, primarily due to its shorter service life. The noise impacts in disability adjusted life years (DALYs) were higher by two to three orders of magnitude compared to non-noise impacts, and the use of SDA can reduce 40 % of the total DALYs. Noise appears to play a significant role in the LCA of road pavements. However the trade-off between greenhouse gas and energy related impacts, on the one hand, and health effects, on the other hand, requires critical consideration by decision makers when promoting low-noise pavements.

Theme C Translating noise impacts into monetary terms to influence policy making

Translating noise impacts into monetary terms is an important step for the economic appraisal of policies and projects that have environmental consequences, either as deliberate aims or as indirect effects. Monetary values can also be applied to benefits/impacts that do not have conventional market prices, such as wellbeing. Environmental cost benefit analysis plays a prominent role in policy and decision making. Its main advantage is that it provides comparable and less biased decision based on inputs quantified in a consistent manner across projects and types of impacts [95]. The downside is that there may be variations in the methodologies and strength of the evidence for monetizing the true impact of specific environmental hazards. Furthermore, a single value does not reflect the often unequal distribution of the impact across a population.

14 articles and 2 reports were identified in our search covering the topic of economic valuation of noise/soundscape and its effects.

[96] summarise a report published in 2018 by the Interest Group on Noise Abatement of the European Network of the Heads of Environment Protection Agencies (EPA Network) on decision and cost benefit methods. Five different methods were identified for quantifying the benefits associated with noise interventions. The most frequently used methods amongst a network of European environment agencies were cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) – see Figure *2*. However the authors also noted big differences (up to a factor of 10) in the cost values used and which costs were taken into account between different EU countries, even those with comparable levels of welfare.

Overview of decision methods

method	decision criteria	remarks
cost-minimization	cheapest measure that fulfils the target	the output is fixed, to the required noise reduction; costs are then the only variable parameter
cost-effectiveness (CEA)	optimal ratio between noise reduction and costs	for noise, the output parameter is usually the noise reduction (in *dB *persons*)
cost-utility (CUA)	optimal ratio between public health (utility) parameter and costs	the health impact contains various endpoints; the impact is expressed in DALY/QALY units
cost-benefit (CBA)	optimal ratio between multiple, monetized criteria,summed to a single value, and costs	every benefit is translated to monetary units, e.g.using WTP
multi-design criteria analysis (MDCA)	highest score as a weighted sum over multiple criteria, each on a different arbitrary scale	costs and benefits are scored, then combined on a numeric scale using weighting factors

Figure 2 Different methods for quantifying the benefits associated with noise interventions. Reproduced from [96]

Five studies investigated the impact of transport noise on housing prices. [97] investigated the influence of road traffic noise on housing prices in four municipal areas in the city of Bari (Southern Italy). A review by [98] summarises findings from 18 studies that investigated the impact of noise on property prices (Poland, Scotland, Germany, Netherlands, Norway, USA, Hong Kong, Ecuador, Italy, Denmark & Hungary). [99] estimated the benefits of noise mitigation by its capitalization into property prices, using a national noise mitigation programme (noise barriers and façade insulation) run by the Swedish Road Administration. Property prices appreciated by 10–12 percent on average, with larger price increases for properties with lower energy efficiency and exterior quality. A gain-to-funding ratio of 1.4 to 1.7 was calculated for this noise mitigation programme. [100] investigated the causal noise effects from the Minneapolis-Saint Paul (MSP) International Airport on surrounding home values that are abatement eligible from those that are ineligible, based on two soundproofing initiatives between 1990 and 2014. Aircraft noise persistently and significantly reduced the rate of appreciation of abatement ineligible homes by approximately two percentage points per decibel over three years prior to a property's sale, while the effect on eligible homes was fully mitigated. In a separate study [101], the same authors used data on nearly one million resident noise complaints as an alternative measure of aircraft noise pollution and estimated the complaint effect on Minneapolis home values from 2006 through 2017. They argue that their complaint-based approach is advantageous for evaluating the noise discount on home sale prices as the spatial coverage reaches far beyond the contour thresholds. The primary findings suggested that noise complaints are indeed positively correlated with aircraft noise pollution and a 10% increase in annual local noise complaints reduced property values by around 0.05%, on average. This noise pollution effect persisted for roughly 10km past the airport — nearly twice the distance of the outer most contour curve.

Decisions on noise interventions can be informed by a wide range of factors; and noise may not always be the primary driving factor (for example, maintenance of road network). In a study presented in two papers, [102, 103] present an assessment method to fully compare the performance of pavement resurfacing policies, taking into account tax revenues, road operator's and users' savings, domestic production and employment, net present value, users' time savings and noise reduction health benefits, as well as protection of natural resources, biodiversity and human health. In Part II they apply this method on a 10-km-long section of French highway to fully compare the performance of various types of pavement resurfacing policies for all relevant stakeholders, including roadside neighbours. The authors

gave little detail on how the noise emissions were translated into health impacts, however it seems that they have based the relationship on number of people highly annoyed (citing [104]). [105] applied a modified life cycle assessment for low-noise urban roads, including the health effects (high annoyance and sleep disturbance) from road traffic noise in a road test section in Switzerland. The health cost due to road traffic noise was around 9 times the cost due to pavement production. The total costs (production, GHG emission and health impact) of low noise pavement (SDA) with 10 and 15 service years were comparable. Both were 10–17 % lower than the cost of the traditional road pavement (SMA). [106] developed a method for evaluating infrastructural interventions for the mitigation of noise generated by roads. The method considers a series of parameters (environmental, social, economic and health) that goes beyond a single economic metric. Noise was included under *environment* (noise reduction), and also under *health* (annoyance, sleep disturbance, cardiovascular problems and tinnitus), citing the WHO 2011 *Burden of Disease from environmental noise* report [107]. The method was applied for evaluating noise mitigation interventions around a section of a single carriageway road in Italy. [108] developed an automatic decision model to determine the optimal noise barrier placement to manage health impacts, productivity, and costs associated with construction noise. The authors applied evidence from transport noise to quantify the health impacts (annoyance and ischaemic heart disease) from construction noise, also citing the WHO 2011 *Burden of disease from environmental noise* report. Their case study shows that users of such models can choose whether they want to minimize the cost to the construction company, minimize health impacts for nearby residents, or try to achieve a balance between the two.

[109] applied a method developed by the French National Agency for Ecological Transition (ADEME) for estimating the social cost of noise to the Ile-de-France region. They estimated the cost at 42.6 billion € per year, i.e. 29% of the national total. The assessment included five sources of noise (transport, neighbourhood, construction, hospitals and occupational) and two types of costs: non-market costs (the economic valuation of the loss of well-being and healthy life of the exposed populations) and market costs (related to productivity losses, property depreciation, health expenses and noise mitigation). The health effects with the highest costs were, in decreasing order: sleep disturbance, high annoyance, cardiovascular disease, psychological disorder, obesity, hearing loss, learning difficulties, public health insurance claims and Type 2 diabetes.

[110] analysed the negative health effects of road traffic noise in the EU over the period 2020-2035 for a baseline scenario, and with various noise abatement scenarios such as quiet road surfaces, quiet tyres, and electric vehicles. Monetized health benefits were used as input for a cost-benefit analysis of the scenarios over the period 2020-2035 (see also subsection *Reports on Theme A and Theme D*).

Two studies looked at monetization from a soundscape/quiet areas perspective. Whilst interest in soundscape has been increasing in recent years, research on the economic valuation of soundscapes is still in its infancy. The challenge is that the uptake of soundscape approaches relies on established methodologies for identifying and measuring their value and impact, but such methodologies can only be developed with enough case studies where the impact of soundscape approaches can be studied and potentially valued. [95] present a conceptual framework on this emerging topic, by addressing ten questions covering the definition and scope for soundscape valuation, such as (1) Where does the value of soundscape lie? and (5) Should soundscape be valued as individual experience or public assets? The authors suggest that stated preference methods are the most appropriate valuation methods in the near and medium term, given the perception- and context-based nature of soundscape. However quantitative soundscape metrics that link subjective perceptions to objective acoustic and contextual factors will be needed to enable monetisation. [10] considered the economic value of quiet areas and soundscapes in a report on Quiet areas, soundscaping and urban sound planning. They present several case

studies, including two Swiss studies looking at whether location and environmental quality (including green spaces) resulted in changes in property value, a UK study that provided rough estimates for the direct use value of green open space, a statistical analysis from the UK showing the partial dependency of real estate property price on distance to green space, and two studies on eco-tourism from Finland and China.

Table 5 Summary characteristics of articles and reports on noise economic analysis

Paper/report	Study type	Sound sources	Impacts/benefits monetised
EPA Network	Methods for quantifying the benefits associated with noise interventions	Environmental	n/a (methodological)
Morano et al. 2021	Impact of noise on house prices in Italy	Road traffic	Property prices
Farooqi et al. 2022	Review	Non-specific	Property prices
Lindgren 2021	Impact of traffic noise mitigation on house prices	Road traffic	Property prices
Friedt & Cohen 2021	Effect of noise on housing prices of those eligible and ineligible for sound insulation	Aviation	Property prices
Friedt & Cohen 2021	Relationship between noise complaints and impact on property prices	Aviation	Property prices
de Bortoli et al. 2022	performance of various types of pavement resurfacing policies	Road traffic	Unclear
Piao et al. 2022	life cycle assessment for low-noise urban roads	Road traffic	Annoyance and sleep disturbance
D'Alessandro et al. 2022	evaluating infrastructural interventions for the mitigation of noise generated by roads	Road traffic	annoyance, sleep disturbance, cardiovascular problems and tinnitus
Choi et al. 2022	determine the optimal noise barrier placement to manage health impacts	Construction	annoyance and ischaemic heart disease
Mietlicki et al. 2022	estimating the social cost of noise to the Ile-de-France region	transport, neighbourhood, construction, hospitals and occupational	loss of well-being and healthy life of the exposed populations) and market costs (related to productivity losses, property depreciation, health expenses and noise mitigation
Salomons & Dittrich 2021	HIA of road traffic noise in the EU	Road traffic	health
Jiang et al. 2022	Soundscape valuation	Soundscapes	n/a (methodological)
EPA Network	Soundscape valuation	Soundscapes	Property prices, value of green space, eco-tourism

Some of the examples listed in this section (summarised in Table 5) are not directly linked to health effects attributable to noise or soundscape. Nevertheless, it is important to note that a cost benefit analysis should aim to include a complete list of costs and benefits. Monetizing all the costs associated with noise (e.g. health, property prices, value of quiet, etc) may justify the inclusion of additional, or more effective (but costlier) mitigation measures, which would ultimately lead to better health outcomes.

Theme D Monitoring progress of policies aimed at reducing the noise health burden

[111] assessed the effectiveness of two major policy interventions to control noise pollution in Nepal. First, the compliance of the National Sound Quality Standard 2012 enforcement was assessed by comparing the measured noise level with WHO 1999 and NSQS guideline value (55 dB daytime) and NSQS for different zones (55 or 65 dB). Second, the effectiveness of the No Horn Regulation was studied by evaluating the measured noise level of 12 sites in Kathmandu. The No Horn Regulation prohibits honking except in case of emergency and turning. In 65.2% of the sampled locations, the noise level was found to exceed the WHO and NSQS limit. Although the regulation was not strictly followed, after its enforcement the noise level was reduced by 2.1 dB(A).

[112]'s review explores the overall effectiveness of hearing conservation programs in preventing occupational noise-induced hearing loss. The effectiveness is deemed to be uncertain and unquantified, while the incidence and cost of occupational hearing loss remain inexplicably high. Billions of annual audiograms conducted worldwide have not been aggregately utilized or applied to predict early NIHL The paper discusses what is necessary to transform this individual screening test into a medical surveillance process directly linked to aggregate corrective and prevention actions.

[113] discuss the practical implications of a new Building Regulation introduced in England in 2022 to mitigate overheating risk. A requirement of the regulation is that the strategy to mitigate overheating must take into consideration the occupants' safety and comfort. If internal noise levels exceed 40 dB $L_{Aeq,8\ hr}$, or 55 dB L_{Amax} more than 10 times a night, then windows cannot be assumed to be open during the night-time period. The authors discuss some of the complexities associated with such a condition, including the measurement vs modelling of external noise, sources of uncertainty, and demonstrating compliance and required acoustic expertise of the person responsible for signing off the building design.

[114] examine the impact of the New Deal aircraft noise control policy introduced in Schiphol (Amsterdam) in 2008 on depressive symptoms using data from the Longitudinal Aging Study Amsterdam (LASA). The data suggest that the policy did not lead to a reduction in noise levels in the treatment areas relative to the control areas, and it had no significant impact on levels of depressive symptoms

Theme E Recommendations for further noise and health research from policy making

Our review did not identify any documents specifically focused on recommendations for further noise and health research. However, many reports and articles that were reviewed included sections with such recommendations. Consolidation of such recommendations in a single review or repository may be warranted. It is important that such an exercise does not decouple the recommendations from the contextual circumstances in which they were made.

CONCLUSION

The findings of this review suggest that noise and health research is having an increasingly important role in influencing policy and decision making. Reviews of flagship noise policies developed specifically to improve health outcomes, such as the European Noise Directive, have highlighted the significant challenges of reducing the public health burden attributable to noise. Therefore there needs to be more emphasis on research that demonstrates how this health burden can be reduced. Such research needs to take a holistic approach of noise exposure reduction, non-acoustic factors, health equity and careful consideration of competing economic, social and environmental priorities.

As noted in the Introduction, the topic of this review is particularly challenging to review in a

comprehensive manner. The database search of scientific articles has identified articles from across the world, including low to middle income countries (and even one from space), and on a wide range of noise sources. However we acknowledge that a lot of knowledge in this area is contained within reports written in the respective countries' official languages, and few such reports end up being summarised in scientific journals or widely publicised (which would increase the odds of being promoted by a search engine). For this review we relied on ICBEN Team 9 members to share documents from their respective regions, however we acknowledge that this approach led to a strong bias towards European publications. This limitation can be managed in future reviews by ensuring that the ICBEN Team 9 membership is geographically diverse to better reflect ICBEN's international scope and audience.

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APPENDIX 1 – SEARCH TERMS

Pubmed

#1

"Noise"[Mesh] OR "Noise, Transportation"[Mesh] OR "Noise, Occupational"[Mesh] OR "Hearing Loss, Noise-Induced"[Mesh] OR ((rail*[tiab] OR aircraft[tiab] OR airport*[tiab] OR road*[tiab] OR highway*[tiab] OR traffic[tiab] OR vehicle*[tiab] OR transport*[tiab] OR environment*[tiab] OR neighb*[tiab] OR industry*[tiab] OR leisure[tiab] OR occupation*[tiab]) n1 noise[tiab])

#2

"Policy"[Mesh] OR "Environmental Policy"[Mesh] OR "Policy Making"[Mesh] OR "Health Policy"[Mesh] OR "Fiscal Policy"[Mesh] OR "Guideline Adherence"[Mesh] OR "Legal Epidemiology"[Mesh] OR (policy[tiab] OR policies[tiab] OR legislat*[tiab] OR regulat*[tiab] OR (noise[tiab] n1 limit*[tiab]))

#3

"Economics"[Mesh] OR economic[tiab] OR feasibil*[tiab] OR "impact assess*"[tiab]

Search: #1 AND #2 AND #4 Filters: from 2021 – 2022	47 hits
Search: #1 AND #3 AND #4 Filters: from 2021 – 2022	24 hits

Scopus

((TITLE-ABS-KEY (noise W/1 (rail* OR aircraft OR airport* OR road* OR highway* OR traffic OR vehicle* OR transport* OR environment* OR neighb* OR 24ndustry* OR leisure OR occupation*)) AND (TITLE-ABS-KEY (policy OR policies OR regulat* OR economic OR feasibil* OR "impact assess*" OR (noise W/1 limit*))) AND (TITLE-ABS-KEY (health OR wellbeing OR {quality of life}))) AND PUBYEAR > 2020 AND PUBYEAR < 2023)

217 hits

Web search

Google search terms 'Noise Health Policy' for period 2021-2022 resulted in 9 relevant hits, 4 of which were duplicates.

APPENDIX 2 – PRISMA FLOWCHART