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Environmental Transport Noise and Health: Evidence from Ireland (Noise–Health)

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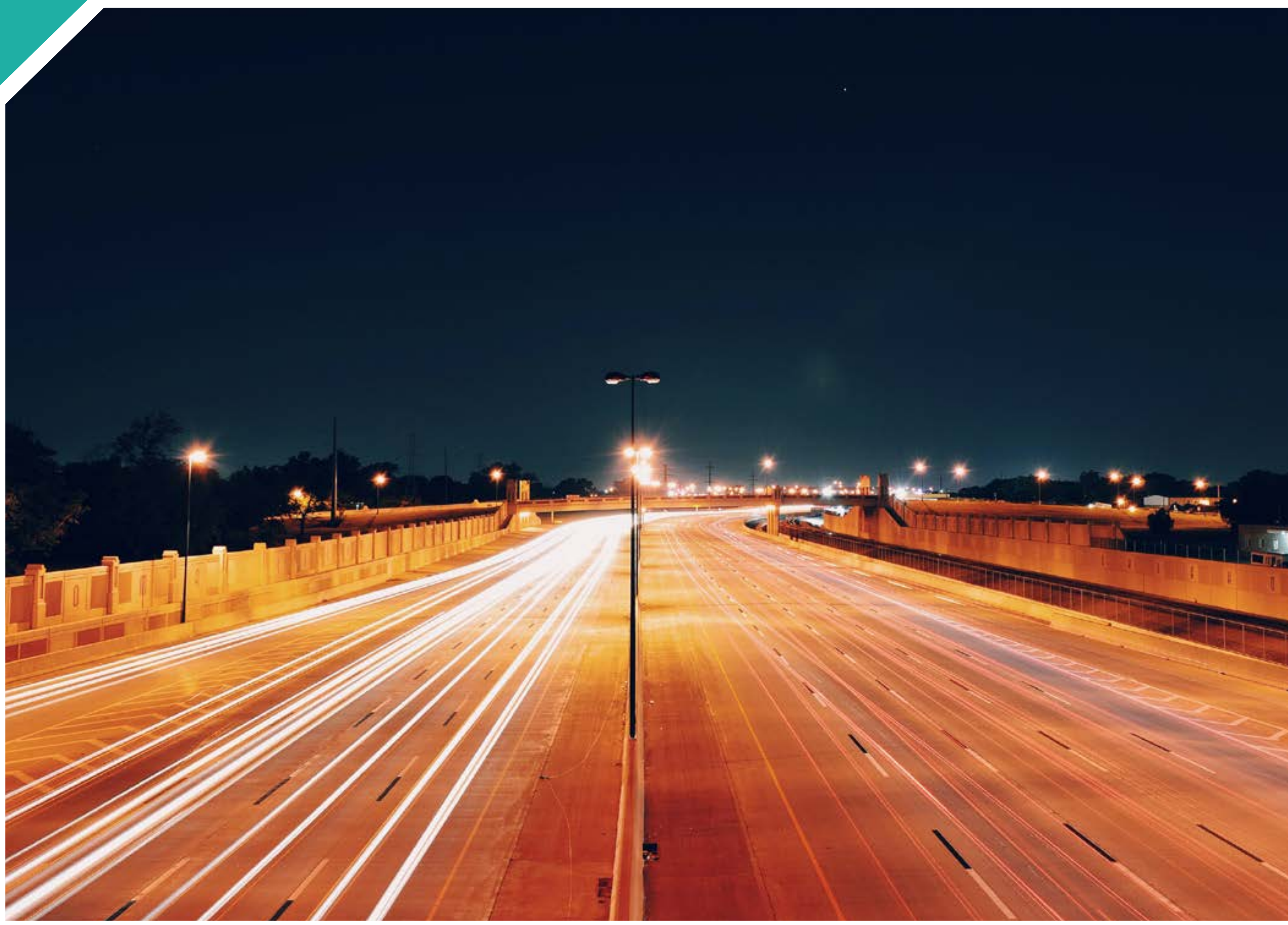

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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> Prosecute those who flout environmental law and damage the environment.

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> Oversee the implementation of the Environmental Noise Directive;
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2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2021–2030

Environmental Transport Noise and Health: Evidence from Ireland (Noise–Health)

(2017-HW-MS-10)

EPA Research Report

Prepared for the Environmental Protection Agency

by

University College Dublin and The Economic and Social Research Institute

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The Noise–Health Ireland project aimed to identify and assess the relationship between environmental noise and health in a national and international context and identify policy recommendations for considering noise in Irish policy. The principal output of the project related to the establishment of a national evidence base for the harmful effects and burden of disease of environmental noise in Ireland, informed by high-quality data analysis coupled with recommendations for policy and practice. This final project report summarises the main research findings and recommendations associated with the Noise–Health project.

Chapter 2 describes the key mechanism through which environmental noise is understood to affect physiological response and summarises the evidence linking environmental noise exposure to annoyance, sleep disturbance and cardiovascular disease. The chapter also presents a "matrix of association", which synthesises the "strength of current evidence" for associations between wide-ranging health outcomes and exposure to environmental noise from road, air and rail sources.

Chapter 3 examines the relationships between noise exposure and Irish health data. The analysis enhances the evidence base regarding the association between environmental noise exposure and various health and wellbeing outcomes. Methodological contributions include:

- Noise pollution data are spatially linked to Irish health data.
- Socio-demographic and behavioural characteristics are accounted for.
- Analysis focuses on an older population (a cohort not extensively studied in the literature).
- The possible confounding effects from air pollution are factored into the analysis.

Chapter 4 provides a national estimate of the harmful effects and burden of disease from environmental noise in the Irish population for 2017, the latest year for which population exposure statistics are available. From an international perspective, this analysis represents the first estimate of harmful effects from environmental noise in Europe at the time of writing, while, nationally, it is the first estimation of burden of disease from environmental noise in Ireland. The analysis is particularly relevant, since Commission Directive (EU) 2020/367 suggests that harmful effects assessment may be a legal requirement for all EU Member States as part of the strategic noise mapping process from 2022 onwards. As such, the chapter:

- provides an analysis of current approaches internationally for estimating harmful effects/burden of disease from environmental noise;
- assesses the appropriateness of various approaches; and
- produces an assessment of harmful effects and disease burden for noise-induced ischaemic heart disease, high annoyance and high sleep disorder.

The chapter also provides several recommendations, including (1) to apply the harmful effects method rather than the burden of disease method; (2) to use incidence statistics over prevalence statistics in the assessment of risk; (3) to include a more extensive road network in future rounds of strategic noise mapping; (4) to suggest that it might be worth reconsidering population exposure statistics for aircraft noise in Ireland, since, unlike road and railway sources, results diverge dramatically from international comparisons; (5) to recommend that, if required, disability weight and duration of disability statistics should be acquired from the latest World Health Organization (WHO) publications; and (6) to recommend that relative risk and absolute risk statistics should be acquired from the latest WHO publications.

Chapter 5 presents a discussion regarding how EU-level Environmental Noise Directive-related policy and practice and national policy and practice currently operate in relation to the management of environmental noise in Ireland. Accordingly, in relation to EU-level-related policy and practice, the chapter focuses on the European policy context, limit values, quiet areas and public engagement; in relation to

national policy and practice, the chapter focuses on the Irish policy context, road source selection in the strategic noise mapping process, the requirement for centralisation in the strategic noise mapping process, noise management policy and practice in the Irish planning system, and the EPA Industrial Emissions Directive licensing system in relation to industrial noise assessment. Associated recommendations are provided in the final chapter.

Chapter 6 concludes this final project report by outlining key recommendations regarding how national policy and practice can be improved in relation to the management of environmental noise in Ireland and how "noise–health" considerations can be better incorporated in Irish policy. These recommendations aim to strengthen the capacity of Irish policymakers to design, apply and supervise effective and systematic policies for environmental noise in Ireland.

1 Introduction

1.1 The Noise–Health Project

The Noise–Health project aims to identify and assess the relationship between environmental noise and health in a national and international context and identify policy recommendations for considering noise in Irish policy. The principal output of the project relates to the establishment of a national evidence base for the harmful effects and burden of disease arising from environmental noise in Ireland.

The project comprises four work packages (WPs):

- WP 1 – Review of current state of knowledge;
- WP 2 – Noise and health: investigating causal relationships using Irish health data;
- WP 3 – Quantifying the harmful effects and burden of disease from environmental noise in Ireland;
- WP 4 – From knowledge to practice.

The specific objectives of the study are:

- to provide a state of knowledge review of the relationship between environmental noise and health and wellbeing;
- to combine noise modelling and health microdata to examine causal relationships between noise exposure and health and wellbeing outcomes at the city-wide scale for Dublin and Cork;
- to provide a national estimate of the harmful effects and burden of disease from environmental noise in disability-adjusted life years (DALYs);
- to develop recommendations and guidelines for the integration of noise considerations into relevant policy streams;
- to build capacity, knowledge and awareness among key professional stakeholders of the relationship between noise from transport and health and wellbeing.

The purpose of this document is to provide a final project report summarising the main research findings and recommendations associated with the Noise–Health project, cofunded by the Environmental Protection Agency (EPA) and the Health Service Executive. This document is intended to provide an evidence base for understanding the risk to public health from population exposure to environmental noise from transport sources. The report addresses concepts associated with the noise–stress relationship, dose–effect relationships and health-promoting environments in cities as a means to inform policy and practice and to improve health and wellbeing across urban and rural spaces.

1.2 Structure of the Report

The structure of this report proceeds as follows:

- Chapter 2 provides a summary review of the current state of knowledge for noise–health relationships. This includes exploring the evidence base linking environmental noise exposure and health and wellbeing. In this regard, the physiological response to environmental noise is explained, as is the relationship between environmental noise and annoyance, sleep disturbance and cardiovascular disease. In addition, the evidence base relating to noise mitigation and abatement strategies is also outlined.
- Chapter 3 outlines a summary of an urban-based analysis investigating the causal relationships between environmental noise and health using data from The Irish Longitudinal Study on Ageing (TILDA). The analysis was conducted to contribute to the evidence on the association between environmental noise exposure and various health and wellbeing outcomes.
- Chapter 4 summarises the results from an analysis regarding the quantification of harmful effects and burden of disease from environmental noise in Ireland. The analysis provides a national benchmark analysis focusing on noise-induced ischaemic heart disease (IHD), annoyance and sleep disturbance.
- Chapter 5 discusses how EU-level Environmental Noise Directive (END)-related policy and practice and national policy and practice currently operate in relation to the management of environmental noise in Ireland.
- Chapter 6 concludes this final report document by outlining key recommendations in relation to how national policy and practice concerning the management of environmental noise in Ireland can be improved.

2 Environmental Noise and Health

2.1 Introduction

Noise is ubiquitous, particularly in urban areas, and is an important feature of daily living and activity. However, noise can result in both auditory and non-auditory negative health outcomes and is a serious risk to public health and wellbeing. The auditory effects of noise on human health have been studied extensively, and there exists widespread awareness of the molecular functions, systems and structures responsible for auditory conditions such as tinnitus, hearing loss and nerve damage (Basner *et al.*, 2014). Such negative auditory effects can occur at noise levels over 75–85 decibels (dB) ($L_{eq,8hr}$)[1] and can be caused by a one-off extreme impulse noise or noise of prolonged duration, which usually occurs in an occupational or industrial setting (U.S. Department of Health and Human Services, 1998). A much more common source of noise, and one less understood in terms of its negative impact on public health, is environmental noise and the non-auditory effects associated with it. Environmental noise is defined by the World Health Organization (WHO, 1999, p. 1) as "noise emitted from all sources, except noise at the industrial workplace", with sources including "road, rail, air traffic, industries, construction and public work, and the neighbourhood". In relation to health, the negative outcomes of environmental noise are typically non-auditory because levels tend not to exceed 75 dB for continuous periods. Since the publication of the World Health Organization (WHO) *Guidelines for Community Noise* in 1999 (WHO, 1999), the *Night Noise Guidelines for Europe* in 2009 (WHO, 2009) and the *Burden of Disease from Environmental Noise* in 2011 (WHO, 2011), there has been substantial progress in the study of non-auditory health-related outcomes associated with the impact of environmental noise on populations. As a result, the understanding of how, and the extent to which, environmental noise affects public health has advanced considerably in recent years. In response to such developments, WHO recently published new noise guidelines for the European region which update its recommendations regarding environmental noise in Europe (WHO, 2018). Such revisions were urgently required since an estimated 65 million people in Europe are exposed to levels of environmental noise that exceed previous WHO (1999) recommended levels (Pershagen *et al.*, 2017).

According to the European Environment Agency (EEA), the four main sources of environmental noise disturbance in urban areas in Europe, in terms of extent, are road traffic noise, railway noise, aircraft noise and industrial noise (EEA, 2017). In terms of the severity of disturbance caused by environmental noise, the majority of existing research indicates that aircraft noise causes the most severe disturbance, followed by road traffic noise, railway noise and industrial noise (Seidler *et al.*, 2017). Owing to its prevalence, as well as the relative severity of disturbance associated with it, road traffic noise is the most researched environmental noise source in relation to negative impacts on public health. In this context, it is estimated that half of the population of the European Union is exposed to levels of road traffic noise considered sufficient to have negative impacts on health and wellbeing (Weyde *et al.*, 2017), with road traffic noise considered the second most prevalent environmental risk, after fine particle pollution, to human health in Europe (Hänninen *et al.*, 2014).

An increasing number of studies have examined the impact of transport noise, largely in the context of road traffic noise, and its association with annoyance (e.g. Kluizenaar *et al.*, 2011), sleep disturbance (e.g. Halonen *et al.*, 2012) and incidence of cardiovascular disease (e.g. Ndrepepa and Twardella, 2011). More recent research has extended the investigation to include associations with respiratory conditions (e.g. Carey *et al.*, 2016), diabetes (e.g. Ashin *et al.*, 2018), obesity (e.g. Christensen *et al.*, 2015), immune system dysfunction (e.g. Kim *et al.*, 2017), cognitive impairment and psychological stress (e.g. Seidler *et al.*, 2017) and fetal and childhood development (e.g. Gupta *et al.*, 2018), with emerging literature proposing a potential link between environmental noise and cancer, with particular focus

1 An 8-hour equivalent continuous A-weighted sound pressure level in decibels [dB(A)].

on breast and colorectal cancer at this initial stage of research (e.g. Hansen, 2017).

2.2 The Physiological Response to Environmental Noise

In terms of physiology, the non-auditory effects of environmental noise, as mediated by sleep disturbance and stress-related annoyance,[2] cause a physiological response to stress. This physiological response is generated as an immediate stress response by the sympathetic–adrenal–medullary (SAM) axis. The SAM axis produces catecholamines (Aich *et al*., 2009) and, as a prolonged stress response, the hypothalamic–pituitary–adrenocortical (HPA) axis produces glucocorticoids, including cortisol (Wallas *et al*., 2018). To visually represent causal pathways of physiological response, a flow diagram has been developed to describe noise–health relationships, informed by the most up-to-date evidence (see Figure 2.1).

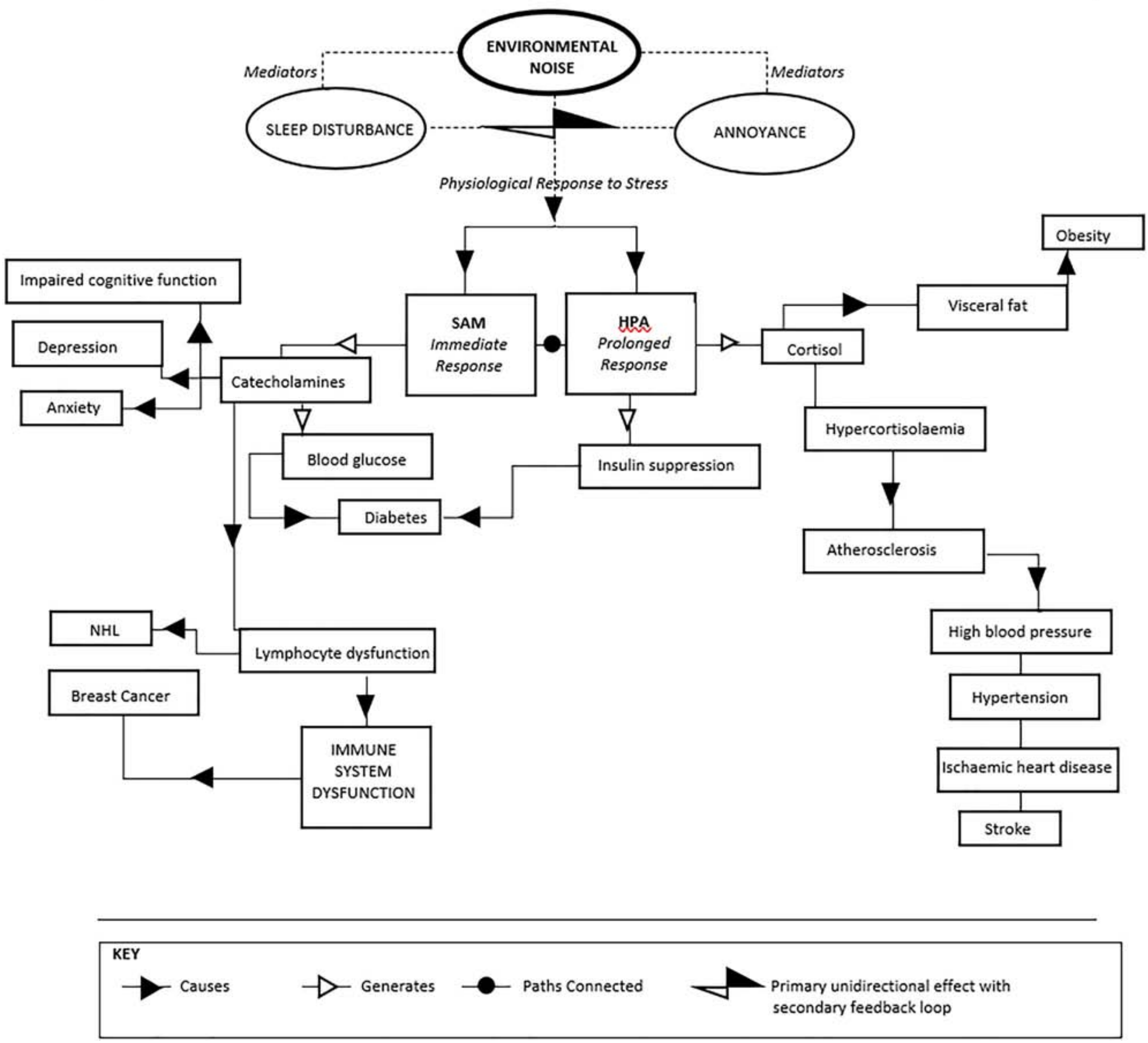

Figure 2.1. Physiological response to environmental noise

2 Environmental noise is believed to be mediated indirectly through sleep disturbance and annoyance, which causes a physiological response (Héritier *et al*., 2014; Riedel *et al*., 2015). It is also likely that perceived annoyance is primarily the result of sleep disturbance (Prather *et al*., 2012); however, perceived annoyance may also feed back into sleep disturbance in a cyclical fashion.

Catecholamines include adrenaline (epinephrine), noradrenaline (norepinephrine) and dopamine. These chemicals function as neurotransmitters, transmitting signals from neuron to neuron, and as hormones, regulating a variety of physiological functions such as those relating to the cardiovascular and respiratory systems. Catecholamines and cortisol stimulate energy resources and increase blood glucose, which has been primarily associated with the metabolic dysfunction that causes and exacerbates diabetes (Recio *et al*., 2016). The overproduction of cortisol, which is a long-term stress response to prolonged exposure to environmental noise and/or disruption of recuperative sleep, leads to the accumulation of high levels of cortisol. This process is known as hypercortisolaemia (Tobías *et al*., 2015) and ultimately results in atherosclerosis (Recio *et al*., 2016), which is the main pathology associated with a number of cardiovascular complications including high blood pressure, hypertension, IHD and stroke. Cortisol overproduction also increases the retention of visceral fat in adipose depots (Pyko *et al*., 2015) resulting in an increased risk of obesity, which in turn increases the risk of diabetes. As previously outlined, cortisol also increases blood glucose, but the HPA axis is also responsible for insulin suppression (Recio *et al*., 2016), which again increases the risk for diabetes.

2.3 Annoyance

Noise-induced annoyance, as it is presented in scientific research, is a retrospective evaluation based on previous experience over a certain period of time (Guski *et al*., 2017). The experience is generally conceived as the regular disruption of daily activities taking place within the home, such as verbal communication, working, watching TV, listening to music, reading or sleeping (Schultz, 1978). The experience elicits a psychological response consisting of the disturbing and frustrating realisation that one cannot influence the cause of disturbance, which can manifest in an emotional and/or attitudinal response (Guski, 1999). According to WHO (2011), 25% of Europe's population living in agglomerations of over 250,000 inhabitants are highly annoyed by road traffic noise exceeding 55 dB L_{den} (the equivalent noise level over a whole day but with penalties for night-time and evening noise). In general, studies concerning the relationship between environmental noise and annoyance tend to report that exposure to aircraft noise causes the highest annoyance response, followed by road traffic noise and lastly railway noise. For example, in an analysis of 823 participants in eight metropolitan regions in France, Gille *et al*. (2017) found that aircraft noise was reported to be the most annoying, followed by road traffic noise and finally railway noise. In addition, in a study investigating the cumulative impact of transport noise on a population of 10,000 in the Frankfurt Rhine-Main metropolitan district of Germany, Wothge *et al*. (2017) found that aircraft noise was significantly more annoying than either road traffic or railway transport noise at a standardised sound level, in terms of loudness and frequency, suggesting that the perception of noise annoyance is heavily influenced by average sound pressure. Such conclusions are also reflected in recent research by Sung *et al*. (2016), who analysed noise annoyance among a stratified random sample of 2000 participants of the metropolitan regions of Seoul and Ulsan in South Korea.

In a study of 2612 participants in Malmö, Sweden, Bodin *et al*. (2015) found that, at levels of between 45–54 dB, railway noise was significantly less annoying than traffic noise, but that there was no significant difference between noise sources at higher noise levels. Such findings suggest that future research analysing the impact of transport noise on health should incorporate specific sound indicators. In summary, it may be concluded that the experience of annoyance is most severe in the case of aircraft noise, followed by road traffic noise and, finally, railway noise, not necessarily because of the level of noise emitted from each source, but due to the character of the noise and the frequencies that characterise each noise source. For instance, the sudden rise time and intermittent pattern of aircraft noise can be more annoying than the background hum of road traffic noise. Nevertheless, exposure to road traffic noise is the most problematic source in metropolitan regions, simply because of its pervasiveness. In a study of environmental noise disturbance experienced by 4336 participants in Montreal (Ragettli *et al*., 2016), road traffic noise was reported to be the main cause of self-reported annoyance, followed by aircraft noise, with proximity to the noise source significantly increasing the risk of annoyance, which corresponds with the findings of established research (e.g. Di *et al*., 2012). Furthermore, it seems that the public is increasingly aware of the effect of noise-related annoyance on health. Okokon *et al*. (2015), in a study of 1112 randomly selected participants in Finland, found that a higher proportion of participants (17%) perceived themselves to be adversely affected by road traffic noise than by traffic exhaust pollution (13%). In fact, Okokon *et al*. (2015) found that 80% of Finnish participants reported being adversely affected by road traffic noise.

It has been long established, and is intuitive, that housing quality (i.e. quality of insulation) and the layout of rooms, particularly bedrooms (i.e. proximity to noise), have impacts on noise-related annoyance (e.g. EEA, 2014). Rasmussen and Ekholm (2015) found that Danish participants living in multistorey dwellings were more likely than participants living in other dwellings to report annoyance due to traffic noise (15.6% vs 10%, respectively). In relation to the interior composition of dwellings, Bodin *et al*. (2015) found that participants with windows facing open spaces such as gardens self-reported significantly lower annoyance from traffic noise and were less likely to experience issues with concentration than participants with windows that were more exposed to the noise source. If the dwelling contained no windows with access to open space, the likelihood of annoyance from traffic noise increased from between 32% to 50% (Bodin *et al*., 2015).

The subjective nature of noise-related annoyance lies at the heart of the complexity associated with the phenomenon. However, the subjective nature of annoyance is also its most important aspect in respect of understanding the dynamics involved in the noise–annoyance relationship. The subjective experience of annoyance, as well as the physiological response, is known to vary among participants exposed to standardised levels of traffic noise, when all other potentially confounding indicators (e.g. tenure, socio-demographics) are accounted for (Elmenhorst *et al*., 2016). This suggests that individual sensitivity to noise plays a fundamental role in determining noise-related annoyance.

Griffiths and Langdon (1968) define noise sensitivity as a highly subjective individual characteristic which predisposes one individual to experience more annoyance from environmental noise than another individual exposed to the same level and frequency of sound. However, studies are conflicted regarding the relationship between noise sensitivity and health. Although Ljungberg and Neely (2007), in a simulated study of exposure to noise from forestry vehicles, found no difference in cortisol levels between noise-sensitive and non-sensitive participants, Heinonen-Guzejev *et al*. (2004) found that noise-sensitive participants were more likely to experience hypertension, emphysema and stress, while Stansfeld (1992) suggests that noise-sensitive individuals are more predisposed to psychiatric disorders. Research has also suggested that noise sensitivity is closely correlated with sleep disturbance (Marks and Griefahn, 2007). According to Gille *et al*. (2017), noise sensitivity has a stronger effect than noise exposure on annoyance caused by transport noise. Overall, such research indicates that noise sensitivity should be included, if available, as an independent indicator in further studies examining the impact of noise on health.

Using both objective and subjective measurements and differentiating between the impacts of traffic noise on annoyance and sleep disturbance, Frei *et al*. (2014) found that the impact of traffic noise on objective measurements of sleep was independent of subjective measurements of noise annoyance. In fact, the level of objective sleep disturbance was found to be even more significant for those who reported that they were **not** annoyed by traffic noise (Frei *et al*., 2014). On the other hand, subjective measurements of sleep disturbance were found to be predicted by annoyance. This association between self-reported sleep disturbance and noise-related annoyance was found in previous laboratory-based research by Pirrera *et al*. (2010) and Jakovljevic *et al*. (2009). However, the fact that annoyance was found to be highly correlated with subjective measurements of sleep disturbance, but not with objective measurements, is noteworthy. One possible explanation for this disparity may be related to the hypothesis that perceived annoyance is actually the result of sleep disturbance, as indicated in research by Fyhri and Klæboe (2009). The disparity may also be related to the more general correlation between long-term habituation and annoyance rather than the difference between objective and subjective measurements per se. This is because objective measurements of environmental noise and health outcomes tend to be employed in laboratory-based cross-sectional studies, whereas subjective measurements tend to implement more longitudinal approaches (Riedel *et al*., 2015).

Such methodological differences may also contribute to the fact that perceived annoyance tends to be more closely related to adverse health pathologies than are objective measurements (Dratva *et al*., 2010). Such findings are also related to the intrinsic relationship between the subjective perception of environmental noise annoyance and physiological response. The relationship may also be related to the direction of causation, as people who are already ill tend to be more annoyed by noise. For example, Riedel *et al*. (2015) conclude that the objective exposure to road traffic noise is mediated by the subjective response of noise-related annoyance, which ultimately determines the degree of risk of a negative health outcome. They also found that long-term annoyance from road traffic noise has the potential to exacerbate previous pathologies. These findings are supported by research by Niemann and Maschke (2004) showing that continual annoyance from noise is associated with several self-rated pathologies including cardiovascular and respiratory conditions, as well as depression.

2.4 Sleep Disturbance

The epidemiological evidence associating sleep disturbance with negative health events is well documented (Watson *et al*., 2015), and sleep disturbance is regarded as one of the most significant negative health impacts associated with environmental noise (Fritschi *et al*., 2011). Objective measurements of sleep disturbance are generally obtained using electrophysiological tests, commonly a multi-parametric test called polysomnography, while subjective measurements are usually obtained from self-reported surveys (WHO, 2011). Polysomnography is the most robust objective measurement, combining electroencephalography (measurement of brain electrical signals), electro-oculography (e.g. measurement of eye movements) and electromyography (measurement of muscle tone) (Basner and McGuire, 2018). Although accurate information regarding sleep structure, sleep phase and cortical arousal within sleep can be accurately assessed only using electrophysiological testing, the invasive nature of participation and the need for a highly skilled practitioner to perform the tests mean that sample sizes and the number of studies being undertaken are small (Basner *et al*., 2007). Hence, generalisability is inherently problematic in this regard. There are also less invasive methods of assessment, but they are inherently less robust (Basner and McGuire, 2018). These include actigraphy and signal awakenings. The former is assessed through wrist movements measured using watch-like devices (Ancoli-Israel *et al*., 2006), while the latter involves participants signalling sleep awakening using push-button devices (Basner and McGuire, 2018). In terms of subjective measures, self-reported questionnaires on the nature of sleep awakening are also often used in assessing the impact of noise on sleep and, although less reliable than objective measures, nevertheless have been applied successfully in informing exposure–response parameters (Miedema and Vos, 2007).

Using both objective and subjective measurements, Pirrera *et al*. (2014) determined that participants living in areas exposed to road traffic noise perceived their environment as subject to noise disturbance and, in general, considered road traffic noise to negatively affect their wellbeing. However, although objective measurements found no significant association between sleep disturbance and traffic noise, subjective measurements indicated that traffic noise was definitively related to both difficulty falling asleep and poor quality of sleep (Pirrera *et al*., 2014). It is important to note here that Pirrera *et al*. (2014) contend that the analysis of the impact of noise exposure may be inaccurate unless inside, in addition to outside, environmental noise is measured, and both objective and subjective indicators of sleep disturbance are used, to provide a holistic analysis. However, the subjective dimension of sleep disturbance caused by environmental (i.e. transport) noise is often difficult to disentangle. Elmenhorst *et al*.'s (2016) analysis of sleep disturbance (measured using polysomnography) caused by aircraft noise found that participants with a negative perception of air traffic found it harder to fall asleep, experienced more sleep disturbance and experienced less slow-wave sleep (SWS) or non-rapid eye movement (NREM) sleep. This is important since it is believed that during SWS the body repairs and regrows tissue, builds bone and muscle, and strengthens the immune system. The suggestion is that sleep disturbance and subjective dimensions of negative effects related to aircraft noise are correlated. However, it remains unknown whether sleep disturbance influences negative perception or prior negative perception influences sleep disturbance (Elmenhorst *et al*., 2016).

In the context of railway noise, Smith *et al*. (2017) examined the extent to which vibration influenced sleep disturbance (measured using polysomnography) and found that both vibration and noise activated an acceleration in heart rate and were influential in causing sleep disturbance. The study is of great interest because, although vibration and noise are processed in different parts of the sleeping brain, they result in identical outcomes (Smith *et al*., 2017).

As previously stated, many studies emphasise the importance of sleep disturbance and perceived annoyance as mediators of a number of negative health outcomes. It has been consistently demonstrated that sleep disturbance caused by environmental noise diminishes the body's ability to repair itself and has the potential to increase the risk of cardiovascular disease (Basner *et al*., 2014). According to Majde and Krueger (2005), the necessary process of rejuvenating the immune system is one of the main reasons why animals require sleep. The correlation between sleep disturbance and increased risk of vulnerability to infectious disease is well founded in the medical literature and potentially can be explained by the negative impact of the antibody response to the antigen capsular polysaccharide that occurs during sleep disturbance (Prather *et al*., 2012). Sleep disturbance not only increases the risk of infection, but also exacerbates any pre-existing infection (Toth, 1995; Prather *et al*., 2012). Hence, sleep disturbance caused by environmental noise has the potential to adversely affect the immune system and, therefore, is a major health concern. Sleep disturbance and awakening caused by exposure to transport noise disrupts SWS, which is essential for the body's recuperative process, and also disrupts REM sleep (Belojevic *et al*., 1997). According to Spiegel *et al*. (2003) and Ising *et al*. (2004), a disruption in recuperative sleep results in an increase in cortisol levels in subsequent waking hours. Fundamentally, noise-related sleep disturbance is not mitigated by habituation, but in fact is exacerbated by long-term habituation. This is because long-term exposure to environmental noise results in overproduction of cortisol (Maschke, 2003), resulting in the accumulation of cortisol (so-called hypercortisolaemia) (Tobías *et al*., 2015), which in turn can lead to atherosclerosis (Recio *et al*., 2016), widely considered the primary pathological state associated with cardiovascular disease (Münzel *et al*., 2018).

2.5 Cardiovascular Disease

More than any other negative health risk, exposure to environmental noise in metropolitan areas has been associated with increased risks of serious cardiovascular incidence (Babisch *et al*., 2006) such as myocardial infarction (Selander *et al*., 2009) and stroke (Sørensen *et al*., 2011). Tobías *et al*. (2014) found a significant correlation between environmental noise and increased risk of cardiovascular mortality and morbidity factors, including hypertension, arteriosclerosis and heart rate irregularity (Tobías *et al*., 2015). Research by Münzel *et al*. (2018) also found that environmental noise was significantly correlated with an increased risk of hypertension, congestive heart failure, myocardial infarction and stroke, while research by Cai *et al*. (2017) indicated that the combined effect of road traffic noise and air pollution significantly increased the risk of cardiometabolic incidents.

As previously mentioned, in physiological terms, environmental noise causes stress resulting in a neuroendocrine response, which in turn results in cortisol overproduction (Recio *et al*., 2016). This overproduction of cortisol ultimately results in atherosclerosis (Recio *et al*., 2016) and is caused by the long-term accumulation of cortisol known as hypercortisolaemia (Tobías *et al*., 2015). Atherosclerosis leads to the production of endocrine antigen capsular polysaccharide, a pro-coagulant that negatively affects immune system repair and neuroendocrine awakening (Hartman and Frishman, 2014). Environmental noise has also been identified as a stressor that results in excess lipids in blood and exacerbation of endothelial dysfunction, as well as disturbance of the blood clotting system and platelet accumulation, which has the potential to cause serious cardiovascular disease (Recio *et al*., 2016). Related to this physiological process is the fact that the stress response has been found to alter the normal production of lipid and high-density lipoprotein (Qureshi *et al*., 2009). The relationship between environmental noise and cardiovascular disease is usually attributable to chronic long-term sleep disturbance, which is also associated with stress-related annoyance, as previously discussed. For example, after controlling for air pollution, Kälsch *et al*. (2014) found a significant relationship between sleep disturbance caused by road traffic noise and atherosclerosis. Azuma and Uchiyama (2017) found that sleep disturbance and annoyance caused by environmental noise were significantly associated with an increased risk of cardiovascular disease. Such analysis corresponds with the understanding that sleep disturbance and annoyance act as mediators in the relationship between environmental noise and increased risk of negative health outcomes. According to Paunović *et al*. (2009), the impact of environmental noise on the cardiovascular system is also influenced by psychosocial and demographic factors, which include subjective indicators such as attitudes and personality traits, idiosyncratic noise sensitivity and the length of time that participants have resided at their dwellings (e.g. habituation). Such subjective responses to noise are mediated by the limbic system, and the hypothalamus, pituitary gland and adrenal gland, which are involved in endocrine activity that develops in the adrenal cortex with the secretion of cortisol.

Laboratory-based research by Paunović *et al*. (2014) found that exposure to road traffic noise was associated with increases in blood pressure caused by vasoconstriction in conjunction with decreased cardiac output. Schmidt *et al*. (2015), in contrast, in laboratory-based research, found that noise-induced night-time disturbance was significantly associated with vasodilatation. In more recent research, Zijlema *et al*. (2016) found a correlation between traffic noise and an increase in heart rate, but not an increase in blood pressure. Babisch *et al*. (2014) also found that exposure to road traffic noise was significantly associated with a higher risk of hypertension, with systolic hypertension generating more significant correlations with road traffic noise than general symptoms including blood pressure measurement, self-reported diagnosed hypertension and the use of anti-hypertension medication. However, in this case, length of habituation was not found to be a factor (Babisch *et al*., 2014). Chang *et al*. (2014) analysed the impact of various frequencies of road traffic noise on hypertension among 820 participants in central Taiwan. A correlation between low-frequency and mid-frequency traffic noise and risk of hypertension was found, and it was suggested that the impact of noise on hypertension may be mediated by the neuroendocrine system, with annoyance leading to increased production of cortisol, even at low noise levels.

Based on research undertaken in the USA, Swinburn *et al*. (2015) estimate that a decrease in environmental noise of 5 dB would reduce the prevalence of hypertension in the USA by approximately 1.4% (1.2 million people) and of coronary heart disease by 1.8% (279,000 people). Hypertension is a manifold phenomenon composed of a multitude of physiological dysfunctions which variously contribute to cardiovascular disease. Some of the most important physiological dysfunctions are endothelial dysfunction (e.g. Poitras and Pyke, 2013) and oxidative stress (e.g. Koc *et al*., 2015). Endothelial dysfunction is caused by an “imbalance between the production and bioavailability of endothelium-derived relaxing factors (EDRFs) and endothelium-derived contractile factors (EDCFs)” (Silva *et al*., 2012, p. 1). This imbalance is associated with the overproduction of oxygen reactive species and a deficiency in antioxidant capacity, commonly referred to as oxidative stress (Silva *et al*., 2012). Exposure to environmental noise as a risk factor for stress has been shown to exacerbate endothelial dysfunction (Recio *et al*., 2016). The association between stress and endothelial dysfunction caused by neuroendocrine awakening has been studied by Poitras and Pyke (2013). Endothelial cells control the vascular response to stress (Recio *et al*., 2016), and endothelial dysfunction is caused by a reduction in the production of endothelial cells, which are also responsible for relieving the damage and abrasion caused by the normal functioning of the vascular system (Recio *et al*., 2016). Research by Wang *et al*. (2007) found that psychological stress was physiologically manifest in oxidative stress in the tissue of animals. Hence, oxidative stress is also an important biological marker in the relationship between environmental noise and cardiovascular incidence. Koc *et al*. (2015) found significant correlations between environmental noise and the risk of oxidative stress caused by the overproduction of free radicals. This inhibits the ability of antioxidants within cells to neutralise the damaging effects of these free radicals (Recio *et al*., 2016). In a systematic review pertaining to reports regarding the impact of noise on cell oxidation in tissue, Molina *et al*. (2016) determined that exposure to environmental noise had the potential to induce oxidative stress in a variety of tissues, resulting in cellular deterioration. Research by Schmidt *et al*. (2013) into the effect of aircraft noise found that sleep disturbance caused by aircraft noise with a maximum of 60 dB was not correlated with increases in cortisol levels, but *did* negatively affect the endothelial system, which indicates that oxidative stress is also an important factor in relation to the impact of environmental noise on sleep disturbance.

According to Babisch (2008), approximately 3% of IHD in metropolitan areas is associated with exposure to road traffic noise. Pershagen *et al*. (2017), in a meta-analysis of 61 longitudinal studies assessing risk, concluded that road traffic noise significantly increased the risk of IHD. Indeed, Vienneau *et al*. (2015) found that populations exposed to environmental noise of between 50 and 71 dB have a greater risk of IHD than the WHO (2011) guidelines would suggest and corroborated research by Babisch (2008), who found that the risk of IHD may be initiated at a lower level of environmental noise than formerly suggested. Vienneau *et al*. (2015) estimate that for every 10 dB increase in environmental noise, the risk of IHD increases by 6%, suggesting that to limit the impact of environmental noise on health, the risk parameters should be reduced to 50 dB. According to Vienneau *et al*. (2015), long-term habituation potentially increases the likelihood of IHD, which is associated with the physiological outcome of hypercortisolaemia (i.e. the long-term accumulation of cortisol production). However, long-term habituation may also be related to socio-economic factors such as reduced ability to purchase or rent a higher-quality, better-insulated, dwelling (Vienneau *et al*., 2015). Sørensen *et al*. (2014) found that road traffic noise was associated with an increased risk of ischaemic stroke, while air pollution was not. On the other hand, air pollution was associated with an increased risk of death from stroke, while exposure to traffic noise was not (Sørensen *et al*., 2014).

Nevertheless, the combined impacts of both traffic noise exposure and air pollution had the strongest correlation with the risk of ischaemic stroke (Sørensen *et al*., 2014). This corresponds with research by Beelen *et al*. (2009) and more recent research linking the combined effects of air and noise pollution on cardiometabolic incidents by Cai *et al*. (2017). Roswall *et al*. (2015) found that road traffic noise and air pollution were independently correlated with the risk of myocardial infarction and also that the combined effect of both pollutants correlated with higher risk factors of myocardial infarction. However, Roswall *et al*. (2015) found that railway noise was not related to myocardial infarction, which may be related to widespread research indicating that railway noise is perceived to be less annoying than road traffic noise (Miedema and Oudshoorn, 2001). According to a study of traffic noise exposure in Belgrade (Paunovic and Belojević, 2014), the correlation between traffic noise and IHD was minor relative to other conditions including obesity, hypertension and physical inactivity. Indeed, in a longitudinal study of 13,512 participants in Skåne, Sweden, Bodin *et al*. (2016) found no evidence of an association between road traffic noise and risk of myocardial infarction or IHD. Halonen *et al*. (2012) also found little correlation between road traffic noise and stroke, as associated with hypertension and carotid intima–media thickness. Furthermore, while Dzhambov and Dimitrova (2016) found that road traffic noise *did* increase the risk of stroke, statistical correlations were not found to be significant, with significant increases of risk of stroke found only in respect to aircraft noise.

2.6 Moderating, Mediating and Confounding Factors

In analysing the relationship between environmental noise exposure and health outcomes, studies have variously attempted to control and account for the influence or potential influence of a wide range of variables. Such variables (e.g. gender, duration of exposure, sensitivity) may, either independently or in combination, explain or partly explain a given association or non-association. The consideration of the influence of such variables is vital in assessing the validity of an identified association or non-association. Such influencing variables are generally categorised as moderating, mediating or confounding variables – or moderators, mediators and confounders – which need not be mutually exclusive.

Moderators are interactions that change the size and/or direction of the effect of the exposure on an outcome. In the case of environmental noise, moderators might include building type (e.g. apartment, house), composition of rooms, quantum of open space outside the building, noise sensitivity of individual respondents, pre-existing medical conditions, proximity to a given noise source, fluctuating traffic flow or the noise level from a given source at the point of measurement compared with other sources at the same noise level. Mediators lie on the causal pathway between exposure and outcome. To account for the potential mediating effects of intervening variables, studies have variously explored the mediating effects of length of tenure (i.e. habituation), night work and air pollution in exploring the association between wide-ranging health and wellbeing outcomes and exposure to environmental noise. While potentially on the causal pathway, these mediators may well be related to other factors. For example, long-term habitation may itself be related to an inability to purchase or rent a higher-quality, better-insulated, dwelling (Vienneau *et al*., 2015). In turn, it may well be the effect of confounding socio-economic variables that better explains the relationship. Confounding variables are heterogeneous characteristics which could jointly determine particular health outcomes and the level of exposure to environmental noise in the local area. These include socio-demographic and economic characteristics such as age, neighbourhood classification, gender, income category, marital status, employment status, education level and psychosocial factors such as respondent perceptions. The status of exposed populations and individuals in terms of such characteristics has the potential to influence both their propensity to have a particular medical condition and their exposure to environmental noise. Finally, it should be noted that Douglas and Murphy (2020) found considerable methodological differences in the treatment of moderators, mediators, and confounders that have informed the WHO (2018) *Environmental Noise Guidelines for the European Region*. Douglas and Murphy (2020) contend that this is primarily because no designated standards were outlined for contributors in respect of the management of potential "effect modifiers" (i.e. moderators, mediators and confounders) by WHO. Hence, Douglas and Murphy (2020) recommended that a clear delineation of potential "effect modifiers" be explicitly outlined for the development of standards in prospective systematic reviews.

2.7 Conclusion

Research undertaken to date suggests that exposure to environmental noise can increase the risk of cardiovascular and metabolic complications, immune system dysfunction, diabetes, obesity, depression, anxiety and cognitive impairment. Furthermore, studies are emerging that propose links between environmental noise and various cancers including breast cancer, colorectal cancer and non-Hodgkin's lymphoma. Such analysis has focused on road traffic noise, as this source of noise is the most prevalent in the urban environment. However, more recent research has considered broader and combined sources of transport sources – road, rail and air (e.g. Gille *et al*., 2017). In the context of the growing interest in the relationship between environmental noise and wide-ranging health outcomes, the negative impact of environmental noise on public health is increasingly recognised as a serious issue as societies urbanise. The stark reality is that the world's urban population is set to double from 3.10 billion in 2014 to 6.4 billion in 2050 (United Nations Department of Economic and Social Affairs, 2014). Given this growing body of evidence, current exposure–response models used by WHO, including the most recent guidelines (WHO, 2018), will need to be updated to incorporate new insights obtained from recent research.

3 Noise–Health Analysis

3.1 The Irish Longitudinal Study on Ageing

The first task involved in this analysis related to securing access to, and cleaning data from, The Irish Longitudinal Study on Ageing (TILDA). TILDA is a nationally representative longitudinal study of over 8000 people aged 50 years and over in Ireland, and collects information on all aspects of health, economic and social circumstances. TILDA is harmonised with the Survey of Health, Ageing and Retirement in Europe, the English Longitudinal Study of Ageing, the Health and Retirement Survey (HRS) and the HRS international network of studies. The geocode of each TILDA respondent's home address is recorded, which allows the dataset to be linked with other geocoded spatial data. The Noise–Health project employed data from the third wave of the survey, which was carried out between March 2014 and October 2015 among 6396 individuals who by then were aged 54 years and over. In the third wave of TILDA, data were collected using three different methods. First, interviews were conducted by trained interviewers in each respondent's home using computer-assisted personal interviewing (CAPI). Second, participants were given a self-completion questionnaire, which captured more potentially sensitive data, to fill out and return by post. Finally, respondents were invited to attend a nurse-led health assessment at specialised health assessment centres, or if this was not possible a modified partial assessment in their homes. Data gathered from all three stages in this study were used in the present analysis. Data on estimated noise exposure were available for respondents living in Dublin and Cork, providing a final sample size of 1706 participants. A rich set of health and wellbeing variables was captured by TILDA, enabling the analysis of health and wellbeing across a wide range of outcomes. Table 3.1 lists the outcome variables included in the statistical analysis and the method through which each variable was collected by TILDA.

3.2 Noise Exposure: Modelling Exposure to Road Traffic Noise

Estimated levels of population exposure to road traffic noise at exposed residential building façades in the cities of Dublin and Cork were utilised for this analysis. Where a building had more than one receiver point on its most exposed façade, the largest decibel value was applied for the current study. Road traffic noise exposure levels were estimated in decibels (dB) using "Common Noise Assessment Methods in Europe" (CNOSSOS-EU), a common framework for strategic noise mapping and population exposure estimation developed for EU Member States. According to the CNOSSOS-EU and in line with Commission Directive (EU) 2015/996 which replaces Annex II of Commission Directive (EU) 2002/49, noise receiver points were assigned to the façades of residential buildings in Dublin and Cork at 4 m above ground level. The CNOSSOS-EU model was found to converge closely with roadside measurements (i.e. obtained using sound level meters) during high-medium [i.e. within 0.2–2 dB(A)] and low-medium [i.e. within 0.1–0.6 dB(A)] traffic flow conditions within the Dublin agglomeration (see Murphy *et al*., 2021). As the CNOSSOS-EU model generated accurate results (within 2 dB(A) of the true noise levels) in relation to road traffic noise within an Irish agglomeration, it was deemed suitable for accurately modelling a population's exposure to road traffic noise.

Input data included source data such as vehicle classifications, for example whether or not vehicles were cars, heavy vehicles etc., traffic counts and vehicle speed (based on local speed limits) for individual road segments. Data such as building height and dimension, noise barriers, road surface characteristics, and ground cover and ground elevation characteristics and environmental data, such as temperature, humidity and atmospheric pressure, were obtained from the designated noise mapping bodies for the case study locations. These digital datasets were collated over several years between 2012 and 2016 and were employed in the most recent round of strategic noise mapping in 2017 (round 3), thereby representing the most comprehensive datasets available for each agglomeration. Noise exposure modelling was completed using the Predictor-LimA Advanced V2019.02 software package. For CNOSSOS-EU modelling, assessment of noise levels at the most exposed façade for single dwelling units was applied in combination with an assessment

Table 3.1. Health and wellbeing outcome variables included in this research

Outcome	Variable	Source in TILDA
Cognitive health		
Global cognitive function	Montreal Cognitive Assessment (MoCA)	Health assessment
	Mini-Mental State Examination (MMSE)	CAPI
Executive function	Animal naming test (ANT)	CAPI
	Colour Trail Test 2 (CTT-2)	Health assessment
Memory	Immediate recall	CAPI
	Delayed recall	CAPI
Processing speed	Choice reaction time (CRT)	Health assessment
	Colour Trail Test 1 (CTT-1)	Health assessment
Mental wellbeing		
Quality of life	Control, Autonomy, Self-realisation and Pleasure 12-item (CASP-12) scale	Self-completion survey
Depression	Center for Epidemiological Studies Depression (CES-D) scale	CAPI
Anxiety	Hospital Anxiety and Depression Scale – Anxiety subscale (HADS-A)	CAPI
Stress	Perceived Stress Scale (PSS)	Self-completion survey
Worry	Penn State Worry Questionnaire (PSWQ)	Self-completion survey
Physical health		
Sleep	Self-reported trouble falling asleep/waking up too early	CAPI
	Objective sleep duration/sleep restlessness	Sub-sample study[a]
Obesity	Objective (BMI ≥ 30 kg/m^2)	Health assessment
Body mass index (BMI)	Self-reported	CAPI
	Objective	Health assessment
Diabetes	Self-reported	CAPI
	Objective	Health assessment
Blood pressure	Objective	Health assessment
	Takes antihypertensive medication	CAPI
Heart condition	Self-reported	CAPI

Source: TILDA.

[a]In a separate study on a subsample of respondents, TILDA objectively measured respondents' sleeping patterns using accelerometers.

of noise levels at each façade for residential buildings with more than one dwelling, in accordance with Commission Directive (EU) 2015/996; L168/95 (see Murphy *et al.*, 2021). The number of inhabitants per building (equation 3.1) was estimated using CASE 1B criteria:

$$\text{Inh}_{\text{building}} = v_{\text{building}}/v_{\text{total}} \times \text{Inh}_{\text{total}} \qquad (3.1)$$

To estimate population exposure to road traffic noise, residential dwellings were identified and calculated noise levels were applied to these buildings. To identify residential buildings, the commercially available An Post GeoDirectory database was used. Census data for Small Area Population Statistics available from Central Statistics Office (CSO) Ireland were utilised to incorporate population statistics into the dataset (see Murphy *et al.*, 2021).

As any potential health effects of exposure to road traffic noise were hypothesised to be mediated through sleep disturbance and stress-related annoyance, L_{night}, an EU indicator of annual average noise levels for night-time periods, was utilised. L_{night} acts as the exposure variable and was measured at the most exposed façade at the residence of TILDA respondents. "Night-time" was defined as an 8-hour period between 23:00 and 07:00. No data were available on the times at which TILDA respondents were usually in their residence; however, it was assumed that most TILDA respondents spent this overnight period at home.

3.3 Merging Data and Statistical Approach

The results generated from the population exposure estimation analysis were spatially joined to data from the third wave of TILDA analysis within the geographic information system (GIS) platform QGIS 3, utilising the Ordnance Survey Ireland (OSi) PRIME2 dataset of land use. Each noise data point was assigned to a geocode using building footprints from the PRIME2 dataset. Façade receiver points that fell within the building footprint were linked to the geocode of that building following the approach taken by Tzivian *et al*. (2017). Individual TILDA respondents were then linked with noise data points using geocodes, thus assigning an estimated level of noise exposure to each respondent at their place of residence.

In terms of the statistical approach used, regression models were applied to various outcomes to identify and measure the association between road traffic noise and health and wellbeing data provided by TILDA, adjusting for a range of potential confounding socio-economic and behavioural factors, as well as for other environmental stressors. These factors were (1) age, (2) gender, (3) marital status, (4) employment status, (5) education, (6) household income, (7) physical activity,[3] (8) social connectedness,[4] (9) whether or not participants had any discernible health limitations, (10) whether or not participants were alcohol dependent and (11) polypharmacy.[5] Statistical analysis was conducted using the statistical software package Stata 14. For each health and wellbeing outcome variable, a regression model was employed, with estimated noise exposure as an explanatory variable. Initially, univariate models were run for each health outcome to identify relationships with noise exposure at univariate level. If outcomes were significantly associated with noise exposure, models were then adjusted for individual socio-demographic and behavioural characteristics, enabling the identification of any relationships that were independent of differences in these characteristics. Individual characteristics in the models included age, gender, employment status, education, household income, physical activity, social connectedness, the presence of a long-term health limitation, the presence of an alcohol problem and the regular use of five or more medications (polypharmacy). Data on ambient air pollution associated with traffic and industrial emissions were available for a subsample of respondents from Dublin City.

3.4 Results

3.4.1 Cognitive health

Fully adjusted results of models (excluding air pollution exposure) relating to cognitive health outcomes are summarised in Tables 3.2–3.5 and outlined further in Mac Domhnaill *et al*. (2021). Results are displayed for noise exposure as the independent variable and fully adjusted for socio-demographic, behavioural and health characteristics. Results are reported for average marginal effects in terms of quintiles of noise exposure relative to the highest quintile of exposure. The average marginal effect of the independent variable is the average of predicted changes in the outcome variable when that independent variable changes by one unit, holding all other covariates constant. Since outcome variables are standardised using z-scores, marginal effects can be interpreted as proportions of a standard deviation. *P*-values indicating the probability of obtaining results as extreme as the observed results under the null hypothesis are also reported. When considering statistical significance, a *p*-value less than 0.05 is typically regarded as indicative of statistical significance at the 95% confidence level.

From an initial examination of global cognitive function using the MMSE, respondents in the third quintile of noise exposure make more errors than respondents in the lowest quintile. This result suggests that moving from the lowest quintile of noise exposure to the middle quintile is associated with an increase in the number of errors made. However, the statistical evidence that this average marginal effect is different from zero is relatively weak according to its corresponding *p*-value, and the association is not reflected in higher quintiles of noise exposure. Overall, this represents an unclear result.

3 The classification of physical activity was based on the International Physical Activity Questionnaire Scale (see Craig *et al*., 2003).

4 The classification of social connectedness was based on the Berkman–Syme Social Network Index (see Berkman and Syme, 1979).

5 Polypharmacy, according to TILDA, means consistent use of at least five different medications.

Table 3.2. Average marginal effects of noise exposure on global cognitive function outcome variables[6]

	MMSE errors (*n* = 1678)		MoCA errors (*n* = 1407)	
Noise [dB(A)]	d*y*/d*x* (95% CI)	*p*-value	d*y*/d*x* (95% CI)	*p*-value
35.7–45.8	(Ref.)		(Ref.)	
45.9–48.9	0.012 (–0.109, 0.133)	0.847	–0.151 (–0.290, –0.013)	0.034
49.0–51.2	0.198 (0.066, 0.329)	0.003	–0.011 (–0.153, 0.130)	0.875
51.3–53.7	–0.030 (–0.150, 0.091)	0.628	–0.123 (–0.261, 0.014)	0.078
53.8–69.3	0.108 (–0.030, 0.247)	0.125	–0.011 (–0.160, 0.138)	0.886

Notes: Noise exposure is categorised using quintiles. Cognitive health outcome variables standardised using z-scores. Results correspond to models that adjust for socio-demographic, behavioural and health characteristics.

CI, confidence interval; Ref., reference.

Table 3.3. Average marginal effects of noise exposure on executive function outcome variables

	ANT score (*n* = 1667)		CTT-2 time (*n* = 1394)	
Noise [dB(A)]	d*y*/d*x* (95% CI)	*p*-value	d*y*/d*x* (95% CI)	*p*-value
35.7–45.8	(Ref.)		(Ref.)	
45.9–48.9	–0.053 (–0.195, 0.088)	0.457	–0.099 (–0.233, 0.035)	0.147
49.0–51.2	–0.117 (–0.259, 0.025)	0.107	–0.083 (–0.229, 0.064)	0.269
51.3–53.7	–0.115 (–0.250, 0.020)	0.096	0.037 (–0.122, 0.196)	0.648
53.8–69.3	–0.209 (–0.346, –0.072)	0.003	0.059 (–0.078, 0.195)	0.399

Notes: Noise exposure is categorised using quintiles. Cognitive health outcome variables are standardised using z-scores. Results correspond to models that adjust for socio-demographic, behavioural and health characteristics.

CI, confidence interval; Ref., reference.

Table 3.4. Average marginal effects of noise exposure on memory outcome variables

	Immediate recall score (*n* = 1678)		Delayed recall score (*n* = 1967)	
Noise [dB(A)]	d*y*/d*x* (95% CI)	*p*-value	d*y*/d*x* (95% CI)	*p*-value
35.7–45.8	(Ref.)		(Ref.)	
45.9–48.9	0.074 (–0.062, 0.211)	0.284	0.137 (0.005, 0.270)	0.043
49.0–51.2	0.031 (–0.103, 0.164)	0.654	0.055 (–0.085, 0.195)	0.442
51.3–53.7	0.110 (–0.026, 0.246)	0.114	0.087 (–0.048, 0.223)	0.207
53.8–69.3	0.041 (–0.099, 0.180)	0.570	0.054 (–0.079, 0.187)	0.424

Notes: Noise exposure is categorised using quintiles. Cognitive health outcome variables are standardised using z-scores. Results correspond to models that adjust for socio-demographic, behavioural and health characteristics.

CI, confidence interval; Ref., reference.

Using the ANT to assess executive function, a negative correlation between noise exposure and cognitive performance was found, with an average marginal effect at the highest quintile supported by a low *p*-value. Compared with respondents in the lowest quintile of noise exposure, respondents in each of the other quintiles exhibited a lower ANT score. These results suggest a negative correlation between noise exposure and executive function. The CTT-2, which also evaluates executive function, similarly suggested a negative correlation between noise exposure and executive function, although statistical significance was weaker. This could be attributed to the smaller sample size used for the CTT-2 than for the ANT. In the case of memory, using the immediate and delayed recall test, no statistical significance was found. Similarly, when assessing processing speed using the CTT-1 and total time in the CRT, no statistical significance was found. Following this, respondents' ANT score was subjected to further scrutiny. Focusing

6 In Tables 3.2–3.5, all outcome variables are standardised using z-scores; the results correspond to models that adjust for socio-demographic and health characteristics, and d*y*/d*x* denotes the marginal effect.

Table 3.5. Average marginal effects of noise exposure on processing speed outcome variables

	CTT-1 (time) (*n* = 1412)		CRT (total time) (*n* = 1322)	
Noise [dB(A)]	dy/dx (95% CI)	*p*-value	dy/dx (95% CI)	*p*-value
35.7–45.8	(Ref.)		(Ref.)	
45.9–48.9	–0.092 (–0.208, 0.025)	0.123	0.000 (–0.149, 0.149)	1.000
49.0–51.2	0.078 (–0.110, 0.266)	0.413	0.035 (–0.117, 0.186)	0.653
51.3–53.7	–0.028 (–0.151, 0.094)	0.649	0.083 (–0.080, 0.245)	0.319
53.8–69.3	–0.030 (–0.148, 0.088)	0.616	0.087 (–0.082, 0.255)	0.315

Notes: Noise exposure is categorised using quintiles. Cognitive health outcome variables are standardised using z-scores. Results correspond to models that adjust for socio-demographic, behavioural and health characteristics.

CI, confidence interval; Ref., reference.

on a subsample of 730 respondents living in Dublin City enabled further adjustment of the exposure to ambient air quality, using NO_2 as a proxy for general air pollution. Complete results for this subsample analysis of the ANT are presented in Table 3.6.

Once air pollution was included in this subsample analysis between noise exposure and ANT score, no statistical significance was found. Instead, a statistically significant association between ANT performance and exposure to air pollution was found for the fourth and highest quintiles. It is therefore possible that air pollution exposure may account for the correlation between the ANT and road traffic noise exposure illustrated in Table 3.3. However, it may also indicate that this subsample analysis, owing to a smaller sample size, lacks the statistical power to detect the independent association with road traffic noise.

Table 3.6. Subsample analysis (*n* = 730): noise exposure, air pollution and executive function (ANT score)

	Executive function (ANT score)			
	Noise exposure		Air pollution	
Quintile	dy/dx	*p*-value	dy/dx	*p*-value
Lowest	(Ref.)		(Ref.)	
Second	–0.07	0.42	–0.17	0.12
Third	–0.32	0.01	–0.21	0.07
Fourth	0.08	0.49	–0.38	0.00
Highest	–0.02	0.91	–0.47	0.00

Ref., reference.

3.4.2 Mental wellbeing

Fully adjusted results of regression models for mental wellbeing are summarised in Table 3.7. Like the results for cognitive health, these results are fully adjusted for socio-demographic, behavioural and health characteristics. As shown in Table 3.7, a significant negative association between exposure to road traffic noise and quality of life was found, as measured by the CASP-12 scale. Moving from the highest quintile of noise exposure to the second lowest or lowest was associated with an increase on the CASP-12 scale. *P*-values that correspond to these average marginal effects at lower quintiles of noise exposure are low. This association is independent of the socio-demographic and behavioural characteristics considered in this investigation.

Table 3.7. Average marginal effects of noise exposure on mental wellbeing outcome variables

Noise exposure quintile	Quality of life: CASP-12 (*n* = 1356)		Depression: CES-D (*n* = 1675)		Anxiety: HADS-A (*n* = 1679)		Stress: PSS (*n* = 1426)		Worry: PSWQ (*n* = 1356)	
	dy/dx	*p*-value	dy/dx	*p*-value	dy/dx	*p*-value	dy/dx	*p*-value	dy/dx	*p*-value
Lowest	1.08	0.01	–0.06	0.84	0.10	0.70	–0.10	0.71	–0.70	0.29
Second	1.07	0.01	0.22	0.45	0.09	0.72	–0.08	0.78	–0.88	0.15
Third	0.04	0.93	0.53	0.08	0.15	0.58	0.36	0.17	–0.21	0.75
Fourth	0.67	0.11	–0.03	0.92	0.38	0.88	0.22	0.39	–1.23	0.05
Highest	(Ref.)		(Ref.)		(Ref.)		(Ref.)		(Ref.)	

Ref., reference.

On the other hand, no statistically significant association was found between noise exposure and depression, anxiety, stress or worry, as measured by the CES-D scale, HADS-A, the PSS and the PSWQ. Once again, in a subsample of 568 respondents living in Dublin City, for which data regarding ambient air quality were available, no significant associations were found between road traffic noise and CASP-12 scale score (see Table 3.8). However, in this instance, no statistically significant relationship was found between exposure to air pollution and CASP-12 score. This may indicate that this subsample analysis, owing to the reduced sample size, lacks the statistical power to detect the association between quality of life and either road traffic noise or air pollution.

3.4.3 Physical health

The results of univariate regression modelling relating to physical health outcomes, including self-reported and objective measures of sleep disturbance, objective measures of obesity, self-reported and objective measures of body mass index, diabetes and blood pressure and self-reported heart conditions found no statistically significant correlation between road traffic noise and these health outcomes. For this reason, further multivariate adjustments were not conducted.

3.5 Discussion

In terms of cognitive health, the evidence indicates that exposure to road traffic noise at night may be negatively associated with executive function. However, a subsample analysis suggested that this association may also be explained by exposure to air pollution. No evidence was found of a relationship between road traffic noise and global cognitive function, memory or processing speed. There is some evidence that road traffic noise may be negatively associated with quality of life, but the results are ultimately inconclusive. No evidence was found of a relationship between noise and depression, anxiety, stress or worry. There was limited evidence of an association between noise exposure and various measures of sleep, body mass index and blood pressure and the prevalence of obesity, diabetes and heart conditions.

Table 3.8. Subsample analysis: noise exposure, air pollution exposure and CASP-12 score

	Quality of life: CASP-12 ($n=568$)			
	Noise		Air pollution	
Quintile	dy/dx	*p*-value	dy/dx	*p*-value
Lowest	1.17	0.14	0.07	0.94
Second	0.93	0.26	–0.14	0.88
Third	0.77	0.48	0.08	0.93
Fourth	0.80	0.30	–0.02	0.98
Highest	(Ref.)		(Ref.)	

Ref., reference.

The study has several limitations. First, while this research contributes to the evidence base in relation to older adults, the results cannot be generalised to the whole population. Second, while TILDA allows us to explore associations between noise exposure and a wide range of health outcomes, one cannot empirically study the mechanisms behind any association. Third, exposure to road traffic noise was measured at the most exposed façade of the TILDA respondents' residences. In the absence of information on the layout of respondents' homes, it is assumed that exposure at the most exposed façade is a reliable proxy for night-time exposure for that individual. Fourth, this study is cross-sectional in nature and thus we cannot make any causal inference; finally, due to data limitations, we are able to adjust models of air pollution for only a relatively small subsample in Dublin City. Subject to data availability, the application of models to include both environmental noise and air pollution to a larger sample would be beneficial.

Overall, this research makes several valuable methodological contributions to the knowledge base in relation to environmental noise and health. First, by spatially linking high-quality modelled noise pollution data based on the new CNOSSOS-EU standard to TILDA, a methodology is presented that exploits a rich dataset which includes measures of various health and wellbeing outcomes, in addition to detailed socio-demographic and behavioural characteristics. Such a methodology enables the identification of any association between road traffic noise and health outcomes that are independent of these characteristics. Second, this research is focused on the older population, considered to be a group particularly vulnerable to environmental stressors, though not yet extensively studied in the literature. Furthermore, data on air pollution are included in this analysis to isolate any associations that are independent of these other environmental stressors.

4 Quantifying Harmful Effects and Burden of Disease from Environmental Noise in Ireland[7]

4.1 Introduction

As outlined in Chapter 2, WHO has recently published new noise guidelines for the European region which update its recommendations regarding environmental noise in Europe (WHO, 2018). Following this publication, Annex III of Commission Directive 2002/49/EC, referring to provision of dose–effect relations in the assessment of harmful effects caused by environmental noise, was amended with the ratification of Commission Directive (EU) 2020/367 (European Union, 2020). Commission Directive (EU) 2020/367 describes how harmful effects such as IHD, high annoyance (HA) and high sleep disturbance (HSD) in the context of road, rail and aircraft noise may be calculated in those EU Member States that transpose the directive into law.

4.2 Calculating Harmful Effects and Burden of Disease

4.2.1 Relative risk and exposure–response

In epidemiology, relative risk (RR) refers to the probability of a particular negative health outcome in an exposed population relative to the probability of occurrence of the same negative health outcome in a non-exposed population (Porta, 2014). Statistically, an RR value of 1 indicates that the level of exposure within a population has no influence on the outcome within that population, while an RR value of < 1 indicates that, as population exposure increases, the risk associated with a particular negative health outcome decreases. Finally, an RR value of > 1 indicates that, as population exposure increases, the risk associated with a particular negative health outcome also increases.

To perform a RR assessment, a standardised exposure–response relationship based on the latest scientific evidence is necessary. In the context of cardiovascular and metabolic effects, WHO (van Kempen *et al*., 2018) has generated exposure–response curves based on meta-analyses and has produced incidence, prevalence, and mortality RR statistics for the measurement of environmental noise-induced hypertension, IHD, stroke and diabetes type 1 and 2 in an exposed population. Accordingly, the natural logarithm of the RR and its variance per 10 dB have been calculated by van Kempen *et al*. (2018) for the association between environmental noise and cardiovascular disease. For example, for IHD, an incidence RR statistic of 1.08 [95% confidence interval (CI): 1.01–1.15] is presented by van Kempen *et al*. (2018, p. 7). Based on this analysis, the RR of IHD caused by road traffic noise is presented in Commission Directive 2020/367 L67/134 as:

$$RR_{IHD,i,road} = e^{\left[\left(\frac{\ln(1.08)}{10}\right)\cdot(L_{den} - 53)\right]} \text{ for } L_{den} > 53 \text{ dB} \quad (4.1)$$

$$RR_{IHD,i,road} = 1 \text{ for } L_{den} \leq 53 \text{ dB} \quad (4.2)$$

4.2.2 Population-attributable fraction

The estimated RR, once calculated, is applied to generate the population-attributable fraction (PAF). In epidemiology, the PAF is the proportion of incidence in a population that can be attributed to a certain calculated risk factor (Porta, 2014). The PAF formula is presented in Commission Directive (EC) 2020/367 L67/135 as:

$$PAF_{x,y} = \{\textstyle\sum_j [P_j\,(RR_{j,x,y} - 1)] / \sum_j [P_j\,(RR_{j,x,y} - 1)] + 1\} \quad (4.3)$$

The $PAF_{x,y}$ formula presented here is derived from two RR assessment equations. The first equation relates to the standardised approach used in epidemiological research for calculating a comparative RR assessment for a particular health outcome as a function of

7 This chapter presents a condensed version of a detailed report available for download at https://www.noise-health.com/reports--articles.html (accessed 10 May 2022).

population exposure (P) relative to the non-exposed population:

$$\mathrm{AF} = P(\mathrm{RR} - 1)/P(\mathrm{RR} - 1) + 1 \quad (4.4)$$

as outlined in *National Burden of Disease Studies: A Practical Guide* (WHO, 2001, p. 126). The second equation relates to an alternative generalised PAF approach:

$$\{\sum(P_i \cdot \mathrm{RR}_i) - 1\}/\{\sum(P_i \cdot \mathrm{RR}_i)\} \quad (4.5)$$

outlined in *Burden of Disease from Environmental Noise* (WHO, 2011, pp. 9–10). In the first equation, the attributable fraction is represented as the decrease in a negative health outcome that would be observed if population exposure to the risk factor was zero (WHO, 2001). In the second equation, the PAF represents a generalised formula more suitable for large-scale comparative analysis (WHO, 2011).

4.2.3 Absolute risk and exposure–response

To estimate harmful effects and burden of disease for HA and HSD, absolute risk (AR) is applied instead of RR. In epidemiology, AR is the probability of a disease event and is usually conceptualised as the number of disease events taking place within a population divided by the number of persons within that population (Porta, 2014). Since a standardised exposure–response relationship is required to perform a risk assessment, exposure–response curves based on meta-analyses were generated on behalf of WHO for HA (Guski *et al.*, 2017) and for HSD (Basner and McGuire, 2018). For example, in the context of road traffic noise, Commission Directive (EU) 2020/367 L67/135 presents the following regression equations for HA and HSD, derived from Guski *et al*. (2017) and Basner and McGuire (2018), respectively:

$$\mathrm{AR}_{\mathrm{HA,road}} = (78.9270 - 3.1162 \times L_{\mathrm{den}} + 0.0342 \times L_{\mathrm{den}}{}^2)/100 \quad (4.6)$$

$$\mathrm{AR}_{\mathrm{HSD,road}} = (19.4312 - 0.9336 \times L_{\mathrm{night}} + 0.0126 \times L_{\mathrm{night}}{}^2)/100 \quad (4.7)$$

To estimate the total number of persons affected by the harmful effects of noise-induced IHD, estimated risk statistics are applied to the exposed population, presented in Commission Directive (EU) 2020/367 L67/136 as:

$$N_{x,y} = \mathrm{PAF}_{x,y,i} \times I_y \times P \text{ for road only} \quad (4.8)$$

Similarly, to estimate the total number of persons affected by the harmful effects of noise-induced HA and HSD the estimated risk statistic is applied in Commission Directive (EU) 2020/367 L67/136 as:

$$N_{x,y} = \sum[n_j * \mathrm{AR}_{j,x,y}] \quad (4.9)$$

Directive 2020/367 L 67/134 defines AR as the "occurrence of the harmful effect in a population exposed to a specific level of environmental noise". This does not indicate that only populations exposed to a certain threshold level (e.g. L_{den} greater than 53 dB or L_{night} greater than 43 dB) should be assessed. Hence, for the calculation of AR populations below these threshold levels were assessed for this analysis. Similar approaches have been applied in more recent research (e.g. Hegewald *et al.*, 2021).

4.2.4 Environmental noise-induced burden of disease – the application of risk

Burden of disease refers to the impact of a disease measured in terms of morbidity and mortality. It is commonly quantified in terms of DALYs, which combine morbidity, quantified as the number of years lost owing to a disability or disease state (YLD), and mortality, quantified as the number of years of life lost (YLL) due to premature death caused by a disease state. According to Prüss-Üstün and Corvalán (2006), one DALY can be conceived as 1 year of healthy life lost, and the overall measure of burden of disease can be considered to be a measure of the differential between the prevailing health status of a population compared with an ideal health status (e.g. where the individual lives to the average national life expectancy of their gender and is free of disease). As described in WHO (2011, p. xiv) the method for environmental noise burden of disease assessment is as follows:

$$\sum_i (N_i^m \cdot L_i^m + N_i^L \cdot L_i^f) + (I \cdot \mathrm{DW} \cdot D) \quad (4.10)$$

$$\mathrm{YLL\ (Mortality)} + \mathrm{YLD\ (Morbidity)} = \mathrm{DALYs}_N \quad (4.11)$$

Similar to the application of risk in the estimation of harmful effects, PAF and AR statistics are applied to noise-induced cardiovascular disease estimates and noise-induced HA and HSD estimates, respectively, to arrive at an estimate. By applying the risk statistic, the noise-induced burden of disease (see WHO, 2011) is estimated for noise-induced cardiovascular disease as:

$$\sum_i (N_i^m \cdot L_i^m + N_i^L \cdot L_i^f) + (I \cdot \mathrm{DW} \cdot D) \times \mathrm{PAF}_{x,y,i} \quad (4.12)$$

$$\mathrm{YLL\ (Mortality)} + \mathrm{YLD\ (Morbidity)} = \mathrm{DALYs}_N \quad (4.13)$$

and, for noise-induced Ha/HSD, as:

$$\sum_i (I \cdot \mathrm{DW} \cdot D) \times \mathrm{AR}_{j,x,y} \quad (4.14)$$

$$\mathrm{YLD\ (Morbidity)} = \mathrm{DALYs}_N \quad (4.15)$$

The discussion will now turn to the application of incidence and prevalence-based approaches in the assessment of environmental noise.

4.2.5 The application of incidence and prevalence statistics

In epidemiology, incidence is essentially the number of newly diagnosed cases of disease in a period, whereas prevalence is the number of persons within a population currently experiencing a particular disease state (Rothman, 2012). It is important to note that both incidence and prevalence statistics are commonly used in environmental noise-related burden of disease analysis. For example, with respect to environmental noise, Tobollik *et al*. (2019) apply a prevalence-based approach when examining the burden of disease from road traffic, railway and aircraft noise in Germany, as do similar burden of disease analyses (e.g. Begou *et al*., 2020). However, incidence and prevalence statistics are qualitatively and quantitatively different and cannot be compared. The former relates only to new cases of a disease state diagnosed in a given period, typically a calendar year, while the latter refers to all cases of the disease present within a population during the period regardless of the time of first diagnosis. Therefore, annual rates generated using prevalence-based approaches will inevitably be higher, and often far higher, than rates generated using incidence-based approaches for disease states that tend to affect individuals for longer than a year. In the *Burden of Disease from Environmental Noise: Quantification of Healthy Life Years Lost in Europe* (WHO, 2011), while it is stated that incidence statistics should be used in calculations (WHO, 2011, p. 7), when discussing national health data to be applied in calculations, the terms incidence and prevalence are used interchangeably throughout the document (see WHO, 2011, pp. 8, 9, 19, 21, 23). However, the application of prevalence in the estimation of risk is incorrect. This is because, unlike prevalence, risk depends on the percentage of an at-risk population that presents with a particular disease state within a particular time period (Alexander *et al*., 2017). Incidence statistics should always be applied in preference to prevalence statistics when both are available if risk is to be assessed correctly. It should be stated at this point that the present analysis applies an incidence-based approach to the assessment of environmental noise-induced disease, akin to similar research (e.g. Mueller *et al*., 2017).

4.3 Methodology

This section outlines the methodology employed to assess the harmful effects and burden of disease related to noise-induced IHD, HA and HSD in the Irish population for 2017. The first section describes the process of estimating population exposure using acoustic propagation models where datasets were available using the CNOSSOS-EU method. The second section describes the methodology used to perform the "noise–health" assessments, including the health and demographic data required.

4.3.1 Estimating population exposure to environmental noise

In estimating population exposure to environmental noise in Ireland, the new CNOSSOS-EU calculation method was applied where possible. In the context of road sources within the Dublin and Cork agglomerations, round 3[8] acoustic propagation models, provided by local authorities, were calculated using the CNOSSOS-EU method (see Murphy *et al*., 2021, pp. 31–38 for a full description). It is important to note that analysis of round 3 data indicated that the extent of road source polyline data (excluding buffer zone) varied considerably across local

8 Round 3 refers to the third round of the strategic noise mapping process 2017.

authorities (see section 5.5 for information regarding recommendations associated with this issue). For affected local authority areas, noise models were generated for a complete road network, in addition to that applied for the round 3 (2017) strategic noise mapping process. Estimated traffic flow values derived from round 3 data were systematically applied using OSi road typology profiles (see Murphy *et al*., 2021, pp. 34–37). The CNOSSOS-EU calculation method was also applied to round 3 datasets in the context of rail sources within the Dublin agglomeration. Models for rail sources were generated for Luas tram rail and Irish Rail (see Murphy *et al*., 2021, pp. 37–38).

In accordance with the CNOSSOS-EU method, an assessment of noise levels at the most exposed façade of buildings with one dwelling was applied in combination with an assessment of noise levels at each façade in the case of residential buildings with more than one dwelling, as per Commission Directive (EU) 2015/996; L168/94-5 (European Union, 2015). The number of inhabitants per building under CNOSSOS-EU was estimated using CASE 1B criteria:

$$\text{Inh}_{\text{building}} = v_{\text{building}}/v_{\text{total}} \times \text{Inh}_{\text{total}} \quad (4.16)$$

Table 4.1 shows the number of persons exposed to road traffic and railway noise levels using this approach. Estimates were calculated using the CNOSSOS-EU methodology and lower cut-off levels for road and rail sources were set in accordance with WHO (2018) guidelines and Commission Directive (EU) 2020/367. Acoustic modelling was performed using Predictor LimA version 2019.3.

4.3.2 *Population exposure using statistics submitted under round 3 strategic noise mapping, 2017*

Owing to the unavailability of specific datasets, acoustic propagation models were not generated for the present analysis in a number of limited cases. For road and rail sources outside agglomerations, for rail sources within the Cork agglomeration, and in the context of major airports, population exposure estimates were derived from results reported to the European Commission under the previous round of strategic noise mapping in 2017, in which the CRTN-TRL method was used for road sources, the RMR-1996 method for rail sources and the third edition of European Civil Aviation Conference Doc 29 of the *Report on Standard Method of Computing Noise Contours around Civil Airports* (ECAC, 2005) was used for aircraft sources. Table 4.2 shows the number of persons exposed to road traffic, railway and aircraft noise levels above 55 dB L_{den} and 50 dB L_{night}.

4.4 Methodology for Assessment

4.4.1 *Required data*

To calculate the harmful effects of environmental noise as presented in Commission Directive (EU) 2020/367, the following data are required for the year in question:

- national population statistics;
- national incidence estimates;
- RR estimates;
- AR estimates.

Table 4.1. Number of inhabitants exposed to road and rail noise sources in Ireland as of 2017 (CNOSSOS-EU)

Road traffic noise (round 3 dataset)			Road traffic noise (OSi dataset)		Railway noise		
dB	L_{den}	L_{night}	L_{den}	L_{night}	dB	L_{den}	L_{night}
45–49		375,746		330,757	44–45		27,488
50–52		196,190		231,053	46–49		54,956
53–54	159,330	104,942	178,382	114,596	50–53		10,105
55–59	418,766	192,942	515,142	237,346	54–55	29,952	8517
60–64	272,700	171,345	349,718	219,738	56–59	44,756	8269
65–69	147,821	37,294	152,980	38,596	60–64	36,827	5391
70–74	56,490	2416	64,326	2700	65–69	12,034	781
>75	13,570	94	16,896	96	70–74	3219	306
					>75	169	3

Note: Blank cells indicate that these figures are under the prescribed noise limit threshold outlined under the END. Therefore, they do not represent population exposure estimates and are not reported for strategic noise mapping purposes.

Table 4.2. Number of inhabitants exposed to road, rail and aircraft noise sources (round 3 statistics, 2017)

	Road traffic noise outside agglomerations		Railway noise – Cork agglomeration		Railway noise outside agglomerations		Aircraft noise – Dublin and Cork agglomerations[a]	
dB	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}
50–54		69,700		100		4500		620
55–59	96,500	57,700	300		6500	1700	26,700	400
60–64	64,500	19,300	100		5500	300	1500	
65–69	51,500	500			1100		300	
70–74	15,500				100			
> 75	300							

[a]Ireland did not report round 3 population exposure statistics for aircraft noise outside agglomerations

Population statistics were acquired for 2017 from Central Statistics Office Ireland (CSO, 2017) for the year ending April 2017. Incidence estimates for Ireland were acquired from the Global Burden of Disease (GBD) database for 2017[9] (Institute for Health Metrics and Evaluation, no date). The GBD database is a systematic quantification of health status and includes incidence statistics for all EU Member States. Its estimates are derived from surveillance data, survey data and outpatient and inpatient registration (Wilkins *et al.*, 2017). It should be noted that the GBD database is regularly updated and therefore statistics change regularly for all years starting from 1990. RR and AR estimates were obtained from the latest meta-analysis performed by WHO (2018), as previously described.

To calculate burden of disease as presented in WHO (2011) the following data are required for the year in question:

- national population statistics;
- national incidence estimates;
- national mortality estimates;
- national life expectancy estimates;
- duration of disability estimates;
- disability weight (DW) estimates;
- RR estimates;
- AR estimates.

Population, incidence, RR and AR assumptions were obtained as previously described. Mortality and life expectancy estimates, required to calculate the YLL, were derived from the CSO Vital Statistics for 2017 (CSO, 2017). Duration of disability and DW estimates were acquired from WHO (2004, 2011, 2018) where appropriate.

4.4.2 *Calculating road traffic noise-induced ischaemic heart disease*

Assumptions specific to the assessment of road traffic noise-induced IHD for an Irish population as of 2017 are described in Table 4.3:

4.4.3 *Calculating noise-induced high annoyance*

Unlike calculations regarding the harmful effects and burden of disease related to environmental noise-induced IHD, relatively few assumptions are needed to estimate noise-induced HA, and these relate only to burden of disease calculations. Table 4.4 outlines these assumptions.

4.4.4 *Calculating noise-induced high sleep disturbance*

Similar to the assessment of HA, relatively few assumptions are required to estimate noise-induced HSD compared with noise-induced IHD. Table 4.5 outlines the assumptions as they relate to DW and duration of disability.

4.5 Results

This section outlines the results pertaining to the assessment of the harmful effects and burden of

9 Data retrieved via http://ghdx.healthdata.org/gbd-results-tool (accessed 31 March 2022).

Table 4.3. Assumptions used for the assessment of road traffic noise-induced IHD

Indicator	Male	Female	Total	Degree of error[a] (95% CI and DW range)	Source
Incidence cases	9260	4416	13,676	1.01–1.15	GBD database 2017
Incidence rate			0.29		Calculated
Incidence RR			1.08		van Kempen *et al.* (2018)
Mortality RR			1.05	1.01(0.97)–1.13	van Kempen *et al.* (2018)
Mortality	2526	1712	4238		CSO (2017)
Life expectancy	82	85.5	83.75		CSO (2017)
DW			0.405	0.405–0.477	WHO (2004, 2018)
Duration of disability			1 year		WHO (2011)

Note: Based on the total population in Ireland for the year 2017 (4,792,500).

[a]Where RR values are reported as ≤1.00 by van Kempen *et al.* (2018), an RR value of 1.01 is applied to perform the RR calculation. An RR of 1.01 represents the lowest possible risk statistic that can be utilised to calculate RR. This is because, as previously described, RR values of 1 represent no risk.

Table 4.4. Assumptions used for the assessment of noise-induced HA

Indicator	Total	Degree of error (DW range)	Source
DW	0.020	0.010–0.120	WHO (2004, 2018)
Duration of disability	1 year		WHO (2011)

Table 4.5. Assumptions used for the assessment of noise-induced HSD

Indicator	Total	Degree of error (DW range)	Source
DW	0.070	0.040–0.100	WHO (2009, 2018)
Duration of disability	1 year		WHO (2011)

disease related to noise-induced IHD, HA and HSD in the Irish population in 2017.

Table 4.6 describes the PAF and attributable cases estimated for the harmful effects of road traffic noise-induced IHD for the Irish population as of 2017, and, in the context of road sources, describes results for both a round 3 road profile and an OSi road profile (see section 4.3.1). The table shows that 256 cases (i.e. 1.87% of total IHD incidence) of road traffic noise-induced IHD were estimated for the Irish population as of 2017.

Table 4.7 outlines burden of disease results for road traffic noise-induced IHD according to mortality and morbidity PAF and in terms of the YLLs, YLDs and DALYs. The table shows that an estimated 3445 DALYs were attributable to road traffic noise-induced IHD as of 2017, composed of 3360 YLLs (0.95% of total IHD mortality) and 85 YLDs (1.85% of total IHD incidence).

Table 4.8 outlines the number of attributable cases estimated for the harmful effects of road traffic noise-induced HA for the Irish population in 2017. The table shows that 267,580 cases (5.58% of the total population) of road traffic noise-induced HA, 25,247 cases (0.53% of the total population) of railway noise-induced HA and 3644 cases (0.08% of the total population) of aircraft noise-induced HA were estimated for Ireland as of 2017.

Table 4.6. Harmful effects of road traffic noise-induced IHD in Ireland in 2017

Indicator	Round 3 road profile		OSi road profile	
	PAF (%)	Cases	PAF (%)	Cases
Total for agglomerations	3.70 (0.48–6.74)[a]	173 (22–313)	4.59 (0.60–8.29)	203 (26–367)
National total[b]			1.87 (0.23–3.40)	256 (32–474)

[a]Figures in parentheses are the 95% CI.

[b]The national total estimate accounts for major road sources outside agglomerations and is calculated for the entire population of Ireland as of 2017.

Table 4.7. Burden of disease from road traffic noise-induced IHD in Ireland in 2017

	Round 3 road profile					OSi road profile				
	Mortality PAF	YLL	Morbidity PAF	YLD	DALYs	Mortality PAF	YLL	Morbidity PAF	YLD	DALYs
National total	0.81	2851	1.63	72	2923	0.95	3360	1.85	85	3445
Minimum	0.16	573	0.16	9	582	0.19	676	0.19	11	687
Maximum	2.08	7355	2.40	158	7513	2.44	8641	2.81	186	8827

Minimum and maximum values represent the range of uncertainty.

Table 4.8. Harmful effects of environmental noise-induced HA in Ireland in 2017

Attributable cases (number)	Round 3 road profile	OSi road profile	Railway noise	Aircraft noise[a]
Total for agglomerations	174,124	206,466	22,897	3644
National total		267,580	25,247	3644

[a]Ireland did not report round 3 population exposure statistics for aircraft noise outside agglomerations and therefore estimations for populations within agglomerations and nationally are identical.

Table 4.9 outlines the estimated YLDs relating to the burden of disease associated with road traffic, railway and aircraft noise-induced HA for the Irish population as of 2017. The table shows that 5351 YLDs were estimated in relation to road traffic noise-induced HA for 2017, 442 YLDs were estimated in relation to railway noise-induced HA and 73 YLDs were estimated in relation to aircraft noise-induced HA in Ireland for 2017.

Table 4.10 outlines the estimated number of attributable cases associated with the harmful effects of road traffic, railway and aircraft noise-induced HSD in the Irish population for 2017. The table shows that 95,870 cases (2% of the total population) of road traffic noise-induced HSD, 13,721 cases (0.91%) of railway noise-induced HSD and 360 cases (0.01%) of aircraft noise-induced HSD were estimated as of 2017.

Table 4.11 outlines the estimated YLDs associated with the burden of disease caused by road traffic, railway and aircraft noise-induced HSD in the Irish population for 2017. The table shows that 4568 YLDs were estimated in relation to road traffic noise-induced

Table 4.9. Burden of disease (YLDs) from environmental noise-induced HA in Ireland in 2017

Attributable cases (number)	Round 3 road profile	OSi road profile	Railway noise	Aircraft noise
Total for agglomerations	3482 (1740–20,893)	4129 (2064–24,774)	401 (200–2401)	73 (26–308)
National total		5351 (2067–26,384)	442 (201–2557)	73 (26–308)

Note: Values in parentheses indicate the margin of error.

Table 4.10. Harmful effects of environmental noise-induced HSD in Ireland in 2017

Attributable cases (number)	Round 3 road profile	OSi road profile	Railway noise	Aircraft noise
Total for agglomerations	64,132	75,216	13,387	360
National total		95,870	13,721	360

Table 4.11. Burden of disease (YLDs) from noise-induced HSD in Ireland in 2017

Attributable cases (number)	Round 3 road profile	OSi road profile	Railway noise	Aircraft noise
Total for agglomerations	2969 (1697–4240)	3584 (2048–5119)	180 (103–257)	27 (15–39)
National total		4568 (2053–5452)	185 (103–261)	27 (15–39)

Note: Values in parentheses indicate the margin of error.

HSD for 2017, 185 YLDs were estimated in relation to railway noise-induced HA and 27 YLDs were estimated in relation to aircraft noise-induced HA.

4.6 Discussion

4.6.1 Interpreting and contextualising results

In summation, road traffic noise is by far the most influential contributor to noise-induced harmful effects and burden of disease, followed by railway and aircraft noise. In terms of both harmful effects assessment and burden of disease estimation, HA is the largest contributor to environmental noise-induced cases and DALYs, followed by HSD and IHD. More specifically, in relation to road traffic noise-induced IHD, the results indicate an estimated 256 cases of IHD attributable to road traffic noise for the Irish population in 2017. This figure represents 1.87% of all 13,676 IHD cases in Ireland in that year. In terms of burden of disease, the figure is equivalent to 3445 DALYs for road traffic noise-induced IHD. This burden of disease estimate represents 4.09% of the 84,251 IHD DALYs reported in the GBD database[10] (The Institute for Health Metrics and Evaluation, no date) for Ireland in 2017. In relation to road traffic noise-induced HA, results indicate an estimated 267,580 cases of HA attributable to road traffic noise. To contextualise these estimated statistics, this represents 5.58% of the total population and 14.01% (206,466 cases) of the population in agglomerations. In terms of burden of disease, the figure is equivalent to 5351 YLDs for road traffic noise-induced HA. In relation to road traffic noise-induced HSD, the results indicate an estimated 95,870 cases of HSD attributable to road traffic noise for the Irish population in 2017. This represents 2.00% of the total population and 5.89% (75,216 cases) of the population in agglomerations. In terms of burden of disease, the figure is equivalent to 4568 YLDs for road traffic noise-induced HSD.

4.6.2 Burden of disease results – comparison with other disease states

In relation to burden of disease estimation for noise-induced IHD, HA and HSD, a total of 14,091 DALYs were estimated to be associated with noise-induced disease in the Irish population in 2017. The vast majority of these were attributed to road traffic noise (i.e. 13,364 DALYs). According to the GBD database,[11] this estimate represents 1.22% of estimated DALYs for all disease states (i.e. 1,152,427 DALYs) in Ireland for 2017. The estimate is higher than estimated DALYs for air pollution (i.e. 10,685 DALYs), an observation which corresponds with research by Mueller *et al*. (2017) and Tainio (2015). The estimated DALY statistic for noise-induced disease is also higher than DALY estimates for low intake of fruits and vegetables (i.e. 12,922 DALYs), and is similar to the Irish DALY estimate for child and maternal malnutrition (i.e. 14,243 DALYs). This is noteworthy, since Eriksson *et al*. (2017) reported that DALY estimates for environmental noise were similar to and not higher than that for low intake of fruits and vegetables in the Swedish context. This comparison with other disease states emphasises the need for policy and planning authorities to regard environmental noise as a serious health concern for the Irish population.

4.6.3 Comparison with international literature

While direct comparison of related studies across nations is difficult, it is nevertheless useful for understanding and contextualising results. In particular, it is notable that cross-national research may vary considerably according to (1) assessment methodology; (2) population exposure estimation methodology; (3) counterfactual parameters; (4) population exposure characteristics; (5) incidence characteristics; (6) underlying attributes associated with particular populations; and (7) approaches to the strategic noise mapping process, including the selection of sources that are mapped. In the last context, it should be noted that it is unlikely that Ireland is an exception in terms of inconsistencies in population exposure results reported under the END.

Overall, the results from harmful effects and burden of disease estimation (Tables 4.12 and 4.13) are, to varying degrees, analogous with international literature, but differ from research conducted by the EEA (EEA, 2020), possibly due to the application of

10 Data retrieved via http://ghdx.healthdata.org/gbd-results-tool (accessed 31 March 2022).

11 Data retrieved via http://ghdx.healthdata.org/gbd-results-tool (accessed 31 March 2022).

Table 4.12. Comparison with international literature: harmful effect estimation

	Risk assessment							
Indicator	**Ireland**	**EEA-33[a]**	**Western Europe[b]**	**Germany[c]**	**Sweden[d]**	**Barcelona[e]**	**Warsaw[f]**	**Belgrade[g]**
Road traffic noise								
IHD PAF	1.87%		1.80%					
IHD cases	256	368				271		
HA cases	267,580	156,038		262,707	131,668			
HSD cases	95,870	40,427		91,660	85,630			
Railway noise								
HA cases	25,247	31,817		26,296	5505			
HSD cases	13,721	15,998		13,415	3939			
Aircraft noise								
HA cases	3644	10,315		16,159				
HSD cases	360	2287		3031				
IHD DALYs	3445						3395	4817
IHD YLDs	85					122		
HA YLDs	5351	6382		5254	2871	6972		
HSD YLDs	4568	4876		5994	4118	3575		

[a]EEA (2020). The 33 member countries of the EEA (EEA-33) included in this analysis do not include Turkey but do include the UK, a former member. Statistics are extrapolated to the equivalence of the Irish population. It should also be noted that burden of disease statistics outlined in EEA (2020) refer to all sources of environmental noise, including industrial sources. Since Ireland does not produce these statistics, they were not included in this analysis.

[b]WHO (2011). Statistics are extrapolated to the equivalence of the Irish population.

[c]Tobollik *et al.* (2019). Statistics are extrapolated.

[d]Eriksson *et al.* (2017). Statistics are extrapolated.

[e]Mueller *et al.* (2017).

[f]Tainio (2015).

[g]Paunović and Belojević (2014). Statistics are extrapolated.

differing incidence statistics[12] and to the utilisation of an incomplete Irish dataset for road sources submitted under the END. In relation to road traffic and railway noise, a general trend appears whereby Irish estimates appear to be similar to those from Germany and the WHO (2011) Western European average while being higher than Swedish estimates (apart from HSD YLDs for Germany, which appear to be significantly higher than other estimates). Again, in relation to EEA (2020), estimations for road traffic noise are much lower than population exposure estimations, possibly because an incomplete profile of road sources is used. The general trend found in studies is not apparent in relation to aircraft noise, as in this case Irish estimates appear quite dissimilar to the German and European averages. Other notable observations include the fact that estimates of noise-induced IHD cases are comparable to those in Barcelona, whereas estimates for IHD YLDs and HA YLDs are lower and estimates for HSD YLDs are higher. Finally, in terms of IHD DALYs, Irish estimates corresponded well with estimates from Warsaw but were lower than estimates for Belgrade.[13] Hence, while the results for road traffic and railway noise-induced harmful effects

12 As previously mentioned, the GBD database is regularly updated and hence incidence statistics may vary depending on when the data are accessed. For example, in 2018 the GBD database presented 15,364 incidence cases of IHD for Ireland in 2016, which was accessed by the EEA (2020) in 2018. Accessing these data in 2021, the GBD database presents 13,561 cases of IHD for Ireland in 2016 (see http://ghdx.healthdata.org/gbd-results-tool; accessed 1 April 2022).

13 However, caution should be advised in respect to this study, since the estimate was based on a cohort analysis of 6000 inhabitants in Belgrade. Moreover, it is unclear whether or not IHD incidence statistics were used for the analysis, reinforced by the fact that results are compared with a prevalence-based study by Stassen *et al.* (2008). This suggests that direct comparative analysis may be problematic in this instance.

Table 4.13. Comparison with international literature: burden of disease estimation

	Risk assessment							
Indicator	Ireland	EEA-33[a]	Western Europe[b]	Germany[c]	Sweden[d]	Barcelona[e]	Warsaw[f]	Belgrade[g]
Road traffic noise								
IHD DALYs	3445						3395	4817
IHD YLDs	85					122		
HA YLDs	5351	6382		5254	2871	6972		
HSD YLDs	4568	4876		5994	4118	3575		
Railway noise								
HA YLDs	442	342		511	110			
HSD YLDs	185	264		939	276			
Aircraft noise								
HA YLDs	73	191		323				
HSD YLDs	27	364		212				

[a]EEA (2020). The 33 member countries of the EEA (EEA-33) included in this analysis do not include Turkey but do include the UK, a former member. Statistics are extrapolated to the equivalence of the Irish population. It should also be noted that burden of disease statistics outlined in EEA (2020) refer to all sources of environmental noise, including industrial sources. Since Ireland does not produce these statistics, they were not included in this analysis.

[b]WHO (2011). Statistics are extrapolated to the equivalence of the Irish population.

[c]Tobollik *et al.* (2019). Statistics are extrapolated.

[d]Eriksson *et al.* (2017). Statistics are extrapolated.

[e]Mueller *et al.* (2017).

[f]Tainio (2015).

[g]Paunović and Belojević (2014). Statistics are extrapolated.

and burden of disease assessment are generally similar to international findings, this is not the case for aircraft noise, which appears to have considerably lower adverse effects in Ireland and contrasts with trends exhibited in relation to road traffic and railway noise. While direct comparison of related studies across nations is difficult, it is nevertheless useful for understanding and contextualising results.

4.6.4 Harmful effects and burden of disease assessment

Commission Directive (EU) 2020/36 introduces a new assessment methodology which has not been officially utilised by EU Member States in the delivery of the END to date. Previously, assessment of environmental noise-induced disease was predominantly calculated using burden of disease methodologies. By utilising both approaches and by comparing the results produced, significant differences were found between both approaches. As such, it appears that the assessment of harmful effects methodology may be preferential to the burden of disease estimation for the following reasons:

1. The harmful effects methodology is more efficient, fewer health data are necessary and it requires less calculation.
2. For assessment that requires the application of incidence statistics, results can be obtained for spatially localised areas rather than overall national figures.
3. Results from harmful effects assessment may be easier to interpret, e.g. it may be easier to comprehend the concept of a disease case rather than a disease DALY.

On the first point, apart from population statistics that are required for both assessments, only incidence statistics are required for harmful effects calculations. On the second point, because harmful effects assessment utilises incidence rates, which represent the proportion of incidence within the population, calculation can potentially be performed at any spatial scale, even at the district electoral division geographical level, if required.

4.7 Study Limitations

Results from this analysis are based on the assumption that the RR estimates (WHO, 2018) are applicable to the Irish context. Apart from potential inaccuracies caused by degree of error, another source of inaccuracy relates to exposure to multiple sources. The assessment of harmful effects and burden of disease does not take multiple sources into account. The lack of ability to quantify the negative health impacts caused by multiple noise sources may lead to considerable underestimation (see Pyko *et al.*, 2015). Another source of inaccuracy involves the presence of air pollution, which is currently unaccounted for in noise assessment methodology, and the potential interaction effects of other multiple pollutants. It should also be noted that this study focused on exposure to environmental noise at residential dwellings only. For this reason, potential negative health impacts associated with work place environments, recreation areas, schools and hospitals were not considered. Finally, acoustics models representing a full road network were generated using a systematic application of default values derived from round 3 data and applied using OSi road typology profiles (see Murphy *et al.*, 2021, pp. 34–38). Ideally, acoustic models would have benefited from estimating traffic flow using traffic simulation models in the absence of real-time data; however, this was not possible considering the scope of this research project.

4.8 Conclusion and Recommendations for Practitioners

From an international perspective, this is the first estimation of harmful effects from environmental noise in a European country. From a national perspective, this is the first estimation of burden of disease from environmental noise in Ireland. We estimated that 256 noise-induced IHD cases, 296,471 HA cases and 109,951 HSD cases, as well as 14,091 DALYs, were attributable to environmental noise from road traffic, railways and aircraft. Results from this analysis indicate that exposure to environmental noise, particularly road traffic noise, accounts for a relatively large proportion of all IHD disease, and those affected by HA and HSD represent a large proportion of the population. In general, these results are in line with the European average and are to be expected. However, the European Commission has recognised that transport noise is a major environmental concern in Europe and that transport-based noise needs to be mitigated as a matter of urgency across the EU. In the light of this, an adequate policy response is required in the Irish context. National noise planning guidance for local authorities is needed to (1) support and promote the proactive management of noise, (2) implement the noise objective in *Project Ireland 2040. National Planning Framework 2040* (Government of Ireland, 2019a) and (3) consider the 2018 WHO noise and health guidelines (see Wall *et al.*, 2020). In relation to assessing the negative health impacts of environmental noise, the following recommendations are suggested for practitioners:

1. Practitioners should apply the harmful effects method outlined in Commission Directive (EU) 2020/367 rather than the burden of disease method outlined in WHO (2011) because the harmful effects method is more efficient, fewer health data are necessary, it requires less calculation time, it permits spatially localised estimates and results may be easier to interpret.
2. Practitioners should apply only incidence rates in the estimation of risk, not prevalence. To do otherwise will lead to an overestimation of HA and burden of disease.
3. It may be worth reconsidering population exposure statistics for major airports in Ireland because, unlike road traffic and railway noise, the results for aircraft noise reported by Ireland are dramatically different from those reported by international comparators. In this regard it is notable that exposure estimates for aircraft noise were based solely on round 3 data and were thus not modelled for this analysis.
4. If required, disability weight (DW) and duration of disability estimates should be acquired from the latest WHO publications.
5. Relative risk (RR) and absolute risk (AR) estimates should be acquired from the latest WHO publications.

5 Managing Environmental Noise in Ireland

5.1 EU-level Environmental Noise Directive-related Policy and Practice

5.1.1 The European policy context

The policy objective that populations should not be exposed to levels of environmental noise considered harmful to their health and quality of life was first established by the Fifth Environmental Action Programme of the European Community (EC) in 1993 (European Communities, 1993). This was followed in 1996 by the European Commission's (EC) Green Paper entitled *Future Noise Policy* (European Commission, 1996), published to initiate debate around environmental noise abatement policy within the EU and to serve as the basis for future legislative proposals. Clearly delineating noise as a pollutant, the document proposed a new framework for noise policy, calling for a directive aiming to harmonise methods of assessing noise exposure across Europe and facilitate an exchange of information. The document outlined a proposal for noise mapping to achieve such objectives, as well as providing information on noise exposure to the wider public. Ultimately, the document aimed to make noise abatement a higher priority in European policymaking.

In response to such developments, and particularly with respect to progress in the study of non-auditory health-related outcomes associated with the impact of environmental noise on urban populations, WHO first published guidance relating to environmental noise in 1999, *Guidelines for Community Noise* (WHO, 1999), followed, 10 years later, by *Night Noise Guidelines for Europe* (WHO, 2009). The documents addressed issues relating to the measurement, health implications, guideline values and management of environmental noise. In 2011, WHO produced guidance regarding the quantification of negative health outcomes caused by exposure to high levels of environmental noise in European populations (WHO, 2011). The document presented a review of scientific evidence and case study analysis that informed the generation of dose–effect relations to instruct European health policy practitioners on how to perform environmental noise-induced burden of disease calculations. In 2018, WHO published new noise guidelines for the European region, updating its recommendations regarding environmental noise in Europe (WHO, 2018), presenting new noise limit guidelines and new parameters for the exposure–response relationship, based on the latest scientific evidence.

Following this, Annex III of Commission Directive 2002/49/EC, referring to the provision of dose–effect relations in the assessment of harmful effects caused by environmental noise, was amended with the ratification of Commission Directive (EU) 2020/367. Directive (EU) 2020/367 describes how harmful effects are to be calculated for IHD, HA and HSD in the context of road, rail and aircraft noise. This Directive represents a major development in terms of "noise–health" policy in Europe, since the outlined methodology may be a requirement for all EU Member States as part of the strategic noise mapping process from 2022 onwards.

5.1.2 Limit values

The END does not prescribe limit values for population exposure to potentially harmful levels of noise in the context of L_{den} and L_{night}. It is therefore open to each EU Member State to apply such limits for its national context. The European Commission (2000) regards it as inappropriate to apply generic EU-wide limit guidelines because of the diversity in the extent and quality of noise abatement measures implemented cross-nationally. Nevertheless, WHO first delineated standardised noise limit guidelines over 20 years ago. Although it is technically open to EU Member States to set their own limit values, Murphy and King (2010) emphasise the importance of establishing limit value guidance at an EU level for L_{den} and L_{night} so that cross-national analyses of the dose–response relationship[14] between noise and health is possible. Juraga *et al*.

14 The dose–response relationship is defined by Crump *et al.* (1976) as the magnitude of the response of an organism as a function of exposure to a stimulus or stressor after a certain exposure time.

(2015) also emphasise the non-enforcement of limit values as a major impediment in the implementation of the END.

For the national context, despite most EU Member States having established compulsory noise limit values enforced by law (Guarinoni *et al*., 2012), at present there are no statutory noise limits defined in Ireland, although noise limits can be set with respect to certain activities under EPA Industrial Emissions Directive (IED) licensing (see European Commission, 2016).

5.1.3 Quiet areas

Regarding the actual definition of quiet areas, the use of the term in the END is vague: there is no indication of the required noise level a location should have to be defined as a quiet area. This is problematic, since it may result in a lack of awareness among policymakers regarding the need to preserve favourable acoustic environments under the terms of the END. The rationale for such vague definition relates to the European Commission's consideration of national and local idiosyncrasy in identifying and preserving quiet areas (Guarinoni *et al*., 2012). However, the absence of a clear definition has led to confusion regarding the exact purpose of quiet areas in the context of the END, whereby disparate methodologies are applied in the definition of quiet areas by different EU Member States. Hence, it seems important that, if harmful noise levels across Member States are to be comparable, noise levels applicable to quiet areas requiring preservation should be too, so that a comprehensive picture of the acoustic environment across the EU can be achieved. Juraga *et al*. (2015) have highlighted that the diverse interpretation and approaches taken to identifying quiet areas has been a major problem in terms of implementing the END.

A number of recent studies have attempted to classify quiet areas more precisely than is outlined in the END. For example, Blanes *et al*. (2019) classify areas in Prague using L_{den} > 55 dB(A) from L_{den} < 55 dB(A) and then, utilising the CORINE (Coordination of Information on the Environment) Land Cover classification system, apply an urban typology to identify potential areas of residential, commercial, open space street and roads, and green space classifications of quiet areas. The "Open source soundscape" pilot project (Radicchi, 2017), which incorporates the Hush City application (Radicchi *et al*., 2016)[15], aims to provide a mixed methodology to identify and analyse quiet areas. Qualitative and quantitative data are collected using interviews, "group soundwalks", and the Hush City application (Radicchi, 2017). These data are then analysed to provide a better understanding of what constitutes a "quiet area" within an agglomeration, with a view to developing a toolkit to preserve quiet areas (Raddicchi, 2017). The intention is to disseminate the results in workshop sessions and public presentations, with the findings contributing to further research in the area.

In a national context, Irish regulations implementing the END also fail to adequately define quiet areas (European Commission, 2016). While admitting that there is "no universally accepted definition of what constitutes a quiet area within an agglomeration" (EPA, 2009, p. 23), the EPA presents a methodology for defining quiet areas by cross-referencing locations on noise maps where noise levels are < 55 dB(A) L_{day} with areas of open space (e.g. public parks, recreational areas, beaches), with Dublin local authorities using a similar methodology (see Dún Laoghaire–Rathdown County Council, 2013). In the context of locations outside an agglomeration, research funded by the EPA attempted to define quiet areas in terms of minimum distance criteria from a noise pollution source (see Waugh *et al*., 2003). However, such research is considerably outdated and thus, Irish authorities may find more up-to-date research from Europe to be beneficial in this regard.

5.1.4 Public engagement

In common with many European countries, public awareness regarding the relationship between noise and health is currently low in Ireland. One of the requirements of the END is that information from the strategic noise mapping process should be disseminated to the public in ways that increase this awareness. It is therefore imperative that Member States advance appropriate strategies to achieve both

15 The "Hush City" application is a mobile app which enables the public to identify and assess quiet areas in cities in order to create an open access, web-based map of quiet areas, with the potential of orientating plans and policies for healthier living, in response to issues framed by European environmental policies.

a coherent level of public consultation and a more successful dissemination of information to the general public. According to the Milieu Ltd review (European Commission, 2010), public engagement remains highly problematic across Member States, with some countries finding it difficult to achieve a satisfactory level of public engagement because of time constraints, with some officials questioning whether or not public engagement is even useful considering that the general public may not be able to even interpret noise maps correctly owing to the technical nature of such maps. In Ireland, the primary tool of public engagement has been the presentation of strategic noise maps on the EPA website. There is no evidence in the literature to suggest that this situation has changed. According to King *et al*. (2011) it is problematic that these strategic noise maps can only be viewed in two dimensions, as such presentation may be difficult for the general public to understand. Reflecting Murphy *et al*.'s (2007) contention that providing a tool for associating numerical noise data with pragmatic acoustic data can serve as a device for relaying information on environmental noise to the general public in a manner more appropriate for public interpretation, Alsina-Pagès *et al*. (2019) carried out a pilot project that has audio-mapped the acoustic environment of a city in Andorra using a similar 3D model. Such platforms may have more potential in terms of public engagement relative to traditional 2D presentations. More generally, there has been an increase in research into the use of crowdsourcing techniques in the strategic noise mapping process, smartphone technology being a dependable and cost-effective substitute for traditional approaches to noise mapping in agglomerations (Murphy *et al*., 2020). This not only involves the public in generating cheaper alternatives to noise mapping, but also achieves a specific form of public engagement through direct involvement in the process. For example, the "iNoiseMapping" project is a crowdsourcing application that compiles and stores data collected by participants using smartphone devices with environmental noise monitoring apps for subsequent analysis (Picaut *et al*., 2019). Another alternative form of strategic noise mapping, called dynamic noise mapping (DNM), has been developed by Bellucci *et al*. (2017). DNM enables the automatic upload of real-time information on environmental noise to an integrated network for the collection and measurement of data, thus enabling the system to identify and record the acoustic impact of environmental noise simultaneously (Bellucci *et al*., 2017). This is made possible by the development of low-cost sensors which can be sited at key locations throughout an agglomeration (Bellucci *et al*., 2017). Furthermore, DNM can provide up-to-date data on environmental noise to the public by way of online platforms or other social media tools.

Clearly, the availability of such social media platforms means that increasing public awareness of noise pollution is not only achievable through the presentation of strategic noise maps. Social media platforms such as Twitter and Facebook have the capability to engage the public and increase awareness among the public regarding the risk to human health posed by environmental noise and the importance of strategic noise mapping (in whichever form it may be presented) and the assessment of noise as a method for quantifying risk (Marques and Pitarma, 2019). For example, Dublin City Council has an active Twitter account, @dublincitynoise, which regularly posts measured noise levels from 14 continuous long-term monitoring devices[16] located across the Dublin City area as part of Dublin's ambient sound monitoring network, established in 2009. The Hush City app (Radicchi *et al*., 2016) is another approach to public participation: it allows members of public to determine and evaluate quiet areas within an agglomeration and encourages the public to be aware of the relationship between environmental noise and health.

Nevertheless, despite the increasing number of studies seeking to engage the public in the process of identifying and assessing environmental noise, and the increasing use of online platforms to increase public awareness, there is no evidence in the literature to suggest that large-scale public awareness of the relationship between environmental noise and health has been achieved.

5.2 National Policy and Practice

5.2.1 The Irish policy context

The END (2002/49/EC; EU, 2002) was transposed into Irish legislation by statutory instrument

16 These are Type 2 Sonitus Systems EM2010 sound level meter instruments.

S.I. No. 140/2006 (Environmental Noise Regulations 2006) (Government of Ireland, 2006). S.I. No. 549/2018 European Communities (Environmental Noise) Regulations 2018 replaced S.I. 140/2006 and was transposed into Commission Directive (EU) 2015/996. Within this legislation, environmental noise is defined as "unwanted or harmful outdoor sound created by human activities, including noise from transport, road traffic, rail traffic, air traffic, and from sites of industrial activity" (Government of Ireland, 2018, [S.I. No. 549] p. 3). The objective of the END is to produce a standardised method for the evaluation and, ultimately, the prevention of health risks caused by population exposure to environmental noise. To achieve this objective, EU Member States are obligated to create and publish strategic noise maps and noise management action plans every 5 years. The EPA has been designated the national authority for the purposes of these regulations in Ireland and exercises broad oversight with respect to fulfilling the requirements of the END.

Regarding environmental, transport and planning policy in Ireland, the relevant legislation concerning environmental noise pollution is the Environmental Protection Agency Act 1992 (Government of Ireland, 1992), with the Department of the Environment, Climate and Communications being responsible for operationalisation (see Figure 2.1). The legislation defines environmental pollution as including "noise that is a nuisance, or that would endanger human health or damage property or damage the environment" (Government of Ireland, 1992; [No. 7], p. 10). As the legislation enables a number of actions to be taken to prevent or mitigate noise pollution, this means that local authorities have legislative authority under the Act to stipulate measures to be taken to prevent or mitigate environmental noise pollution. The Act bestows authority to the EPA to take action to ensure compliance with the conditions of notice to control environmental noise in relation to any premises, process or works, and to recoup the expense of such an action. Therefore, the EPA has the authority to compel an individual or party to take specific action to prevent or mitigate environmental noise, and any individual or party required to take action is obligated to do so or face prosecution. Furthermore, the EPA has the authority to serve notice in relation to activities that it licenses, such as waste disposal operations and activities that require an IED licence under Directive 2010/74/EU (see European Commission, 2010; pp. 10–12 for further details and policy recommendations relating to current operation of IED licences). In relation to aircraft noise, the Irish Aviation Authority (https://www.iaa.ie) is responsible for aircraft noise management and control, while Fingal County Council's Airport Noise Competent Authority was appointed in 2019 to regulate aircraft noise at Dublin airport (Wall *et al*., 2020) under EU regulation No. 598/2014 (Government of Ireland, 2019a). EU regulations regarding the management of noise at large airports are administered in Ireland by S.I. No. 645/2003 *European Communities* (*Air Navigation and Transport Rules and Procedures for Noise Related Operating Restrictions at Airports*) *Regulations 2003* (Government of Ireland, 2003).

Table 5.1 lists the most important policy and legislative documents pertaining to the management of environmental noise in Ireland. The table outlines policy/legislative documents and goals, details relating to the nature and purpose of documents, the department responsible and the extent to which environmental noise is discussed within the documents.

Regarding environmental, transport, and planning policy in Ireland, the National Planning Framework (Government of Ireland, 2019a) provides a policy objective for the management of noise when it is considered to have a harmful effect on public health, with the Department of Housing, Planning and Local Government responsible for this policy objective (see Table 5.1). In line with both this objective and Directive 2014/52/EU, government-funded plans and programmes are required to conduct acoustic assessments as part of the environmental impact assessment reports (EIARs) submitted to the EPA (see section 5.2.4, p. 33, for further details and policy recommendations relating to EIARs). Although not a policy document, it should also be noted that the EPA's recent state of the environment report (see Wall *et al*., 2020) includes a specific chapter on noise for the first time since its inauguration and is part of a 4-year integrated environmental strategy for Ireland. It also includes a general outlook for the management of environment noise and mitigation policy in Ireland going forwards.

Finally, in relation to public health, *A Framework for Improved Health and Wellbeing 2013–2025*

Table 5.1. "Noise–Health" policy map

Policy/legislative document	Policy/legislative goal	Detail	Department	Coverage
S.I. No. 140/2006	Ratification of Directive 2002/49/EC into Irish law	Legislative basis for the assessment and management of environmental noise	Environment, Climate and Communications	Full
S.I. No. 549/2018	Ratification of Directive (EU) 2015/996 into Irish law	Legislative basis for the assessment and management of environmental noise	Environment, Climate and Communications	Full
Environmental Protection Agency Act 1992	To prevent or mitigate noise pollution	Provides legislative authority for local authorities and the EPA	Environment, Climate and Communications	2420 words
National Planning Framework	Promote the pro-active management of noise	National Policy Objective 64 – Noise Quality	Housing, Planning and Local Government	411 words
Environmental Impact Assessment Guidelines 2018	To provide a guidance document for environmental impact assessment	Consideration of human health in planning process	Housing, Planning and Local Government	21 words
A Framework for Improved Health and Wellbeing 2013–2025	Goal 3 – Indicators – Protect the public from threats to health and wellbeing	Healthy Ireland Indicator Description – compliance with environmental and food indicators	Health	15 words
Healthy Ireland Summary Report 2019	To enhance the monitoring and assessment of the various policy initiatives under the Framework	Assessment of disturbance by noise while trying to sleep	Health	76 words

(Government of Ireland, 2013) is intended as a call for action to improve the future health and wellbeing of Ireland's population, with the Department of Health ultimately responsible for this policy ambition. Within this framework, goal 3 presents indicators to assess public health and determine key priorities for improving the health and wellbeing of the population. An environmental component relating to air, water and noise is described as a single component within this document. However, to date, no environmental factors relating to either air, water or noise seem to be considered as indicators within the *Healthy Ireland Summary Report* (Government of Ireland, 2019b), although in this report noise is mentioned as a cause for sleep disturbance (see Table 5.1) but only as a participant response and not as a survey indicator. Although not a recommendation, the Noise–Health project suggests that it might be worth considering performing more environmental noise-related assessments in future Healthy Ireland surveys. In such cases, specific environmental noise-induced HA and HSD assessment could be performed using the latest evidence-based methodologies available.

5.2.2 Road source coverage in the strategic noise mapping process

In performing an estimation of population exposure for road sources in Dublin and Cork agglomerations using round 3 data provided by local authorities, the Noise-Adapt project (see Murphy *et al.*, 2021, pp. 31–38) found that the extent of road source polyline data (excluding buffer zone) assessed in the strategic noise mapping process varied considerably across local authority areas. Table 5.2 outlines the extent of the road network applied in round 3 datasets in Ireland relative to OSi's PRIME2 dataset, which is the official digital road source database for Ireland.

As is evident from the above statistics, while Dublin City performs an assessment for almost all road sources in the local authority area, other local

Table 5.2. Round 3 road source data compared with OSi PRIME2 road source data

Local authority area	Round 3 road coverage (km)	OSi road network (km)
Dublin City	1348 (97% coverage	1389
South Dublin	750 (59% coverage)	1275
Fingal	719 (39% coverage)	1842
Dún Laoghaire–Rathdown	206 (23% coverage)	888
Cork City	156 (31% coverage)	504

authority areas do not, with Dún Laoghaire–Rathdown performing particular poorly with only 23% road coverage. In terms of "noise–health" assessment, population exposure data are vital to the production of accurate estimates.

5.2.3 *Centralisation and the strategic noise mapping process*

Lack of coordination among authorities responsible for noise mapping is an issue commonly cited throughout the EU (Guarinoni *et al*., 2012). Findings from the Noise-Adapt project's focus group research (see Murphy *et al*., 2021, p. 45) with Irish local authorities also emphasises how a lack of coordination among Irish authorities is problematic, citing the need for a more coordinated approach to data collection, with better cooperation between responsible bodies also required so that all authorities implement strategic noise mapping and risk assessment in a uniform manner. If the END is to be successfully implemented across EU Member States, then a comprehensive and systematic national strategy for the evaluation and supervision of environmental noise should be generated. In the UK, the role of implementing the END through the strategic noise mapping process for major roads, railways and agglomerations is managed by a single body (i.e. Defra), with the national airport authority responsible for airports (Turner and Grimwood, 2009). In the Netherlands, a national support unit has been established which is responsible for progress control and provides knowledge-building tools and information exchange facilities via a tailor-made website and facilitates networking and regular meetings between responsible authorities (de Vos, 2009). Again, Noise-Adapt focus group research (see Murphy *et al*., 2021, p. 45) with Irish local authorities identified the need for a more centralised approach to strategic noise mapping both to ensure consistency and to avoid difficulties related to managing various departments involved in the process. Reflecting the situation in the Netherlands, focus group findings also emphasised the need for the development of shared resources to carry out actions for multiple local authorities, which would not only develop consistency and be more time efficient, but would also be a more efficient use of resources (see Murphy *et al*., 2021, p. 45).

5.2.4 *Noise management policy and practice in the Irish planning system*

As previously outlined, in Ireland, the *National Planning Framework* (Government of Ireland, 2019a) includes a specific policy objective for the proactive management of noise where it is deemed likely to have a significant adverse impact on health and quality of life and aims to support the Environmental Noise Regulations through national planning guidance and noise action plans. Therefore, in line with Directive 2014/52/EU, government-funded plans and programmes are required to conduct acoustic assessments as part of the EIARs submitted to the EPA. However, in practice this provision is currently operating at a suboptimal level in the Irish planning system. The issue is primarily related to the fact that no associated policy guidance documentation currently exists regarding the management of noise, which is primarily the responsibility of local authorities.[17] As such, local authorities are responsible for the regulation of most environmental noise sources in Ireland in terms of planning appraisal, the design of associated noise-related terms and conditions, the evaluation of compliance and the application of legal proceedings in response to non-compliance.

17 Responsibility also falls to the EPA but only in limited agricultural, industrial and waste management contexts.

In England, official environmental noise assessment guidance regarding new residential development is available, entitled *ProPG: Planning and Noise – Professional Practice Guidance on Planning and Noise* (Chartered Institute of Environmental Health, 2017). This document presents official guidance on the prescribed methodology to be undertaken for the management of environmental noise in the English planning system with the aim that new residential development should protect the public from the negative health impacts of environmental noise. However, no analogous official guidance and/or standards currently exist in the Irish policy context and, for this reason, the approach taken in the practice of noise management in the Irish planning system is irregular and inconsistent (AACI, 2021). Such irregularity is to be expected because of the complexity associated with acoustics, acoustical assessment and appropriate and context-specific noise management strategies.

Beyond such irregular practices, the Association of Acoustic Consultants of Ireland (AACI) has recently outlined a number of issues common in Irish planning practice; for example, where noise assessment methodology falls far short of best practice criteria, where the prescription of International Organization for Standardization *(*ISO) recommended standards are consistently outdated and where pronounced oversight and omissions commonly occur in the planning application process (see AACI, 2021).

According to the AACI (2021), the vast majority of environmental noise reports produced to meet planning compliance criteria do not perform any assessments of the sources that may actually produce harmful levels of noise; instead they evaluate and assess ambient noise levels only within the site location.[18] This is fundamentally problematic because without measuring the specific noise source and isolating this noise source from the surrounding ambient noise, it is impossible to determine whether or not compliance is actually being met. Accordingly, within most of the environmental noise report documentation associated with planning applications and compliance surveys in Ireland, it seems that the determination of specific noise levels of individual sites is either being overlooked, or at the very best loosely discussed without any reference to empirical evidence (AACI, 2021).

A far less problematic issue, yet one still worthy of note and correction, is the fact that most local authorities prescribe that compliance surveys should correspond to ISO standards that are essentially out of date (AACI, 2021). For example, *ISO Recommendation R 1996: Assessment of Noise with Respect to Community Response* (ISO, 1996a) and *ISO Recommendation R 1996/1*, *2* and *3*: *Description and Measurement of Environmental Noise* (ISO, 1996b) are often prescribed by local authorities despite the fact such ISO standards have gone through several iterations of revision.

As highlighted by the AACI (2021), there exist more general issues in that oversight and omissions are common in the planning application process in relation to how noise is managed by local authorities in Ireland, and this is directly related to a lack of guidance from the relevant department. This is another problematic issue, since the current noise management system operating in the Irish planning regime fails to deliver appropriate anticipatory provisions for the mitigation of population exposure to the harmful effects of environmental noise. The AACI has recently published a much-needed *Environmental Noise Guidance for Local Authority Planning and Enforcement Departments* (AACI, 2021) document. This provides standardised guidance for the enforcement of non-compliance, the assessment of environmental noise reports and the development of noise-related terms and conditions for planning permission and the provision of permits.

As well as providing general guidance for local authorities, the AACI guidance document also references more specific sector-based best practice UK guidance documentation in relation to various sectors including residential development, quarries and wind farms (AACI, 2021). Hence, it may be useful to create Irish best practice guidance documentation for specific sectors, equivalent to current UK guidance documentation.

The number of noise complaints received by local authorities and by the EPA in relation to EPA-licensed facilities has been increasing steadily in recent years

18 A similar situation exists regarding the current EPA Industrial Emissions Directive licensing system associated with industrial noise assessment in Ireland; see section 5.2.5.

(see Wall *et al*., 2020, p. 89). According to *Noise Complaint Statistics for the Republic of Ireland* (Keaney and Keaney, 2020), the majority of noise complaint cases that warrant investigation (i.e. that are not related to noise from a neighbouring property) in Ireland are the result of poor strategic planning. In such instances, either noise sources have been permitted for development near residential dwellings or the development of residential dwellings has been permitted close to pre-existing noise sources. In the latter context, ecologically important developments such as wind farm activities, as well as traditional commercial and industrial developments, are prohibited from expansion due to inappropriate residential zoning (AACI, 2021), which ultimately results in economic inefficiency in terms of commercial/industrial expansion, and a depreciation in the quality of life experienced by residents living in properties close to pre-existing noise-emitting activities. Unfortunately, the source of noise complaints recorded by local authorities is not available to the public; however, according to Wall *et al*. (2020), the EPA is considering classifying these data so that the information may be used as a tool for assessing how environmental impacts affect the population.

5.2.5 The EPA Industrial Emissions Directive licensing system for industrial noise assessment in Ireland

In 2013, the IED licensing arrangement came into effect under Commission Directive 2010/75/EU (European Union, 2010). An IED (formerly Integrated Pollution Prevention Control; IPPC) licence is a single integrated licence issued by the EPA that covers all emissions from a facility and its associated management. In the context of certain large-scale industrial facilities, control of noise emissions is exercised through IED licensing or through planning conditions. An EPA-licensed facility may be required to conduct noise assessments on an annual basis. The nature and scope of this assessment is determined by site-specific conditions and operational history.

In relation to industrial noise, the EPA has drawn up a guidance document entitled *Guidance Note for Noise: Licence Applications, Surveys and Assessments in Relation to Scheduled Activities (NG4)* (EPA OEE, 2016). This provides general guidance and sets limits for licensed facilities. In the context of noise assessment, NG4 guidance states that “the fundamental requirements for the Annual Noise Survey are to determine whether or not the licensed activity complies with the noise limit values as set out in its licence and to ensure that there is no evidence of tonal or impulsive characteristics at night-time” (EPA OEE, 2016, p. 39), whereby “the results of the Annual Noise Survey must be presented to the Agency … and should be reviewed and completed prior to the submission of the Annual Environmental Report (AER)” (EPA OEE, 2016, pp. 41–42). AERs are submitted to the EPA for the evaluation of respective annual noise assessments to determine whether individual industries are compliant with EPA regulation or if it is necessary for Ireland to generate strategic noise maps of industrial sources under the terms of Directive 2002/49/EC (European Union, 2002).

To gain a better understanding of the annual assessment of noise from industrial sources in Ireland and how this process is regulated by the EPA, the Noise-Adapt project (see Murphy *et al*., 2021, pp. 39–42)[19] conducted a review of all AERs submitted between 2017 and 2019 for the Dublin and Cork agglomerations.[20] The review found that it is currently not possible for the EPA to determine whether or not individual industries are, in fact, compliant with EPA regulations. Similar to the way specific noise sources are not isolated from ambient noise sources in environmental noise reports submitted to local authorities to meet planning compliance, it was found that although ambient noise sources external to the industrial site are commonly cited as the reason for noise level exceedance, such noise sources are not isolated from the industrial noise source being assessed and vice versa (see Murphy *et al*., 2021, pp. 39–42). In such cases, various assumptions are made in an effort to classify external noise sources that may be contributing to measured values. The most common assumption quoted relates to exceedance being the result of road traffic noise, whereas other assumptions cite bird song and alarms

19 Available to download at http://www.noisemapping.ie/useful-outputs.html (accessed 4 April 2022).

20 AER reports can be found under the Licence Enforcement Documents section of the EPA resource at http://www.epa.ie/terminalfour/ippc/index.jsp (accessed 4 April 2022).

as factors in the classification of external noise sources. However, no evidence is provided to support these assertions. It is owing to this classification that the responsible party charged with reporting these values can qualify that the measured values exceeding EPA limit values complies with IED licence terms. However, this classification is entirely based on subjective commentary and is unsupported by any empirical evidence. Although this does not confirm non-compliance at these sites, it does underline the need for the sites in question to provide a more robust evidence base than is currently demonstrated for claiming compliance.

6 Conclusions and Recommendations

Based on the previous analysis and the discussion presented in Chapter 5 regarding how both EU-level END-related policy and practice and national policy and practice currently operate in relation to the management of environmental noise in Ireland, the objective of this chapter is to develop recommendations and guidelines for the integration of noise considerations into relevant policy streams. The chapter also outlines recommendations for improving national policy and practice in relation to the management of environmental noise in Ireland. These recommendations aim to strengthen the capacity of Irish policymakers to design, apply and supervise effective and systematic policies for environmental noise in Ireland.

6.1 EU-level Environmental Noise Directive-related Policy and Practice Recommendations

1. The END should be amended to stipulate limit values for population exposure to potentially harmful levels of noise in the context of L_{den} and L_{night} at the EU level and Ireland should use its influence to push for the imposition of limit values on a phased basis across the EU.
2. The EPA should work towards establishing national environmental noise limits in Ireland to protect public health. Ireland has had noise legislation in place since the 1990s, prior to the introduction of the END in 2002 (European Commission, 2016). However, this legislation does not provide guidance with regard to noise emission thresholds that would trigger a mitigation response from authorities. Thus, there is an urgent need for existing noise regulations to be reviewed and updated. In particular, Ireland should consider including noise limit values for triggering a mitigation response on a phased basis over the next decade.
3. There is a requirement for a more robust definition of quiet areas in the END so that such areas can be defined and preserved (where necessary). Ireland should support this at EU level. However, in the absence of coordinated action at EU level, Irish authorities should develop a national definition of quiet areas based on international best practice and the best available scientific knowledge so that this important public health benefit is preserved and maintained.
4. There is a need for explicit guidelines at the EU level for public engagement and consultation to play a greater role in the dissemination of strategic noise mapping results. Such guidelines would also be beneficial in raising public awareness about noise pollution and how it should be tackled at local and community level. In this regard, Ireland should use its influence at EU level to propose guidelines. Given the current absence of EU guidelines, Ireland should develop national guidelines on public engagement and consultation for the dissemination and promotion of engagement with strategic noise mapping results.

6.2 National Policy and Practice Recommendations

1. As outlined by Wall *et al*. (2020), Ireland should develop an ambient noise strategy to direct efforts towards best practice and guidance in relation to the management of environmental noise nationally. Such a strategy is essential to protect public health in the future, appropriately mitigate the negative impacts of environmental noise and better understand the scale of the environmental noise pollution issue in Ireland.
2. Noise mapping bodies should work towards submitting strategic noise mapping data to the European Commission that include a complete road network for agglomerations. The current approach to map only selected roads in agglomerations results in underestimates of absolute levels of population exposure to environmental road traffic noise and, as a result, the scale of harmful effect estimates under Commission Directive (EU) 2020/367 will be underreported.

3. The role of responsibility for the strategic noise mapping process should be centralised into a single responsible body to ensure implementation of the END is consistent, to avoid difficulties related to managing various departments involved in the process and to maximise the use of resources.
4. Although this project has not conducted an evaluation of the noise complaints process in Ireland, the operation of the noise complaints process is vitally important in terms of noise–health outcomes. Currently, Ireland has no systematic and centralised strategy for recording or managing noise complaints nationally. Complaints tend to be handled by individual local authorities that can typically be reached only during weekday office hours. Such a system is not fit for purpose, especially if noise pollution disturbance occurs during night-time hours. If public health is to be appropriately protected into the future, it is essential that the existing noise complaints system is reviewed and aligned with best practice internationally.
5. There is an urgent need for an official, standardised noise management guidance document that addresses environmental noise concerns in all areas of planning including new residential developments, infrastructure projects and industrial developments. Ideally, such a document would have a basis in Irish legislation for planning and development practice (also see Wall *et al*., 2020, p. 90).
6. Future best practice for all noise compliance surveys, including those conducted as part of the EIARs within the Irish planning system and those conducted under the EPA IED licensing system in relation to industrial noise assessments, should ensure that the specific noise source under investigation is isolated from ambient background noise to correctly determine compliance.
7. Local authorities should prescribe that compliance surveys correspond to the latest edition of the relevant ISO standard.
8. The relevant department should develop sector-specific and nationally based best practice guidance documentation for Ireland, equivalent to UK guidance and other international (e.g. European Acoustics Association) documentation, for the following areas: industrial installations not covered by the EPA IED licensing system, waste facilities not covered by the EPA IED licensing system, scrap metal facilities, quarries, wind farms, solar farms (no international standards currently exist), pubs and clubs, concerts and festivals, kennels and dog care centres (no international standards currently exist), sports and leisure facilities, activities related to outdoor shooting, heat pumps and similar plant installations, and activities related to construction.

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Abbreviations

ANT	Animal naming test
AR	Absolute risk
CAPI	Computer-assisted personal interviewing
CASP-12	Control, Autonomy, Self-realisation and Pleasure 12-item scale
CES-D	Center for Epidemiological Studies Depression scale
CNOSSOS-EU	Common Noise Assessment Methods in Europe
CRT	Choice reaction time
CSO	Central Statistics Office
CTT-2	Colour Trail Test 2
DALY	Disability-adjusted life year
dB(A)	Decibel – a measure of the relative loudness of sounds in air as perceived by the human ear
DNM	Dynamic noise map
DW	Disability weight
EEA	European Environment Agency
END	Environmental Noise Directive
EPA	Environmental Protection Agency
EU	European Union
GBD	Global burden of disease
HA	High annoyance
HAD	Hospital Anxiety and Depression
HPA	Hypothalamic–pituitary–adrenocortical
HRS	Health and Retirement Survey
HSD	High sleep disorder
IED	Industrial Emissions Directive
IHD	Ischaemic heart disease
L_{den}	The L_{eq} (equivalent noise level) over a whole day, but with a penalty of 10 dB for night-time noise (23:00–07:00) and 5 dB for evening noise (19:00–23:00). See Directive 2002/49/EC L 189/18.
L_{night}	The L_{eq} (equivalent noise level) over the 8-hour night period of 23:00 to 07:00 hours. See Directive 2002/49/EC L 189/18.
MMSE	Mini-mental State Examination
OSi	Ordnance Survey Ireland
PAF	Population attributable fraction
PSS	Perceived Stress Scale
PSWQ	Penn State Worry Questionnaire
RR	Relative risk
SAM	Sympathetic–adrenal–medullary
SWS	Slow-wave sleep
TILDA	The Irish Longitudinal Study on Ageing
WHO	World Health Organization
WP	Work package
YLD	Years lost due to a disability or disease
YLL	Years of life lost

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
> Sceitheadh fuíolluisce uirbigh;
> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
> Foinsí radaíochta ianúcháin;
> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Thásscairí a chur ar fáil;
> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
> Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
> Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
> Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Environmental Transport Noise and Health: Evidence from Ireland (Noise–Health)

epaResearch

Authors: Enda Murphy, Jon-Paul Faulkner, Ciarán Mac Domhnaill, Seán Lyons, Anne Nolan and Owen Douglas

Identifying Pressures

Noise is found everywhere, particularly in urban areas, and is part of daily living and activity. However, noise can be a serious risk to public health and wellbeing. While there appears to be a strong association between transport noise and health and wellbeing, significant gaps exist in the literature. Even more pertinent is the lack of an evidence base for the harm and burden of disease caused by environmental noise at the national level to inform policy. This report addresses these knowledge gaps. First, while there is recognition of the relationship between noise and health, there is a more limited understanding of dose–effect mechanisms and of the cause and effect relationships. Second, the scale of the problem in Ireland is poorly understood, complicating the integration of noise considerations into relevant health, transport and planning policies. These could be addressed by combining the fine-grained microdata available from this study with noise modelling data at the city scale.

Informing Policy

This report outlines key policy and practice recommendations for managing environmental noise in Ireland. It also details how "noise–health" considerations can be better incorporated into Irish policy. These recommendations aim to strengthen the capacity of Irish policymakers to design, apply and supervise effective and systematic policies in this area.

Developing Solutions

This reports presents evidence-based solutions and recommended interventions that have the potential to unlock unsustainable practices in relation to environmental noise mitigation and health. In doing so the report (1) supplies the evidence base to establish the links between environmental noise and health; (2) provides a benchmark study of the existing disease burden from environmental noise to establish a baseline noise–health disease burden that can be reduced in future through improved national practice and appropriate policy solutions; (3) undertakes applied city-based research to understand the causal relationship between noise and health so that targeted policy interventions can be established; (4) uses this knowledge to develop innovative guidance and evidence-informed noise mitigation solutions for reducing people's exposure to environmental noise.

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