CHAPTER

8

Conclusions and Future Directions

Environmental noise pollution is a complex issue. The previous chapters in this book illustrate the multifarious nature of issues surrounding the understanding and control of sound that is out of place. The problem with noise pollution though is that it is not only a complex issue but also a highly persistent one. As a public nuisance concern, it has been steeped in the awareness of the public consciousness for millennia but has not really been taken seriously enough by policymakers who have tended to prioritise other seemingly more pressing environmental issues. And so, despite centuries of scientific endeavour along with attempts to control and mitigate noise, the problem continues to rumble on. Indeed, the rise in the ownership and use of private transport over the last century has arguably turned the rumble of noise pollution into something of a roar.

Until relatively recently, there was certainly some truth in the notion of environmental noise as the forgotten pollutant. Others (such as air pollution and stench) have been given much greater attention in policymaking over the last century and, while they have not been eliminated entirely, they have certainly been controlled to a much more significant degree. In fact, one might be forgiven for thinking that the damage (in terms of public health and general annoyance) associated with noise pollution is not really improving at all. Certainly, of all pollutants, noise is one that is practically impossible to escape from in our daily lives. The rapid urbanisation of populations witnessed throughout the globe over the last century combined with the growth in private transport has meant that both neighbourhood noise annoyance and noise from transportation sources are becoming a more pressing problem.

However, these are not the only reasons why noise is still a major contemporary pollution issue. There are numerous reasons. A crucial additional one is alluded to by Goldsmith (2012) who informs us that because the ear evolved largely as a warning system, noise is considered

by humans to be intrinsically disturbing. This relationship is what gives the ear its extraordinary sensitivity allowing it to detect even the slightest flows of wave energy in the air. As Goldsmith (2013, p. 269) points out: 'even a perfectly sound-proofed building is hardly better than a shoddy one if the smallest of its windows is broken'. Indeed, this is also what makes mitigating noise pollution such a difficulty – it is very much an all-or-nothing kind of business. In other words, partially mitigating noise will have very little effect on the level of disturbance being felt by a person subjected to noise. Moreover, precisely because some people are more sensitive to noise than others, it means that reducing noise below a certain level may be acceptable to one person but not to another who might still feel disturbed.

The issue of the subjective nature of noise annoyance poses quite a problem for those who are interested in developing and standardising units of measurement that convey the extent of the intensity of noise. We know that the decibel and the A-weighted system were developed precisely for this purpose, but they are far from being perfect. We also know that the various indicators used to measure annoyance and disturbance are fairly crude in that they do not adequately deal with the varying range of subjective human responses to different noise sources, nor do they deal adequately with different types of noise, in particular impulsive, intermittent and low-frequency noise. And of course, all of these issues pose problems for policymakers that are attempting to regulate the extent of noise.

It is also important that we do not forget the major societal changes that have occurred over the last half century which has made the problem of noise pollution even more difficult and complex to tackle. The traditional past societal arrangement of individuals working a typical 9–5 day has changed significantly with increasingly flexible working arrangements bringing about a more varied 'working day' which can often overlap with the night-time period. Of course, greater night-time activity means that that noise is becoming increasingly difficult to control during traditional sleeping hours between 11 pm and 7 am and this is where the major problem lies in terms of the health implications of noise-induced sleep disturbance and related secondary effects. Other changes in the way city regions are planned and organised over the last half decade have also impacted on noise pollution. The traditional past approach of mono-functional zoning where polluting activities (e.g. heavy industry, manufacturing) were separated from residential areas is no longer typical practice in urban and regional planning. The restructuring of western economies away from manufacturing industry to more service-oriented and 'cleaner' industry has allowed for more mixed-use zoning systems to be adopted. In fact, this approach is now considered best international practice in the vast majority of developed countries. Thus, employment, housing, retail

and entertainment facilities now exist adjacent to each other in urban areas, meaning that the noise produced from the intermixing of these land use activities (e.g. commuting, socialising, shopping among others) is felt to a much larger degree by present-day households than by households under past land use arrangements.

While the tone of the foregoing discussion might suggest then that the problem of environmental noise is getting worse, it is merely attempting to reflect more broadly on the situation in which we find ourselves. There really is no concrete way to determine if noise pollution is better or worse now than it was a century ago because the socio-political context was very different then than what we have today. Moreover, how noise was understood, measured and controlled was also very different than current practices while modern technologies simply cannot be compared to those existing even in the relatively recent past. Broadly then, it is virtually impossible to compare the noise situation today with centuries ago because there is simply no common basis for such a comparison. Nor are we suggesting that noise is an insoluble problem or, more importantly, that no progress has been made in understanding environmental noise, its human impacts and how we might control it. On the contrary, progress has been very significant indeed. Many of the major noise sources discussed in this book – automobiles, trains, airplanes – are now subject to much stricter noise limits than they were at any point in the past. Noise from industrial equipment (and therefore industry more generally) is similarly subject to much stricter limits. In addition, many nations have legislated for night-time noise limits at the point of the receiver, modern homes tend to be built with better sound proofing, and mitigation measures have become more effective. And yet, the inescapable (and somewhat depressing) conclusion of the World Health Organisation (WHO) is that 'the trend [for] noise exposure is increasing in Europe compared to other stressors (e.g. exposure to second hand smoke, dioxins and benzene), which are declining' (WHO, 2011, p. 1).

On the face of it, all of this comes across as something of a contradiction – how can we be making progress while the problem is getting worse? The answer of course is that while progress is indeed being made, it is being achieved within the context of a massive increase in the volume of noise-related activity – populations are growing, population distribution is becoming increasingly concentrated and private vehicle ownership and use are increasing at the same time as the role of public transport is declining and these issues have placed significant limits on the impact of progress that has been made. In the context of this book, this is quite a crucial point. The reason is that, quite aside from the book's important description of the technical detail associated with noise pollution, the general narrative running through this chapter has focussed on conveying two key issues. The first is that it documents the *progress* that has been made over

the recent past in understanding the nature of environmental noise pollution, its effect on humans and how it can be better understood and assessed to ensure more effective mitigation and control. The second issue relates to the book's implicit focus on the *limitations* of existing knowledge/understanding in the aforementioned areas of environmental noise pollution and how they might be improved in terms of both future research and practice.

8.1 PROGRESS

Perhaps the most important reason that has contributed to driving progress in our knowledge of environmental noise over the last half century relates to our understanding of the relationship between noise and human health. In particular, we now know much more about the relationship between doses of environmental noise and their direct and indirect health effects as outlined in Chapter 2. There is little doubt that our enhanced knowledge of the detrimental health impacts of long-term noise exposure, even at relatively low levels, has been the catalyst for environmental noise issues to become an important environmental and public health policy consideration.

In relative terms, there has been an explosion of research on the health effects of environmental noise over the last half decade. We have moved from a situation where the nature of dose–effect relationships was only partially understood to a situation where scholars now have a relatively good handle on the nature of the public health problem caused by exposure of populations to excessive environmental noise. As elucidated in Chapter 2, we now know that excessive exposure either causes or is directly associated with a range of health effects, not only primary effects such as sleep disturbance but also a range of secondary effects that are felt as a result of disturbed sleep. We know that the primary effects of noise exposure on health are in terms of annoyance, sleep disturbance, cardiovascular disease, tinnitus and cognitive impairment in children. For example, it is only in the last 20 years that a clear association has been established between noise exposure and higher incidence of cardiovascular disease which has been a major leap forward in understanding. Research has also taught us that annoyance and sleep disturbance resulting from noise pollution exposure act as a significant health stressor which can lead to and/or trigger more serious health problems.

Moreover, the emergence of the DALY[1] has only recently allowed for a quantification of the health effects of environmental noise at the EU level

[1]Daly is a disability-adjusted life year. See Chapter 3 (Box 3.1) for a broader explanation of its origin and Section 3.1 for technical details.

(see Table 3.1) which was not possible a half decade ago. Our understanding of not only the nature of the dose–effect health relationships but also the scale of the problem across the globe is considerably improved. Indeed, the scale of the problem is quite staggering and yet we still do not quite have a complete grasp of it. In 1999, the WHO estimated that almost 50% of European citizens lived in grey areas of acoustical discomfort. While the composition of the EU has changed considerably in the intervening period, the first phase of noise mapping (conducted in 2007) showed that approximately 40 million people across the EU are exposed to noise above 50 dB(A) from roads within agglomerations during the night with a further 22 million exposed outside agglomerations. Given that the WHO (2009) sets 40 dB(A) night-time as the value above which health effects are noticeable (see Chapter 3), these figures emphasise quite clearly not only the (almost) ubiquitous nature of the problem but the fact that the potential problems associated with the overexposure to noise pollution are at such a scale as to consider it a major public health issue for policy makers. But of course, the health effects are not confined to the EU – it simply happens to be the one continent for which we have decent data on the scale of noise pollution exposure. What the European case shows is that environmental noise is a global problem and no nation is immune from its associated problems.

As a direct consequence of improvements in our understanding of the noise–health relationship, noise policy and legislation have underwent very significant and positive changes throughout the EU. As it now stands, there is little doubt that the EU has the world's most progressive noise legislation and policy in terms of attempting to protect its citizens from the detrimental effects of excessive exposure to environmental noise pollution. Quite important is the fact that many other nations beyond the EU have looked towards what the continent has been doing and, while few nations have taken identical steps, there would certainly appear to be much more cognisance of noise as an environmental and public health problem in other nations as a result of EU legislative and policy changes. Since the 1970s, the EU has consistently legislated for stricter permissible noise limits on manufacturers of automobiles, trains, aircraft, outdoor equipment, recreational craft and household appliances. Table 4.1 (Chapter 4) provides a good illustration of the range of legislative Directives that have been issued in these areas. Utilising legislation to drive down permissible noise limits has forced manufacturers to improve their technologies in such a way that they now make much quieter vehicles and appliances than they did in the past.

There is little doubt also that the introduction of the Environmental Noise Directive (END) into legislation in 2002 has been important in getting to grips with the extent of the noise problem across the EU but it has, perhaps, been even more important in raising awareness of

environmental noise as a major environmental concern as well as a public health problem. For the first time, the END has provided a strategic approach to assessing and controlling the environmental noise problem at a supra-national level and this has been a major progression. While the END still only provides estimates of the population exposed across the EU, it has provided the first real glimpse of the scale of exposure across the Union. And as mentioned already, the scale of the problem is considerable. Moreover, these estimates were used as the basis for quantifying the extent of the disease burden associated with night-time noise exposure across the EU in the WHO's recent *Burden of Disease from Environmental Noise* document. This would not have been possible without estimates of population exposure arising from the END. Moreover, the END has also provided a strategic framework for nations within the EU to work together, share information and best practice approaches towards understanding how best to assess and control noise as a pollutant. More broadly, it has facilitated enhanced co-operation among responsible authorities right across the EU and indeed within individual EU nations. All of this represents significant progress. Prior to its introduction, some nations did indeed take the problem of environmental noise seriously, but for others, it was barely on the policy radar. Effectively, because the END mandates a strategic approach across the continent, it has meant that all nations are at least ensuring minimum compliance and engagement with the problem of environmental noise pollution and this is a considerable step in the right direction even if there remains significant work to be done. Indeed, it is quite clear that it is only through a strategic approach that progress can be made on reducing the harmful effects of noise pollution for citizens.

On the technical side, there has also been considerable progress in noise prediction capabilities although perhaps not as much as one might like. Nevertheless, there are a number of significant achievements to note. Perhaps the most noteworthy relates to the ongoing development of common noise calculation models for road, rail, air and industry across the EU. It has long been argued that unless noise calculation is standardised across the EU, it is very difficult to compare the results of population exposure estimates (Murphy and King, 2010). At the EU level, research funding has been provided to support movements in this direction since the turn of the century beginning with the HARMONOISE project and culminating in the standardised CNOSSOS-EU noise calculation model which is due to be introduced and utilised by all nations in the 2017 round of strategic noise mapping. The development of a standardised model has not only been technically complex but also difficult at a practical level given the existing variation in national calculation models across the continent. The movement towards the completion and roll-out of such a model over the next few years represents a remarkable progression on what exists at

present. Ultimately though, the success of the method will be judged on its rate of adoption across all Member States.

The efficiency of developing noise maps is intrinsically linked with the development of the personal computer. When the END was first initiated, it was a computationally intensive task to develop a noise map for an entire city. Even in the last 10 years, the computational efficiency of computers has increased exponentially and a city noise map can now be developed overnight. The possibilities behind harnessing this potential are only just being realised with the development of 3D and interactive noise maps. For example, real sounds can be linked to maps, or maps can be cross-referenced with noise complaints in a city, offering the general public an appreciation and understanding of the concepts associated with environmental acoustics.

Another significant development is the introduction of common indicators of annoyance (L_{den}) and sleep disturbance (L_{night}) across the EU as part of the END. While there are some concerns about the viability of these indicators for doing what they were introduced to do, their introduction has nevertheless ensured that there is a common basis for comparison (at least in terms of indicators) across the continent. This is important because prior to their introduction, a wide variety of indicators were used for assessing annoyance and sleep disturbance within individual nations. However, the use of supplemental indicators, which is catered for under the END, needs to be encouraged. In fact, future research should focus on the potential benefits of supplemental noise indicators which may be used in parallel with L_{den} and L_{night} in the strategic noise mapping process.

Acousticians now also have access to a range of noise-monitoring equipment that was previously unimaginable. It is now possible to measure noise over very long time periods and to monitor results in real time. It is also possible to remotely access real-time sound recordings and analyse frequency spectra at the click of a button. The key challenge for the future is to utilise this technology in the future development of noise and noise assessment studies and noise policy. The need for a single number noise indicator is needed so policy and guideline limits can be changed to offer more detailed noise criteria and thus enhanced protection for citizens. Consider, for example, the A-weighting system which was designed to reflect how the human ear responds to sounds at different frequencies. Modern sound level meters can now produce one-third octave analyses as standard, so design goals may be set in terms of third octave levels instead of an overall dB(A) figure.

The other main area of progress has been in relation to raising awareness. While we have no concrete data which shows that people are more aware of the problems associated with noise pollution now than they were in the past, anecdotal evidence as well as evidence from EU surveys of public attitudes would seem to suggest that there is indeed a greater

awareness of noise pollution among the general public today than in the past. For example, a recent Eurobarometer survey showed that 44% of Europeans believe that noise affects human health to a 'large extent', an increase of 3% since 2006 (European Commission, 2010). The increase suggests, albeit tentatively, that awareness of noise-related health issues is increasing. There is little doubt that this improved awareness is related to the introduction of the END. The legislation mandates that the results of the strategic noise mapping process be disseminated to the general public. While there has been some problems with this (alluded to in the next section), it still remains that noise pollution information is now more accessible and readily available to the general population of the EU than at any time in the past. This is a significant achievement. Moreover, as well as raising awareness among the general public, understanding has also been raised among local authority officials, administrators and policymakers about noise pollution issues. The manner in which the END has been implemented among Member States effectively ensures that local, national and regional officials must co-operate and exchange information, data and knowledge about the noise mapping process in order to ensure national compliance. Moreover, there is now also a much greater degree of dialogue among national officials and policymakers across the EU than there has ever been before.

Perhaps one of the more slow moving areas in terms of progress in recent years has been in the area of noise pollution mitigation. Considerable research has been undertaken, and is ongoing, assessing how mitigation approaches can be improved both in a technical sense and how they can be made more cost effective in an increasingly strained financial environment. Improvements have been made in how buildings are insulated, in more efficient low noise road surfaces, better track and braking systems for railways as well as improvements for design of quieter aircraft, to point out only a handful of progressions. Indeed, researchers have also investigated more innovative solutions to noise mitigation though the concept of soundscapes which aims to focus more on the positive sounds associated with a particular environment (through masking negative sound sources) rather than emphasising the negative aspects of a place (see Chapter 7, Section 7.5.4). However, the pace of progress in this area could certainly be faster. In this respect, noise mitigation is one of the areas that simply must be targeted for significantly more research over the coming years if the problem of environmental noise pollution is to be reduced not only at the European level but also throughout the world.

Over the last two decades, the volume of research activity in the area of environmental noise pollution has increased quite substantially. There have been significant improvements in our understanding particularly of the devices used to measure noise and how noise is modelled at the source as well as how it propagates away from the source. Commercial

software has also improved dramatically, meaning that noise calculations can be completed for much larger study areas than in the past. Moreover, since the introduction of the END into legislation there has been a raft of new research completed not only examining the extent of population exposure in various countries around the world but also investigating ways in which the strategic noise mapping process can be improved or utilised to assist with understanding other noise pollution issues beyond the remit of the END (e.g. noise insulation of buildings, 3D visualisation of noise mapping results). Chapter 4 (Section 4.4) provides details of some of this research, but it is far from being exhaustive. The upshot of the increase in research output in environmental noise pollution is that we now have a much better understanding of environmental noise issues and how they might need to be addressed than at any point in the recent past.

8.2 LIMITATIONS AND FUTURE RESEARCH PRIORITIES

The foregoing section has highlighted the extent of the progress that has been made with respect to environmental noise pollution over the last decade. Nevertheless, this does not mean that the situation is perfect and does not require any further investigation or scrutiny. Rather, there are significant areas where our understanding of environmental noise issues needs further improvement and if recent progress has taught us anything it is precisely that our knowledge is quite limited in a number of areas related to noise pollution, its negative effects and how to control them. In fact, it is the role of scholars, in particular, to identify areas that might be worthy of more scrutiny and offer suggestions for potential solutions that should be investigated through more targeted research that serves as evidence for improving policy.

While the END is symbolic of the significant progress that has been made in recent years, the sheer scale of its ambition as a large-scale noise assessment and reduction programme has meant that it was always destined for teething problems after it was introduced into legislation. One of the major weaknesses of the END and any environmental noise legislation is the lack of clearly stated limit values, particularly for the night-time period, above which noise levels are not legally tolerated. A recent report commissioned by the EU has pointed out that this weakens the impact of the END because it fails to set a common level of ambition for the EU with regard to noise quality (Guarinoni et al., 2012). While it is understandable that noise limits were not put in place immediately under the terms of the END, enough time has now passed and significant intellectual and administrative capacity been developed to ensure that the EU can now

move towards even more ambitious noise reduction targets. These should take the form of limit values that are introduced progressively under amendments to the END legislation. Indeed, 19 Member States (out of 27) already have legally enforced noise limit values. If these are exceeded, measures to control noise and/or to insulate exposed populations are implemented. In some nations, financial penalties are also imposed on those responsible for the source of the pollution. This has led Guarinoni et al. (2012) to recommend that trigger values rather than legally binding limit values should be introduced in the short term with a view to moving towards imposing limit values in the medium term future across the EU.

In relation to the END, there is little doubt that more concrete guidance information needs to be provided to Member States on implementation. In this context, there is certainly scope for guidance information to be provided on strategic noise mapping, action planning, trigger values, the definition of quiet areas as well as specific ways in which results can be disseminated to the general public. In these areas, perhaps the most pressing need for guidance is in the area of noise action planning as well as in the definition of quiet areas. Both of these areas seem to be relatively poorly understood (European Commission, 2011), and the expectation of how the END is to be implemented in these areas is quite confused at present. In relation to action plans, while several Member States produced national guidance on action planning for the first phase of END implementation, many did not. However, the documents already produced by individual nations could certainly be used as a basis from which to develop EU guidance for future rounds of END implementation. Turning to quiet areas, it is clear that the END leaves considerable (perhaps too much) discretion at the hands of Member States in delimiting quiet areas. This needs to be addressed in future research and practice because at the moment, the preservation of areas of good sound quality appears very much as an afterthought in END implementation. Indeed, this has been recognised by the EU and the current EEA Expert Panel on Noise (EPoN) is currently working to produce a green paper on the management of quiet areas specifically within the context of END implementation (Guarinoni et al., 2012).

The introduction of the new annoyance and sleep disturbance indicators L_{den} and L_{night} has undoubtedly been important for standardisation purposes across the EU. However, our knowledge of the suitability of these indicators for adequately representing annoyance and sleep disturbance in the field remains fairly limited. To take L_{night} as an example, it is pretty rare for studies of sleep disturbance in the literature to cover the entire 8-h night-time period. In addition, very few studies have utilised the L_{night} indicator as an expression of sleep disturbance. In fact, it is quite likely that the L_{night} noise indicator underestimates the extent of sleep

disturbance because it averages noise over a long period effectively smoothing out and downgrading the impact of intermittent and impulsive noise events that are known to have a highly negative effect on sleep patterns. Thus, our knowledge of the suitability of such indicators for doing what they are intended to do is somewhat flimsy. If we are to continue to use these indicators in future rounds of noise mapping and population exposure estimation at the EU level, research will need to prioritise investigating their suitability or otherwise for achieving their stated intentions. Bearing this in mind, future research should focus on improving the prediction of subjective sleep disturbance by adding the possibility within the END of utilising noise descriptors other than L_{night}. These could include descriptors penalising noise in the early or late part of the night-time period, descriptors of peak noise levels or noise events to assess the problem of intermittent or impulsive noise more effectively (e.g. SEL, L_{peak}, L_{max}).

While the END has been highly successful at seeking and enforcing international agreement on large-scale strategic noise pollution issues, it has been much less successful at utilising the results of the process to drive real change and action at the local level. In fact, the recently published END implementation report has pointed out that despite the wide-scale noise mapping and exposure estimation of EU populations, it is likely that noise pollution has not been reduced at all (European Commission, 2011). While this shortcoming is largely as a result of a lack of ambition with regard to action planning on behalf of some nations (others have done a very good job), it is also related to the relatively poor way in which results of the process have been disseminated to the general public. A number of scholars have pointed to the piecemeal way in which the public have been invited to engage with noise pollution results and much more could be done in this area (see Guarinoni et al., 2012; Murphy and King, 2010). It is crucial then that in the future, this aspect (public dissemination) of the END is given more thoughtful consideration because raising public awareness about the extent of noise pollution issues is likely to be very important for developing and enhancing public and indeed political support for future noise reduction measures through action planning as well as through further legislation and policy improvements.

There are also significant limitations with how population exposure is estimated across the EU. In large part, these limitations have been forced either by data or by modelling limitations at the national level. In the EU, the imminent standardisation of noise modelling techniques should eliminate the problem of modelling variations. However, the problems associated with data and the method of estimating population exposure have yet to be dealt with satisfactorily. If these limitations are to be addressed, serious consideration must be given to developing a standardised international database of noise input data for noise modelling and population

exposure estimation. And there is no reason at all why this could not be done; to a large extent, we already have a template for how this could work with the international database on aircraft sound power characteristics (see Chapter 5). This general approach could be extended to include other data sources necessary for noise mapping across the EU. Moreover, the recent publication of the *Common Noise Assessment Methods in the EU* (Kephalopoulos et al., 2012) document does provide the basis for standardising how population exposure is estimated in Member States, but refinement and additional clarifications are needed prior to its completion. Ultimately then, there is considerable scope for improvement in understanding, controlling and ultimately reducing the problem of environmental noise pollution, but it is likely that a key pathway towards achieving this goal is through more research and standardisation of approaches not only across the EU but also worldwide. Movements in this direction would not only facilitate relative differences in exposure to be identified across the globe but also enable more concrete indications about the role of variations in best practice environmental noise policy to be delimited, shared and transferred across national boundaries.

While there has been a dramatic increase in the volume of research undertaken investigating the relationship between noise pollution exposure and its impacts on human health over the last two decades, there remains much work to do to improve our understanding in this area. In general terms, there is overwhelming evidence to suggest negative health effects from environmental noise exposure. However, there are many areas where significant *association* has been developed between noise exposure and health conditions, but more research needs to be undertaken to investigate the issue of *causality* more vigorously. For example, the recent WHO (2011) *Burden of Disease from Environmental Noise* report clearly points out that there are some areas where there is not yet sufficient evidence to say definitively that noise is responsible for a particular health condition. For example, while there is increasing evidence demonstrating an association between noise exposure and increased risk of cardiovascular disease, the existing evidence stops short of providing any definitive statement on causality. Indeed, even in terms of association, there are areas that are under investigated. While we know, for example, that there is a clear association between noise exposure from road traffic and increased risk of ischaemic heart disease, including myocardial infarction, there is less evidence for such an association with aircraft noise simply because of a lack of studies investigating the issue (WHO, 2011). In a similar vein, there have been very few studies that have investigated the relationship between rail noise exposure and cardiovascular disease and thus we must reserve judgement on the nature of these relationships until more evidence is made available. Indeed, the link between noise exposure and tinnitus, while well established, remains

fairly poorly understood. In terms of hearing loss, the WHO (2011, p. 100) recently concluded that 'epidemiological studies linking hearing impairment to environmental noise exposure are so sparse that any generalisation can be considered exploratory and speculative'. Moreover, the WHO (2011) also suggest that there is not yet sufficient evidence to suggest that children are more vulnerable (in that they react differently) to noise exposure than other population groups despite some studies suggesting otherwise. In this regard, the reaction of children and other potentially vulnerable groups (e.g. the elderly) to excessive noise exposure needs to be investigated more definitively. On the other hand, existing evidence does suggest that there is a causal relationship between noise exposure and sleep disturbance and 'depending on noise levels, may impair behaviour and well-being during the subsequent period awake' (WHO, 2011, p. 55). There is also sufficient evidence, indicating a causal relationship between noise exposure and annoyance. Clearly then, while our present understanding of these relationships is much greater than at any time in the past, there are some relationships that will require much more significant scrutiny if we are to establish more definitive statements on the impacts or otherwise of environmental noise pollution on public health outcomes.

Finally, the role that technology can and will play in the future prevalence of noise pollution is likely to be considerable. Over the last half decade, the major improvements that have been seen in noise reduction emissions from transport vehicles, in particular cars and aeroplanes, have come primarily from improvements in engine and tyre technology. Looking to the future, there is little doubt that technology will remain pivotal to creating quieter urban and rural environments. One area where this is likely to be crucial in the not too distant future is in relation to the imminent development of electric cars. Given that road traffic noise is the most important source of environmental noise, there is a significant opportunity to reduce pollution and associated health problems through the wider substitution and use of these vehicles over chemically powered ones. Electric cars are much quieter than chemically powered ones although at the moment battery technology does not quite appear to be at a stage that would ensure their widespread adoption. Nevertheless, although they are likely to be equipped with sound that will act as a substitute for engine noise, if it is directional, short range and generally pleasing (or at least not annoying), these vehicles have the potential to allow for a significant reduction in annoyance and sleep disturbance.

Technology will also be important in other areas. The development of low-cost noise measurement devices is likely to play a greater role in the future. The development of noise apps for Smartphones, while currently not very reliable, is likely to become more important as technology improves in the future. It is likely then that the public could contribute much more significantly than at present in providing noise measurement

data through mobile/cell phones in a form of 'citizen science' (D'Hondt et al., 2013). The technology utilised in mobile/cell phones is MicroElectroMechanical Systems (MEMS) microphones which can be constructed relatively cheaply and at a low cost. As the reliability of these microphones is improved in the future, they will undoubtedly provide a much better scope for measurement-based noise mapping or indeed low-cost validation of noise modelling results. We can only hope that these, together with other improvements, will provide for a much quieter future and that quite soon we can truly refer to environmental noise as the forgotten pollutant.

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