

Article

The Price of Noise: An Order-of-Magnitude Economic Assessment of Environmental Noise from a Planetary Health Perspective

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Abstract

Environmental noise has emerged as a pervasive yet frequently underestimated environmental stressor with consequences for biodiversity, public health, and societal well-being. Although a substantial body of epidemiological research has linked chronic transportation-related noise exposure with cardiovascular disease, sleep disturbance, psychological distress, impaired cognitive performance, and premature mortality, comparatively few studies have estimated its broader economic burden within a planetary health framework. This study presents an exploratory order-of-magnitude economic valuation based on a large-cohort epidemiological risk-transfer scenario. A hazard-ratio-based framework was applied to estimate noise-attributable mortality among populations subjected to road traffic environmental noise levels above 60 dB. Both tangible costs, representing forgone economic productivity, and intangible costs, representing societal welfare losses using the Value of a Statistical Life framework, were estimated. Under baseline assumptions, chronic transportation-related environmental noise was associated with approximately 27,692 annual attributable deaths—when applying a hazard-based ratio—estimated annual productivity losses of approximately US\$7.28 billion and welfare losses valued at approximately US\$353.91 billion under the Value of a Statistical Life framework. These findings suggest that chronic transportation-related environmental noise represents a potentially important, though often overlooked, environmental externality with substantial health and economic implications. The proposed framework provides an initial basis for future research evaluating the wellbeing, societal, and economic magnitude of environmental noise within a planetary health context.

Keywords: planetary health; noise pollution; environmental noise; cardiovascular health; sleep disturbance; economic valuation; cost–benefit analysis; environmental sustainability



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1. Introduction

Planetary health recognizes that human health, societal well-being, economic prosperity, and environmental sustainability are fundamentally interconnected and dependent on the homeostasis of Earth's ecological environment [1,2]. Historically, environmental policy has focused primarily on visible forms of ecological pressures associated with industrial revolutions, the current AI revolution, electricity needs, and urban development, including declining air quality, degradation of freshwater systems, emissions that contribute to climate change, reductions in biodiversity, the fragmentation and alteration of natural habitats, and biodiversity loss. More recently, however, attention has shifted toward less visible environmental stressors that can produce substantial ecological, biological, and societal

consequences. Among these emerging concerns, environmental noise pollution has gained recognition as a pervasive yet often underestimated form of anthropogenic environmental degradation [3–6]. The transformation of natural soundscapes began during the Industrial Revolution and accelerated throughout the twentieth and twenty-first centuries as mechanized industry, railways, highways, aviation, maritime shipping, urbanization, and modern transportation systems expanded globally. Today, anthropogenic noise permeates virtually every terrestrial, freshwater, and marine ecosystem, leading many researchers to classify noise as a major environmental stressor with public health consequences rather than simply a nuisance affecting everyday comfort [3–6]. Unlike many conventional pollutants, noise leaves no visible residue in the environment. Nevertheless, its biological, ecological, and psychological effects can be substantial, affecting species ranging from invertebrates and fish to birds, mammals, and humans [3–8].

1.1. Theoretical Framework

Environmental noise can be conceptualized as a negative externality within the frameworks of environmental and welfare economics because individuals and organizations that generate excessive noise often do not bear the full costs imposed on others. Instead, many of these costs—including increased healthcare expenditures, reduced labour productivity and educational performance, diminished quality of life, ecological degradation, and premature mortality—are transferred to households, governments, healthcare systems, and society more broadly. This divergence between private benefits and public costs represents a classic example of market failure and provides a strong theoretical justification for government intervention through regulation, taxation, and enforcement mechanisms [9–14].

The concept of negative externalities was first formalized by Pigou, who argued that markets fail to allocate resources efficiently whenever private costs differ from broader social costs [9]. Coase subsequently demonstrated that, although bargaining may theoretically internalize externalities under ideal conditions, practical barriers such as transaction costs, imperfect information, and the large number of affected individuals frequently prevent efficient private solutions, thereby justifying public regulation [10]. Environmental noise exemplifies these conditions because millions of individuals are simultaneously exposed to transportation, aviation, and industrial noise, making private bargaining virtually impossible. Consequently, transportation noise has increasingly been recognized as an environmental externality requiring policy intervention to improve social welfare [15,16].

From a welfare economics perspective, the objective of environmental policy is to maximize societal well-being rather than private utility alone. Cost-benefit analysis provides a systematic framework for comparing the costs of environmental interventions with the societal benefits generated by reductions in mortality, morbidity, environmental degradation, and productivity losses [15–17]. International organizations, including the Organization for Economic Co-operation and Development (OECD) and the World Bank, increasingly advocate incorporating environmental externalities into economic decision-making, as conventional market prices often underestimate the true societal costs of pollution and environmental degradation [13,14]. Within this theoretical framework, economic valuation serves to internalize environmental externalities by assigning monetary values to health and welfare losses that are otherwise omitted from market transactions, thereby allowing decision-makers to assess the comparative costs of intervention with the costs of inaction [9–14].

From a methodological perspective, hazard ratios provide the critical bridge between epidemiological evidence and economic valuation. In environmental epidemiology, hazard ratios quantify the relative increase in mortality risk associated with a specific environmental exposure while accounting for differences in follow-up time and underlying population

characteristics [18,19]. Although hazard ratios do not directly estimate the absolute number of deaths attributable to an exposure, they provide a robust measure of excess mortality risk that can be translated into an attributable fraction using established epidemiological methods [18,19]. Because hazard ratios are routinely used in longitudinal epidemiological investigations to assess mortality risks associated with environmental exposures, they provide a scientifically robust basis for translating epidemiological evidence into economic valuation models [18,19].

The present study adopts this epidemiological framework because premature mortality represents one of the most policy-relevant outcomes for economic evaluation. The attributable fraction derived from the hazard ratio is applied to the exposed population to predict the number of deaths attributable to chronic environmental noise exposure. These mortality estimates subsequently serve as the principal inputs to both the human-capital approach, which estimates productivity losses, and the Value of a Statistical Life (VSL) framework, which estimates broader societal welfare losses [13–15,20,21]. Consequently, the hazard-ratio-based framework provides a transparent analytical pathway linking epidemiological evidence to economic valuation, cost–benefit analysis, and environmental policy evaluation [9–15,20].

The resulting framework integrates three complementary disciplines into a single analytical model. Epidemiology quantifies the increase in mortality risk associated with environmental noise [18]; environmental and welfare economics translate this excess mortality into tangible and intangible societal costs using established valuation frameworks [9–15,20,21]; and planetary health provides the overarching conceptual perspective by recognizing that environmental degradation simultaneously affects ecological integrity, population health, economic productivity, and long-term societal sustainability [1,2,20]. This interdisciplinary integration forms the theoretical foundation of the present study and distinguishes it from previous investigations that have primarily focused on property-value depreciation, willingness-to-pay estimates, subjective well-being, or localized transportation externalities rather than mortality-based economic valuation [21–30].

Beyond economic valuation, the framework highlights that reducing environmental noise can yield multiple co-benefits for biodiversity conservation, public health, economic resilience, and environmental sustainability. This broader perspective distinguishes planetary health from traditional welfare economics by recognizing the interdependence of ecological systems, human health, and long-term societal prosperity [1,2,20].

1.2. Ecological Consequences of Noise

From an evolutionary perspective, the influence of environmental noise is not surprising. Humans and other species evolved within relatively stable natural acoustic environments. Consequently, physiological stress-response systems that were adaptive for responding to acute environmental threats may become maladaptive when chronically activated by persistent anthropogenic noise. Throughout evolutionary history, sudden loud sounds frequently signalled danger, including predators, environmental hazards, or conflict. In response, terrestrial and aquatic organisms evolved physiological mechanisms to rapidly mobilize energy, increase vigilance, and prepare for survival. While such responses were advantageous when threats were temporary, chronic activation of these systems by continuous environmental noise may contribute to adverse biological outcomes. Similar processes are observed throughout the natural world, where excessive anthropogenic noise disrupts communication, feeding behaviour, migration, reproduction, predator avoidance, and ecosystem functioning [5–8].

The ecological consequences of noise pollution have become increasingly apparent in recent decades. A large meta-analysis examining hundreds of effect sizes across nu-

merous taxonomic groups found significant adverse effects of anthropogenic noise on mammals, birds, fish, amphibians, reptiles, and invertebrates, suggesting that acoustic disturbance has become a widespread ecological stressor operating across ecosystems worldwide [3]. In aquatic and marine environments, noise generated by shipping, sonar, seismic exploration, and motorized transportation has been linked to alterations in communication, hearing, reproduction, habitat selection, migration patterns, and predator–prey interactions [8]. Researchers have further suggested that excessive underwater noise may affect fisheries productivity, biodiversity, ecosystem resilience, and food-web stability, thereby generating broader ecological and economic consequences [8]. Experimental evidence also recommends that noise disturbances may influence animal health through physiological pathways.

Exposure to environmental disturbances (e.g., noise) has been linked to elevated stress hormone levels and other physiological and psychological responses, impaired immune function, and increased susceptibility to infectious disease in animals [4]. In one experimental study, acute noise exposure increased parasite burdens among fish, while chronic exposure reduced survival despite lower pathogen burdens, indicating complex interactions among noise as an environmental stressor, immunity, and disease resistance [4]. Such findings suggest that anthropogenic noise may contribute not only to behavioural disruption but also to broader patterns of morbidity and mortality within all ecological systems.

Bird populations provide some of the most visible examples of anthropogenic acoustic disruption. Since the expansion of industrialization in the 18th and 19th centuries, with the expansion of activity and transportation networks, numerous bird species have altered the frequency, amplitude, and timing of their singing to reduce acoustic overlap with road traffic sounds [5,31–33]. These adaptations may interfere with territorial communication and reproductive success while increasing energetic demands. Recent evidence from Paris, France, demonstrates both the challenges and opportunities associated with urban noise management [31–33]. Through investments in cycling infrastructure, quieter transportation systems, anti-noise road surfaces, and automated monitoring technologies, Paris has reduced environmental noise levels by approximately three decibels over the past decade [31–33]. Nevertheless, many bird populations continue to sing at frequencies substantially higher than those observed in less disturbed environments, suggesting that ecological recovery may lag behind improvements in environmental conditions [31–33].

1.3. Human Health Consequences

Humans, like any aquatic or terrestrial species, appear similarly vulnerable to chronic acoustic disturbances. Environmental noise has been associated with annoyance, sleep disruption, reduced educational attainment, impaired concentration, diminished workplace productivity, psychological distress, hypertension, cardiovascular disease, stroke, and noise-attributable mortality [34–38]. These effects are believed to result from repeated triggering of physiological stress pathways by chronic exposure to environmental noise, which may activate stress-related systems, promoting hormonal dysregulation, cardiovascular stress, inflammation, and sleep disturbance, as well as systemic inflammation and disruption of normal sleep processes [35,38]. Over time, these physiological responses may contribute to chronic disease and diminished quality of life. Within the health sector, consequences of noise pollution, heart disease and stroke have received particular attention [18,39,40].

Large epidemiological studies have repeatedly highlighted positive associations between traffic-related noise and increased cardiovascular risk, stroke, and disease [18,39,40]. In one of the largest studies conducted to date, involving approximately 8.6 million residents, evidence highlights that prolonged exposure to roadway noise is linked with

elevated stroke incidence, related hospital admissions, cardiovascular morbidity, and a greater likelihood of death irrespective of cause, particularly among elderly citizens [18]. Similar findings have been reported across Europe and elsewhere, contributing to growing recognition that environmental noise represents a significant public health challenge rather than merely an environmental inconvenience [35–40].

Sleep disturbance due to noise represents another major pathway through which noise affects human health [38]. Environmental noise can delay sleep onset, increase nighttime awakenings, impair sleep quality, and interfere with physiological recovery processes [38,40–45]. Chronic sleep disruption has been associated with fatigue, reduced productivity, impaired cognitive functioning, obesity, cardiovascular disease, anxiety, depression, and reduced well-being [35,36,46]. The World Health Organization has identified environmental noise as one of the top contributors to years of healthy life in Europe, second only to air pollution in some assessments [36,47]. The psychological effects of prolonged noise exposure have been recognized for decades [38–46]. During the Cold War, intelligence agencies and military researchers examined the effects of sensory manipulation, continuous noise exposure (e.g., music, car noise/traffic around the target, dropping items above, and acoustic noise in which the target recognizes the pattern but remains helpless), and subsequent sleep deprivation due to noise on cognition, performance, and behaviour [48–53]. Historical research on interrogation identified prolonged noise exposure as an effective means of inducing psychological stress, psychosis, fatigue, agitation, confusion, increased suicide risk, mental deterioration, and disorientation [48–53].

During the Northern Ireland uprising by Irish nationalists against British colonialism of the Irish Isles, the unionist security forces employed similar techniques, the so-called “Five Techniques”, which included continuous exposure to loud noise, sleep deprivation, hooding, stress positions, and dietary restriction [52–55]. Similar methods were later reported in investigations of post-9/11 detention practices involving prolonged exposure to loud music and continuous noise in conjunction with sleep deprivation and isolation [49–55]. Although these practices occurred in entirely different contexts, they demonstrate a longstanding institutional recognition that prolonged noise exposure for those in captivity or in neighbourhoods, through loud cars, motorcycles, trains, air traffic, loud music from entertainment districts, or construction, can significantly affect sleep, psychological health, emotional regulation, work or school performance, and overall well-being. Most recently, the Havana Syndrome has emerged in some Western Embassy staff based in Cuba following brief exposure to high-intensity directional acoustic sounds, with affected individuals commonly reporting sudden head pressure, otologic pain, nausea, tinnitus, brain fog, and vertigo-like symptoms allegedly linked to Russian military intelligence units operating on the Caribbean Island alongside other hostile nations [56–59]. The power of noise as a risk to human well-being and mental health shows that the same biological mechanisms that make noise an effective coercive stressor may help explain the adverse health effects associated with chronic environmental noise exposure among civilian populations [60,61].

Among the many contributors to environmental noise, modified vehicle exhaust systems have attracted increasing public and regulatory attention because they are among the most easily preventable sources of transportation-related noise through legislation, enforcement, and monitoring. While advances in engineering and electric vehicles have reduced engine noise and improved fuel efficiency, many modern sports, trucks, muscle, and performance vehicle manufacturers now feature electronically controlled exhaust systems that let drivers switch between quieter, medium, and substantially louder operating modes [62]. Municipalities and police services throughout Canada, Europe, and the United Kingdom have reported increasing complaints about modified mufflers, valved

exhaust systems, street racing, and performance vehicles that intentionally amplify exhaust noise [63–66]. Despite legislation banning modified exhausts on loud cars/motorcycle, people in neighbourhoods frequently complain about sleep disruption, reduced quality of life, stress, and neighbourhood disturbance linked to loud cars/motorcycles [63–67]. Interestingly, emerging psychological research suggests that preferences for loud vehicles may not be randomly distributed throughout the population [68].

In a study involving a large sample of university students (e.g., 529), Schermer [68] found that favourable attitudes toward loud cars/motorcycles and willingness to modify vehicle mufflers were significantly linked with elevated scores on assessments of psychopathy and everyday sadism, with men reporting a substantially greater preference for loud vehicles than women. Psychopathy and sadism (psychological traits linked to lack of empathy, interpersonal violence and animal cruelty) emerged as the strongest predictors of positive attitudes toward loud vehicles, muffler modification, and other similar features [68,69]. Although these findings should not be generalized to all owners of performance vehicles, they suggest that attitudes favouring intentionally amplified vehicle noise may, in some individuals, contribute to behaviours that increase unnecessary exposure to environmental noise. These findings are presented as one possible behavioural explanation for a subset of discretionary vehicle-noise emissions, rather than for transportation noise more broadly [68,69]. From a policy perspective, excessive vehicle noise therefore represents a classic environmental externality in which private enjoyment generates broader public costs borne by residents, pedestrians, wildlife, and society [70].

Recognizing these concerns, governments and municipalities have increasingly explored new approaches to noise management [63–67]. As with automated enforcement systems used for traffic safety and air-quality compliance, several jurisdictions have introduced or proposed automated noise-camera technologies capable of identifying vehicles that exceed established acoustic thresholds, with traffic violation tickets automatically sent to the offenders [63–67]. Toronto, Ottawa, Edmonton, and municipalities in the United Kingdom have recently explored or implemented pilot programs to reduce excessive vehicle noise through automated monitoring and enforcement systems [63–67]. These initiatives reflect a growing recognition among elected officials that environmental noise is not merely a simple inconvenience but a measurable environmental and public health challenge that requires evidence-based interventions to protect the population and neighbourhoods [63–67]. Despite growing evidence linking environmental noise to ecological disruption, cardiovascular disease, sleep disorders, mental health concerns, and reduced quality of life, relatively limited reviews have tried to estimate the global economic burden of noise-attributable mortality using a comprehensive planetary health perspective.

Existing studies have often focused on specific health outcomes or localized interventions rather than on the cumulative global ecological, health, social, and economic costs of environmental noise. Consequently, important questions remain regarding the overall societal costs associated with noise exposure and the gains that could be realized through successful noise-reduction interventions. This study addresses this gap by examining noise pollution within a planetary health framework and evaluating the mortality-related economic burden associated with chronic environmental noise. By synthesizing evidence from environmental science, ecology, public health, transportation, psychology, and economics, the study seeks to contribute to the growing planetary health literature by framing environmental noise as a multidimensional challenge that affects biodiversity, population health outcomes, economic efficiency, and overall quality of life. As recent planetary health analyses have assessed the impact of the load of air pollution-related mortality, the current evaluation extends this systems-based framework to environmental noise, an-

other pervasive yet often underappreciated environmental externality of modern industrial societies [20].

1.4. Environmental Economics and Welfare Valuation of Noise Pollution

The economic consequences of noise pollution have been examined using several complementary valuation frameworks, including hedonic pricing models, contingent valuation studies, subjective well-being analyses, health-cost assessments, productivity-loss approaches, and broader social welfare evaluations. Collectively, these studies demonstrate that environmental noise generates substantial costs that extend far beyond annoyance and property depreciation, affecting healthcare expenditures, labour productivity, quality of life, and noise-attributable mortality [15–18,22–25,71–75].

One of the earliest and most widely used approaches for valuing environmental noise is hedonic pricing [25]. Hedonic studies estimate the economic burden of noise by examining the link between environmental noise exposure and residential property values [22,25]. Various evaluations have shown that transportation-related noise significantly reduces housing prices, with property values declining as exposure to road, rail, and aircraft noise increases [22,25,26]. Noise sensitivity depreciation indices generally indicate reductions of approximately 0.3% to more than 1% in property value for each additional decibel of noise exposure above accepted thresholds [22,25,26]. These findings indicate that housing markets internalize at least part of the perceived burden of environmental noise and provide an indirect estimate of residents' willingness to pay for quieter living environments [22,25–27].

Complementing hedonic approaches, contingent valuation and willingness-to-pay (WTP) studies directly estimate the monetary value individuals assign to noise reduction [22,25–28]. These methods typically ask respondents how much they would be willing to pay to reduce environmental noise exposure or improve local soundscapes [22,25–27]. Research from South Korea found that families were eager to provide annual premiums to support noise-reduction policies, and similar results have been found in Europe, with transportation-related noise generally valued more negatively than residential noise [23,28]. Similar studies conducted in Europe and North America have consistently demonstrated that individuals assign measurable economic value to quieter environments, reflecting the broader welfare losses associated with chronic noise exposure [22,23,28].

More recent research has expanded economic valuation beyond market transactions and stated-preference methods to include subjective well-being and happiness-based approaches [15,24]. Rather than focusing on housing prices or hypothetical payment scenarios, these studies estimate the environmental impact of noise on well-being (assessed subjectively), then quantify the income needed to offset these effects and the resulting reduction in well-being [29,30]. Using survey data from more than 26,000 individuals across 28 European countries, Weinhold found that residential noise exposure significantly reduced self-reported happiness and quality of life [29,30]. The study estimated that compensating households for severe noise exposure would require approximately €146 per month in 2003 prices, equivalent to roughly €172 per month in 2011 prices [29]. These findings suggest that conventional market-based valuation approaches may underestimate the broader psychological and social costs associated with chronic environmental noise [15,24,29].

Health-based economic assessments provide further evidence that noise pollution imposes substantial societal costs. An expanding body of epidemiological evidence indicates that prolonged exposure to transportation-related noise is associated with a heightened risk of hypertension, heart disease, stroke, sleep disturbance, type II diabetes, and noise-attributable mortality [18,36,37,71,76]. In one of the largest studies conducted to date, involving approximately 8.6 million residents, noise exposure from road traffic at levels greater than 60 dB was linked to an increased likelihood of stroke-related hospital

admission and a higher risk of death from any cause, particularly among elderly individuals [18]. These findings support the growing recognition that environmental noise serves as a chronic physiological stressor that can generate substantial healthcare costs through increased disease burden.

The health-related economic burden of noise pollution extends beyond direct medical expenditures. Cardiovascular disease, hypertension, sleep disorders, and mental health conditions contribute to productivity losses, absenteeism, disability, lower grades in school, and reduced workforce participation [77]. Studies examining aircraft, transportation, and occupational noise have estimated substantial annual costs associated with healthcare utilization, educational impairment, lost productivity, and reduced quality of life [15,22,27]. Collectively, these findings suggest that overall health-related impacts may be among the largest components of the estimate attributable to environmental noise.

Occupational noise exposure represents another important source of economic loss. Excessive workplace noise has been associated with hearing impairment, fatigue, reduced concentration, increased accident risk, absenteeism, and lower productivity [78,79]. An analysis of Jordan's phosphate industry estimated that noise-related productivity losses and health-related expenditures generated annual economic losses exceeding 23 million Jordanian dinars [71]. Although such estimates depend on methodological assumptions regarding productivity and health impacts, they illustrate the potentially substantial economic consequences of occupational noise exposure for firms, corporations, governments, and national economies.

Cost-benefit analyses of noise mitigation measures generally demonstrate that investments in noise reduction yield positive economic returns [17,29,72–75]. A Dutch national assessment evaluated a range of interventions, including low-noise pavement, quieter railway technologies, noise barriers, and vehicle-related source controls [17]. Using both hedonic pricing and contingent valuation methods, the study concluded that the estimated benefits substantially exceeded implementation costs under all scenarios examined [17]. Importantly, the authors noted that many environmental and ecological benefits were not included in the valuation, suggesting that the reported estimates likely underestimated the full societal benefits of noise reduction [17].

Recent scholarship has also questioned whether conventional cost-benefit analyses adequately capture the broader social value of environmental quality [80]. Traditional transport appraisals frequently assign substantial economic value to travel-time savings while placing relatively less emphasis on environmental outcomes such as noise reduction, biodiversity protection, and recreational opportunities [80]. Using social-choice valuation experiments, Mouter and colleagues [80] found that citizens often assigned greater value to reductions in noise pollution, the preservation of recreational space, and the protection of biodiversity than conventional transport cost-benefit analyses implied [80]. These findings suggest that traditional economic appraisal frameworks may underestimate the societal value of quieter, healthier, and more sustainable environments [28,80].

Taken together, the literature demonstrates that noise pollution imposes high and multidimensional economic costs through reduced property values, diminished subjective well-being, increased healthcare expenditures, productivity losses, and elevated mortality risks. While previous studies have examined individual components of these costs, comparatively few analyses have integrated ecological, health, and societal impacts within a single planetary health framework at a global level. Consequently, there remains a need for comprehensive economic evaluations that capture the full range of benefits associated with environmental noise reduction. Such an approach is particularly important given that accumulating research suggests that the effects of environmental noise extend beyond human

health outcomes to influence economic productivity, biodiversity, ecosystem functioning, and long-term environmental sustainability.

1.5. Research Rationale and Question

Although a growing list of evaluations has highlighted the ecological, psychological, cardiovascular, and economic consequences of environmental noise, important gaps remain in integrating these findings into a broader planetary health framework. Existing studies have largely focused on individual dimensions of the problem, including property-value depreciation, willingness-to-pay estimates, transportation noise, sleep disturbance, workplace productivity, and subjective well-being. While these studies demonstrate that environmental noise imposes meaningful societal costs, relatively few investigations have attempted to integrate ecological impacts, human health consequences, and economic valuation into a unified framework to inform planetary health policy globally.

The growing recognition of environmental noise as a global pollutant further highlights the need for such an approach. Anthropogenic noise affects biodiversity, ecosystem functioning, animal communication, reproduction, migration, and disease susceptibility while simultaneously contributing to cardiovascular disease, sleep disorders, psychological distress, reduced quality of life, and noise-attributable mortality among humans, as discussed previously. Consequently, noise pollution should be viewed not simply as a localized nuisance but as a multidimensional environmental externality affecting ecological sustainability, public health, and economic productivity.

As discussed above, previous economic evaluations have primarily relied on hedonic pricing models, contingent valuation techniques, happiness-based valuation methods, and productivity-loss approaches. Although these methods provide valuable insights, they often fail to capture the broader mortality burden associated with chronic exposure to environmental noise. Recent epidemiological work has highlighted that prolonged exposure to transportation-related noise is linked to elevated risks of cardiovascular disease, stroke, and death from all causes [18]. For example, among approximately 8.6 million residents, individuals subjected to road traffic noise exceeding 60 dB experienced a modest increase in overall mortality risk (approximately 4%), while stroke-related outcomes were elevated by roughly 5–9%, with variations observed across age groups and exposure categories [18]. Similar associations have been reported in studies examining hypertension, myocardial infarction, and cardiovascular disease [18,36,37].

Viewed from a harm-reduction perspective, these findings suggest that mitigating environmental noise could be a strategy to reduce preventable health harms and associated societal costs. Like air pollution control, interventions that reduce chronic noise exposure can yield substantial public health and economic benefits while improving overall societal well-being [20]. Within the present study, harm reduction is conceptualized as reducing population exposure to environmental noise through evidence-based interventions—including quieter transportation technologies, automated enforcement, urban planning, and regulatory measures—rather than attempting to eliminate all sources of environmental noise. However, the economic implications of noise-attributable mortality remain poorly quantified compared with those associated with air pollution, climate change, or other environmental exposures [20]. Limited studies have attempted to estimate the broader mortality-attributable economic burden associated with environmental noise, using hazard-ratio-based approaches that translate epidemiological risk into societal costs [19].

Accordingly, the present study extends previous economic valuation research by integrating established cost-benefit methodologies with a planetary health perspective. Drawing upon published hazard ratios linking environmental noise to mortality and cardiovascular outcomes, the analysis estimates both tangible and intangible costs associated

with noise-attributable mortality [18–20]. As with recent planetary health evaluations of air pollution, the study applies economic valuation techniques to estimate productivity and welfare losses associated with elevated mortality risk attributable to chronic noise exposure. Accordingly, the present study uses hazard-ratio-based mortality estimation as the epidemiological foundation for translating chronic environmental noise exposure into estimates of tangible and intangible societal costs within an environmental economic and planetary health framework.

Considering the above discussion, the study examines the following question:

What are the estimated annual global economic costs of mortality attributable to road traffic environmental noise exposure at 60–70 dB, both tangible and intangible?

By framing environmental noise as both a planetary and a public health challenge, this evaluation seeks to highlight a more comprehensive assessment of the societal burden of anthropogenic noise and the projected benefits of effective noise-reduction measures.

2. Methods

2.1. Model

This analysis does not seek to derive new values of the relationship between environmental noise and mortality. Instead, it utilizes previously published epidemiological findings and secondary data sources to estimate the economic implications of noise-attributable mortality. In doing so, the study incorporates both market-based costs and broader societal valuations of human life [20]. Rather than proposing a new modelling approach, the analysis draws upon established economic assessment methods widely used in environmental evaluation, transportation planning, and public policy assessment. These include loss-of-productivity approaches and VSL techniques, which are commonly employed to quantify the societal consequences of premature mortality [20].

An evaluation methodology technique was adopted because it provides a means of expressing health impacts in monetary terms that are readily interpretable by policymakers and decision-makers. Translating noise-related mortality into economic estimates allows the potential costs of continued exposure to be compared with the benefits that may result from mitigation and prevention efforts. As such, economic valuation serves as a complementary tool to epidemiological research by highlighting the broader implications of environmental noise for social welfare, economic performance, and long-term societal sustainability.

The purpose of employing globally harmonized parameters in the present study is not to estimate precise country-specific economic burdens but rather to provide a transparent, order-of-magnitude valuation framework that illustrates the potential societal magnitude of mortality-related costs associated with environmental noise. Because internationally standardized data on income, labour-force participation, retirement age, healthcare utilization, and willingness to pay are not consistently available across all countries, globally comparable assumptions were adopted to maintain methodological consistency. Consequently, the present evaluation should be interpreted as an exploratory conceptual model intended to stimulate debate on planetary health policy rather than as a substitute for detailed national or regional economic assessments.

The analysis is based on the hazard ratio reported by Halonen et al. [18], who analyzed approximately 8.6 million residents and highlighted that traffic during the daytime with noise exceeding 60 dB, compared with exposure below 55 dB, was linked with a 4% increase in most of the mortality (hazard ratio = 1.04). This hazard ratio serves as the epidemiological input for the attributable-fraction calculation used throughout the present valuation framework [18].

The hazard ratio was derived from a large population-based cohort and is employed in the present study as a risk-based-transfer scenario rather than as a universally applicable

global exposure-response function. The objective is not to estimate the true global burden of noise-attributable mortality but to illustrate the potential economic implications of applying a well-characterized large epidemiological risk estimate within a transparent, order-of-magnitude valuation framework. Risk-based-transfer methods are widely used in environmental and health economics when globally harmonized exposure-response functions are unavailable. Nevertheless, transferring epidemiological estimates across populations introduces uncertainty because demographic characteristics, housing quality, urban form, transportation systems, healthcare access, socioeconomic conditions, and co-exposure to other environmental hazards may influence both relative mortality risk and the absolute number of attributable deaths. Consequently, the present estimates should be interpreted as illustrative scenario analyses based on the large cohort rather than precise estimates of the worldwide burden of environmental noise.

The mission of the current evaluation is not to estimate country-specific mortality risks but to illustrate the potential magnitude of mortality-related economic costs using a transparent and published epidemiological estimate. While regional differences in demographics, socioeconomic conditions, housing characteristics, healthcare systems, transportation infrastructure, and co-exposure to air pollution may influence the true magnitude of risk, a globally validated exposure-response function for environmental noise is not currently available. Consequently, the estimates presented should be interpreted as standardized, order-of-magnitude approximations intended to support broader planetary health policy discussions rather than precise global burden estimates. Similar increases were observed for cardiovascular morbidity and stroke-related outcomes, particularly among older adults [18].

Unlike previous air-pollution evaluations that relied on published mortality estimates, the present study derives mortality burden from the exposed population. Recent public health estimates suggest that approximately 90 million individuals reside in environments characterized by chronic road traffic noise levels between 60 and 70 dB, primarily in urban areas adjacent to major highways and heavily trafficked road networks [81]. Because the hazard ratio employed in the present study was derived from daytime road traffic noise exposure reported by Halonen et al. [18], the exposed population is interpreted as a simplified approximation of communities subjected to persistent road traffic noise rather than to mixed transportation, railway, construction, entertainment district, or aircraft noise. Consequently, the valuation framework should be interpreted as representing road traffic noise exposure consistent with the epidemiological evidence used to estimate mortality risk [81]. In the present study, this exposure is interpreted as long-term transportation-related environmental noise, consistent with the daytime road traffic exposure category used by Halonen et al. [18], who reported an all-cause mortality hazard ratio for populations exposed to daytime transportation noise exceeding 60 dB relative to individuals exposed to noise levels under 55 dB. Accordingly, the exposed population serves as a globally harmonized approximation for illustrating the economic implications of chronic transportation-related noise exposure rather than a precise estimate for any specific acoustic indicator or jurisdiction. This exposed population serves as the basis for the mortality valuation framework.

To estimate the proportion of mortality attributable to environmental noise exposure, an attributable-fraction approach is employed:

$$AF = \frac{HR - 1}{HR}$$

where

AF = attributable fraction;

HR = hazard ratio.

The attributable fraction is subsequently applied to mortality occurring within the exposed population:

$$D_n = P_e \times M \times AF$$

where

D_n = noise-attributable deaths;

P_e = exposed population;

M = annual mortality rate among the exposed population;

AF = attributable fraction.

This equation provides the bridge between epidemiological evidence and economic valuation by converting relative mortality risk into an estimate of deaths attributable to environmental noise exposure. Variables used previously are listed in Table 1.

Table 1. Variables and parameters used in the mortality estimation.

Variable	Description	Baseline Value	Source
HR	Hazard ratio for all-cause mortality associated with daytime road traffic noise >60 dB compared with <55 dB	1.04	Halonen et al. [18]
AF	Attributable fraction	Derived from the model	Calculated
P_e	Population chronically exposed to road traffic noise (approximately 60–70 dB)	90 million	Epidemiological estimates [81]
M	Annual mortality rate	0.8%	Demographic statistics [82]
D_n	Noise-attributable deaths	Derived from the model	Calculated
z	Remaining working years	35 years (10 & 20 years)	Jozaghi [20]; Jozaghi [83]; Jozaghi [84]
P	Average world income	US\$12,235	Jozaghi [20]; World Bank [85]
D	Discount rate	3% (1% & 5% for sensitivity)	Jozaghi [20]; OECD [86]
Vp	Discounted productivity value per death	Derived from the model	Calculated
VSL	Value of a Statistical Life	US\$12.78 million	OECD [86]; Jozaghi [20]; US EPA [87]

The use of a global crude mortality rate of 0.8% is intended to provide a simplified, internationally comparable approximation of annual mortality in the exposed population. Although age-specific mortality rates, cause-specific cardiovascular mortality, sex differences, labour-force participation, and demographic structure would improve the precision of country-specific estimates, such parameters are not consistently available for global populations exposed to chronic environmental noise. Accordingly, the proposed framework should be regarded as a preliminary, order-of-magnitude estimation model intended to illustrate the potential societal magnitude of mortality-related costs rather than as a comprehensive burden-of-disease or demographic life-table analysis. The use of a globally harmonized crude mortality rate reflects the absence of internationally comparable age-specific mortality, exposure, and life-table data for populations chronically exposed to road traffic noise and was adopted to maintain methodological transparency and comparability across the global valuation framework.

2.2. Variables and Parameters

The discounted productivity value per premature death (Vp) is estimated using the present value of future economic productivity:

$$Vp = \sum_{k=1}^z \frac{P}{(1 + D)^k}$$

where

$z = 35$ remaining working years;

$P = \$12,235$ average global income;

$D = 0.03$ discount rate.

Consistent with previous global economic evaluations, a remaining working life of 35 years and a 3% discount rate are assumed. The assumption of 35 remaining working years represents a simplified global approximation intended to facilitate international comparison rather than to reflect labour-force participation or retirement patterns in any individual country. Furthermore, the assumption should be interpreted as a stylized approximation rather than a prediction of the remaining working life for every individual experiencing noise-attributable mortality. Although epidemiological evidence suggests that mortality risks associated with environmental noise are often greater among older adults, globally comparable data linking age-specific mortality, employment probabilities, retirement age, and productivity losses are not consistently available. Consequently, the present model adopts a standardized working-life assumption to illustrate the potential magnitude of productivity losses within a transparent global valuation framework. While substantial regional variation exists in demographic structures and employment characteristics, the use of globally harmonized assumptions improves transparency and enables the estimated societal burden to be interpreted within a common analytical framework. Similar assumptions have been employed in public health, environmental health, and cost–benefit analyses. The model estimates the discounted value of lost economic productivity over an individual’s remaining working lifespan, rather than per year of income loss.

The overall economic cost arising from environmental noise exposure is estimated as

$$TC = D_n \times Vp$$

where

TC = total tangible cost;

D_n = estimated noise-attributable deaths;

Vp = discounted productivity value per premature death.

The approach is conceptually consistent with economic frameworks established by the World Bank and the Institute for Health Metrics and Evaluation (IHME), which distinguish between reductions in productivity and declines in social welfare attributable to noise-attributable deaths [18].

2.3. Intangible Cost

Beyond the direct economic consequences of lost productivity, the analysis also incorporates the societal value of mortality risk reductions using the VSL approach. The VSL technique is commonly used in environmental, transportation, and health-policy evaluations to assign a monetary value to changes in mortality risk [20]. Rather than measuring an individual’s economic output, VSL represents the monetary value that society assigns to small decreases in mortality risk as a monetary measure of the value individuals place on avoiding premature death, thereby indicating the social value placed on life-saving interventions.

To estimate these non-market costs, the study adopts a central VSL estimate of US\$12.78 million [20]. This value quantifies the broader welfare losses associated with deaths attributable to environmental noise exposure and complements the productivity-based estimates generated by the human-capital approach [20]. This value is consistent with estimates used by the United States Environmental Protection Agency (US EPA) and the OECD, as well as previous planetary health evaluations [20,83,84]. A universal VSL

cannot fully capture the substantial variation in purchasing power, income, and willingness to pay observed across countries [20,83,84]. Nevertheless, a standardized VSL was selected to facilitate international comparability and thereby avoid introducing additional uncertainty when country-specific valuation coefficients are applied across jurisdictions. Accordingly, the welfare values should be examined as globally standardized reference values rather than precise national economic valuations.

The total intangible cost is estimated as

$$IC = D_n \times VSL$$

where

IC = intangible cost;

D_n = estimated noise-attributable deaths;

VSL = statistical life value.

The present study reports productivity losses (tangible costs) and welfare losses (intangible costs) as complementary valuation approaches rather than mutually exclusive economic components. Because the VSL framework highlights society's valuation of mortality risk reduction and may implicitly capture elements of lost productivity and broader welfare, the two estimates are presented separately to avoid potential double counting. Consequently, the study does not recommend interpreting their arithmetic sum as a definitive estimate of total societal costs but rather as complementary perspectives for policy evaluation.

Substituting the epidemiological and economic components yields

$$TEB = \left(P_e \times M \times \frac{HR - 1}{HR} \right) \times (Vp + VSL)$$

This formulation explicitly links epidemiological risk, mortality estimation, and economic valuation into a single, integrated planetary health framework.

2.4. Sensitivity Analysis

In economic evaluation, sensitivity analysis is used to assess the robustness of findings under alternative assumptions and scenarios and to evaluate how changes in assumptions affect estimated outcomes. Consistent with previous economic evaluations, the sensitivity assessment pertains to both tangible and intangible valuation parameters [20,83,84]. For tangible costs, one-way sensitivity analyses examine the influence of alternative discount-rate and remaining working-life assumptions on discounted productivity estimates [20,82].

For intangible costs, lower and upper VSL estimates of US\$4.5 million and US\$16.5 million are employed [20,83,84]. These values provide conservative and upper-bound estimates of societal willingness to pay for mortality-risk reduction [20,83,84]. Together, these sensitivity analyses generate a range of potential economic burdens associated with environmental noise exposure and account for the uncertainty inherent in mortality valuation studies. To further evaluate the robustness of the productivity-loss model, an additional sensitivity estimation was conducted using alternative discount rates of 1%, 3%, and 5%. Under these assumptions, the estimated tangible value per premature death ranged from US\$359,814 at a 1% discount rate to US\$200,338 at a 5% discount rate, with the baseline 3% discount rate producing an estimated value of US\$262,896 per death. The lower-bound, baseline, and upper-bound scenarios presented in Table 2 examine the combined influence of alternative epidemiological and valuation assumptions on the estimated mortality burden. Separate one-way sensitivity analyses were subsequently conducted for the discount

rate and remaining working-life assumptions to evaluate the independent influence of these parameters on productivity-loss estimates.

Table 2. Sensitivity analysis assumptions used in the economic valuation model.

Scenario	Exposed Population (<i>P_e</i>)	Mortality Rate (<i>M</i>)	Hazard Ratio (<i>HR</i>)	Attributable Fraction (<i>AF</i>)	Value of Statistical Life (<i>VSL</i>)
Lower Bound	60 million	0.7%	1.02	1.96%	US\$4.5 million
Baseline	90 million	0.8%	1.04	3.85%	US\$12.78 million
Upper Bound	120 million	0.9%	1.07	6.54%	US\$16.5 million

Note. Productivity loss (*V_p*) and Value of a Statistical Life (*VSL*) estimates are presented as complementary valuation approaches and should not be interpreted as additive components of a single economic burden, as they represent conceptually distinct measures of societal loss.

Applying these estimates to the baseline mortality burden of 27,692 noise-attributable deaths yielded projected tangible costs ranging from US\$5.55 billion at a 5% discount rate to US\$9.96 billion at a 1% discount rate, while the baseline estimate remained US\$7.28 billion at a 3% discount rate. Because the remaining working-life assumption represents an important source of uncertainty, an additional sensitivity analysis was undertaken using alternative remaining working-life assumptions of 10 and 20 years, in addition to the baseline assumption of 35 years. These alternative scenarios were selected to reflect the possibility that a proportion of noise-attributable mortality may occur among older adults approaching or beyond retirement age. The purpose of this analysis is not to estimate age-specific productivity losses but to examine the sensitivity of the valuation framework to alternative assumptions about the working life. Although the sensitivity analysis explores uncertainty associated with income assumptions and mortality valuation, it does not fully capture regional differences in purchasing power, demographic structure, healthcare expenditure, or labour-force participation. These factors should therefore be incorporated into future country-specific economic evaluations.

2.5. Reliability and Validity

Reliability and validity are foremost considerations in economic evaluations [20,82–84,88–90]. Reliability refers to the consistency and reproducibility of the model, whereas validity concerns the extent to which the model accurately assesses the phenomenon under investigation [20,82–84,88–90]. The present framework follows principles outlined in previous methodological evaluations of economic modelling [20,82–84,88–90]. Several factors contribute to the reliability of the analysis, including the simplicity and transparency of the model; the use of published epidemiological and economic data; explicit reporting of assumptions and variables; the incorporation of sensitivity analyses; and consistency with previously published cost–benefit studies [20,82–84,88–90].

The reliability of the framework is strengthened by its transparent structure, explicit reporting of assumptions, use of published epidemiological and economic parameters, and sensitivity analyses examining key model inputs. These features facilitate reproducibility and allow the analytical framework to be independently replicated using alternative assumptions or updated parameter estimates. The validity of the model should be interpreted more cautiously. The framework is intended as an exploratory, order-of-magnitude valuation instead of a formally validated burden-of-disease framework. Although it relies on established epidemiological evidence linking environmental noise exposure with mortality risk and applies widely accepted economic valuation methods, the estimates have not been externally calibrated against independent national burden estimates or evaluated using alternative exposure-response functions.

Consequently, the results should be interpreted as standardized approximations intended to illustrate the potential societal magnitude of mortality-related costs rather than precise estimates of the global burden attributable to environmental noise. Future studies should compare the framework with country-specific burden estimates, incorporate meta-analytic or alternative epidemiological parameters, and undertake additional external validation and robustness testing.

3. Results

The results present model-based estimates of the mortality-related economic burden associated with chronic environmental noise exposure using published epidemiological hazard ratios and the valuation assumptions described in the Methods section. Table 3 summarizes the estimated annual mortality burden and corresponding economic costs under lower-bound, baseline, and upper-bound scenarios derived from the assumptions outlined in Table 2. Collectively, these model-based estimates illustrate that relatively modest increases in mortality risk can translate into substantial societal costs when applied to large populations chronically exposed to transportation-related environmental noise.

Table 3. Estimated annual mortality burden with separate tangible and VSL-based welfare valuations.

Scenario	Estimated Noise-Attributable Deaths	Tangible Costs	Intangible Costs
Lower Bound	8235	US\$2.17 billion	US\$37.06 billion
Baseline	27,692	US\$7.28 billion	US\$353.91 billion
Upper Bound	70,654	US\$18.58 billion	US\$1.17 trillion

Using the baseline scenario described in Table 2, approximately 90 million individuals were assumed to live in environments with typical noise exposure ranging from 60 to 70 dB. Applying the risk-transfer hazard ratio to the assumed exposed population yielded an illustrative estimate of approximately 27,692 annual attributable deaths (Table 3). Although this mortality burden is considerably lower than that associated with major air pollutants, it nevertheless represents a meaningful source of preventable mortality given the widespread prevalence of transportation-related noise exposure in urban environments. Sensitivity analyses using alternative assumptions about remaining working life demonstrated that the productivity-loss estimates varied in proportion to the assumed remaining working years. As expected, shorter working-life assumptions reduced the estimated tangible costs while leaving the VSL-based welfare estimates unchanged. These findings indicate that the productivity-loss component is sensitive to assumptions regarding remaining working life, whereas the broader welfare valuation remains substantially larger across all scenarios.

The estimated tangible economic burden associated with these deaths is approximately US\$7.28 billion annually (Table 3). These costs reflect forgone productivity and economic output resulting from noise-attributable mortality and are based on discounted lifetime earnings over the remaining working lifespan. While tangible costs constitute only a portion of the overall burden, they illustrate that environmental noise exposure imposes measurable economic consequences beyond its direct impacts on overall well-being and health. The estimated VSL-based welfare valuation is substantially larger than the productivity-loss estimate. Under baseline assumptions, welfare losses projected using the VSL framework are approximately US\$353.91 billion annually (Table 3).

As in previous environmental-health evaluations, intangible costs account for most of the cost because they capture society's valuation of mortality-risk reduction rather than solely of lost productivity. Sensitivity analyses demonstrate considerable variation depending on assumptions about exposure prevalence, mortality risk, income levels, valuation

of mortality risk, and discount rates applied to future productivity losses. An additional sensitivity analysis examined the effect of alternative assumptions about remaining working life while holding all other model parameters constant, as shown in Table 4. Assuming 10 remaining working years, the discounted productivity value per premature death was reduced to US\$104,367, resulting in an estimated tangible economic cost of US\$2.89 billion under the baseline mortality scenario. Assuming 20 remaining working years, the productivity value per death increased to US\$182,026, corresponding to tangible costs of US\$5.04 billion. The baseline assumption of 35 remaining working years yielded a discounted productivity value of US\$262,896 per premature death and total tangible costs of US\$7.28 billion. These findings indicate that the productivity-loss component is sensitive to assumptions regarding remaining working life, while the substantially larger VSL-based welfare estimates remain unchanged across these scenarios.

Table 4. One-way sensitivity analysis: remaining working-life assumptions.

Remaining Working Years (z)	Discounted Productivity Value per Death (V_p)	Baseline Noise-Attributable Deaths	Tangible Economic Cost
10 years	US\$104,367	27,692	US\$2.89 billion
20 years	US\$182,026	27,692	US\$5.04 billion
35 years (Baseline)	US\$262,896	27,692	US\$7.28 billion

The findings presented in Tables 4 and 5 further highlight the uncertainty inherent in global mortality valuation and demonstrate that environmental noise remains associated with substantial societal costs across all scenarios examined.

Table 5. One-way sensitivity analysis: discount rate.

Discount Rate	V_p	Tangible Cost
1%	US\$359,814	US\$9.96B
3%	US\$262,896	US\$7.28B
5%	US\$200,338	US\$5.55B

Overall, the results suggest that environmental noise should not be viewed solely as a nuisance or quality-of-life concern. Rather, the findings indicate that chronic exposure to elevated transportation-related noise may generate significant health, economic, and welfare consequences. Through the lens of planetary health, the estimated burden reinforces the growing recognition that environmental noise is a multidimensional challenge affecting population health, societal well-being, and economic productivity. Consequently, the estimated mortality burden provides an economic rationale for evaluating environmental noise-reduction policies. However, the present analysis does not assess the effectiveness, implementation costs, or cost-effectiveness of specific interventions.

4. Discussion

The present study evaluates mortality linked with chronic environmental noise exposure from a planetary health perspective. The present valuation represents only one component of the broader planetary health burden associated with environmental noise. The reported findings indicate that environmental noise is linked with substantial societal costs, including baseline productivity losses of approximately US\$7.28 billion and corresponding VSL-based welfare losses of approximately US\$353.91 billion annually. Although these estimates are lower than those associated with major air pollutants, they nevertheless indicate that environmental noise represents a meaningful public health, economic, and environmental challenge [20].

Importantly, the findings extend beyond conventional discussions of annoyance and quality of life. A growing list of evaluations of evidence highlights environmental noise to heart disease, hypertension, sleep issues, mental disturbances, limited cognitive performance, and deaths [18,39,40,60]. Like air pollution, the adverse effects of noise accumulate over time through repeated physiological stress responses, chronic sleep disruption, and cardiovascular strain [41–45,61]. Consequently, environmental noise may be understood as an underappreciated contributor to chronic disease burden within modern industrial societies.

When viewed through a planetary health lens, the results highlight the close relationship between environmental pressures and human health outcomes and economic productivity. Anthropogenic noise affects wildlife communication, reproduction, migration, disease susceptibility, and ecosystem functioning, while also contributing to adverse health outcomes in humans [3–8]. The findings therefore support the growing recognition that environmental noise is a multidimensional externality affecting biodiversity, population health, societal well-being, and economic resilience [1–8]. Like air pollution and climate-related environmental degradation, noise pollution imposes costs that are largely borne by society rather than by those generating the exposure [20].

The findings also have important implications for public policy. Although the present valuation broadly encompasses transportation-related environmental noise, one illustrative example of a potentially preventable source is the intentional amplification of vehicle exhaust systems. Intentionally amplified vehicle exhaust systems are an illustrative example of a preventable source of discretionary environmental noise, as such noise arises from modifiable behaviours and equipment rather than essential transportation functions; they provide a potential target for public-health interventions. Emerging psychological research has reported associations between preferences for intentionally amplified vehicle noise and certain personality characteristics in specific study populations [68–70]. However, these findings should be interpreted with caution and not generalized to the broader population of vehicle owners. Within the context of the present study, they are presented solely as one possible behavioural explanation for a subset of discretionary vehicle-noise emissions rather than as an explanation for transportation-related noise more broadly.

Consequently, stronger enforcement measures by law enforcement and bylaw officers may represent a promising harm-reduction strategy for reducing unnecessary transportation-related noise exposure. Like speed cameras, red-light cameras, and impaired-driving enforcement, automated noise-camera technologies offer a potential means to improve compliance with existing vehicle-noise regulations while minimizing demands on policing resources and taxpayers [63–66]. Municipal pilot programs in Toronto, Ottawa, Edmonton, and several European jurisdictions suggest that automated acoustic-monitoring systems may offer an efficient means of identifying vehicles that exceed established noise thresholds [63–66]. Because noise violations frequently occur at night, when enforcement resources are limited and sleep disruption is most harmful, automated monitoring may be particularly useful for reducing repeat offences and protecting community well-being [44,61]. However, the present study did not evaluate the implementation costs, effectiveness, or cost-effectiveness of these interventions. Future economic evaluations should examine whether the health and welfare benefits associated with reduced environmental noise outweigh the costs of implementing such programs.

Like regulatory approaches applied to illegal emissions modifications and environmental violations, mandatory minimum financial penalties for automotive businesses that install prohibited exhaust systems may help reduce the supply of noise-amplifying modifications [62,67]. Such measures may be particularly important because enforcement focused exclusively on drivers may fail to address the commercial incentives that facilitate

repeated violations. Licensing consequences, escalating fines, and mandatory compliance inspections may further strengthen deterrence and improve compliance. Vehicle manufacturers also serve an important function. The increasing availability of electronically controlled exhaust systems that switch between quiet, medium, and loud operating modes raises important questions regarding product design and public health responsibility [62]. Governments may therefore wish to consider stricter regulations on maximum permissible vehicle noise levels, restrictions on variable exhaust technologies, and enhanced certification standards for new vehicles. Similar regulatory approaches have successfully reduced vehicle emissions and improved automotive safety over time. Given the growing evidence linking environmental noise to adverse health outcomes, comparable regulatory attention may be warranted for excessive vehicle noise [18,39–45,60,61].

The economic estimates generated in this study suggest that even modest reductions in environmental noise exposure could yield substantial public-health and economic benefits. Previous cost–benefit analyses have reported favourable economic returns for several noise-abatement interventions. However, the present study did not evaluate implementation costs or intervention effectiveness and therefore cannot determine whether these findings would apply to the scenarios examined here [17,72–74]. Previous cost–benefit analyses have consistently demonstrated that noise-abatement programs yield positive net benefits, suggesting that environmental noise reduction should be considered not only as a public health intervention but also as an economically rational policy objective [17,72–74].

More broadly, the findings support the integration of environmental noise into planetary health and sustainability frameworks. Historically, environmental policy has prioritized visible pollutants such as smoke, particulate matter, and contaminated water. However, the evidence reviewed in this study suggests that environmental noise also warrants recognition as a significant environmental stressor affecting both ecological and human systems [3–8,35,36]. As urban populations continue to expand and transportation networks become increasingly concentrated, addressing environmental noise may become an increasingly important component of creating healthier, more sustainable, and more resilient communities while reducing health care cost burden [1,2,20].

5. Limitations and Future Research

Interpretation of the findings should consider several limitations. First, the valuation framework intentionally adopts harmonized assumptions regarding remaining working life, average income, and the VSL globally to provide a transparent order-of-magnitude estimate of the potential societal burden associated with environmental noise. Consequently, the model does not account for regional differences in purchasing power, demographic structure, labour-force participation, healthcare expenditures, retirement age, environmental regulation, or transportation systems. While these simplifying assumptions improve comparability across populations, they inevitably limit the precision of country-specific estimates. Therefore, the findings should be interpreted as globally standardized approximations intended to support planetary health policy rather than precise national economic valuations. Furthermore, the model does not incorporate age-specific life tables, sex-specific mortality rates, survival probabilities, or cause-specific cardiovascular mortality, all of which may influence the estimated number of attributable deaths. Future research should integrate these demographic parameters into more sophisticated mortality models to improve the epidemiological precision and economic valuation of environmental noise.

The results should be viewed as exploratory, order-of-magnitude estimates because they quantify only mortality-related costs and exclude numerous additional ecological, societal and health impacts linked with environmental noise. The epidemiological component of the present valuation represents a risk-based-transfer scenario. Consequently,

the evaluation should not be examined as a direct measurement of the worldwide burden of environmental noise. Future studies should develop region-specific and meta-analytic exposure-response functions to improve the geographic applicability of mortality-based economic valuations. At the same time, several simplifying assumptions—including the use of globally harmonized parameters and a representative epidemiological hazard ratio—introduce uncertainty that may either underestimate or overestimate the true economic burden. Accordingly, the reported values should be examined as a cautious projection of the broader societal load associated with environmental noise exposure. In addition, the exposed population estimate represents a globally harmonized approximation and does not distinguish among specific acoustic metrics (e.g., daytime, nighttime, or day-evening-night noise indicators), transportation modes, or regional exposure distributions. Moreover, the mortality hazard ratio was derived from a large cohort and may not be directly generalizable to populations with different demographic characteristics, environmental exposures, transportation systems, or healthcare contexts.

The present framework is limited to road traffic noise because the epidemiological hazard ratio was derived from a road traffic cohort. Separate exposure-response functions for aircraft, railway, industrial, entertainment district, and mixed transportation noise should be incorporated in future economic evaluations as additional epidemiological evidence becomes available. Future studies should incorporate meta-analytic exposure-response functions or region-specific hazard ratios as additional epidemiological evidence becomes available. Future research should thus develop more comprehensive disease burden frameworks that incorporate morbidity, disability, healthcare expenditures, quality-adjusted life years, and ecosystem impacts associated with chronic noise exposure. Additional studies are needed to evaluate the cost-effectiveness of specific interventions, including automated noise-camera enforcement systems, stricter vehicle-noise regulations, quieter transportation technologies, and urban design strategies to reduce environmental noise.

Future research should also incorporate more comprehensive uncertainty analyses by evaluating the independent influence of individual model parameters through one-way sensitivity analyses, tornado diagrams, and probabilistic techniques such as Monte Carlo simulation. Such approaches would enable a more detailed assessment of parameter uncertainty and improve the robustness of future global and country-specific economic valuations of environmental noise. Finally, comparative international analyses may help identify best practices for balancing transportation needs, economic development, public health, and environmental sustainability within a planetary health framework.

6. Conclusions

Noise linked to industrialization is increasingly highlighted as a key planetary health concern, with consequences that extend beyond mere annoyance and diminished quality of life. By integrating published epidemiological evidence with established economic valuation methods, the present study provides an exploratory, order-of-magnitude assessment of the potential mortality-related economic consequences of chronic exposure to transportation-related environmental noise. Under the assumptions adopted in the present framework, estimated productivity losses vary from approximately US\$2.17 billion to US\$18.58 billion, while corresponding welfare losses vary from about US\$37.06 billion to US\$1.17 trillion.

The evidence suggests that environmental noise is not merely a nuisance but an externality affecting human well-being, economic productivity, publicly funded programs (e.g., health and social services), biodiversity, and societal well-being. From a harm-reduction perspective, interventions such as automated noise-camera enforcement, stricter vehicle-noise regulations, improved urban planning, and greater accountability for illegal exhaust

modifications and manufacturers represent potential policy options whose effectiveness and cost-effectiveness should be evaluated in future research.

As with air pollution, the present valuation suggests that chronic environmental noise may impose substantial societal costs, largely borne by society and taxpayers rather than by those creating the exposure. The estimated economic burden highlights the potential value of evaluating noise-reduction strategies in the environment, although quantifying the economic and health benefits of specific interventions was beyond the scope of this study. At a broader level, the findings highlight the need to more fully incorporate transportation-related environmental noise into planetary health frameworks and reinforce the importance of policies that promote healthier, quieter, and more sustainable communities.

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Abbreviations

OECD	Organization for Economic Co-operation and Development
IHME	Institute for Health Metrics and Evaluation
US EPA	United States Environmental Protection Agency
VSL	Value of a Statistical Life
WTP	Willingness to pay

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