CHAPTER

4

Strategic Noise Mapping

4.1 INTRODUCTION

For environmental noise research, mapping is an extremely important part of the process of quantifying and visualising noise pollution levels (De Kluijver and Stoter, 2003). Indeed, environmental noise pollution is an inherently spatial phenomenon. It varies across geographic space depending on the location of the noise source, the receiver and the intervening obstacles (e.g. the terrain, buildings, barriers). Understanding how it varies across space, how many people it affects and how it can be mitigated is all part of the process of strategic noise mapping. The process of digitally mapping environmental noise across geographic space allows researchers and policymakers to identify locations that are subject to excessive noise levels and if there are individuals residing in those areas affected by excessive pollution. Thereafter, steps can be taken to reduce noise levels so that public health is protected. The mapping process also allows for the identification of areas of good sound quality – often referred to as quiet areas – so that these can be protected into the future as amenity areas for rest or recreation that are free from noise disturbance.

Accordingly, this chapter provides an outline of the strategic noise mapping approach developed and utilised across Member States of the EU. Focus is placed on the EU precisely because it is the world leader in terms of environmental noise policy and related legislation. However, related noise mapping studies and associated research in other jurisdictions are also presented to demonstrate the wide adoption of the EU approach to assessment and mitigation of environmental noise across the globe. In outlining the strategic noise mapping process, emphasis is placed on the principles of the noise mapping process in terms of mapping, modelling, estimating exposure and action planning. However, a critical view of the process is also undertaken in that the chapter provides suggestions throughout for best practice improvements as well as improvements that could be made in related policy and legislation at the EU level.

4.2 EU NOISE POLICY AND LEGISLATION

Legislation attempting to regulate environmental noise is not a recent phenomenon at the EU level. It is a process that has been evolving since the establishment of the economic union back in the 1970s. Table 4.1 presents the extent of legislative instruments in relation to the various sources of environmental noise and demonstrates that the EU has been heavily involved in using these instruments to regulate noise at the point of manufacture through the establishment of permissible noise limits. While that continues to be the case, the important change in direction in relation to environmental noise legislation in recent years is that it has moved from being almost entirely focussed on regulating noise at *source* to attempting to mitigate environmental noise at the point of the *receiver* through the establishment of the Environmental Noise Directive (END).

Within the context of an emerging evidence base suggesting links between exposure to environmental noise and public health concerns, noise policy gained greater prominence in EU environmental policy throughout the 1990s. In 1993, the *Fifth Environmental Action Programme of the European Community* established as a basic objective that individuals should not be exposed to noise levels which may endanger their health and quality of life (European Community, 1993) and established a number of targets for mitigating exposure by the year 2000. Later, the EU *Green Paper on Future Noise Policy* was published (European Commission, 1996) which focussed on stimulating public discussion on a future approach for EU environmental noise policy. The document examined the various environmental impacts of noise, the noise situation in the EU and existing policies to reduce noise exposure. With regard to the latter, it focussed on reducing noise at source and limiting the transmission of noise between the source and receiver (i.e. people affected). It also outlined a framework for the assessment and reduction of noise exposure and future actions for noise mitigation. In this sense, it indicated the importance of shared responsibility across the EU for effective noise policy and reaffirmed that the management and reduction of noise from different sources should be prioritised.

The key document linking noise exposure to public health concerns was produced by the World Health Organisation (WHO) – *Guidelines for Community Noise* (Berglund et al., 1999). This document was seminal in that it established noise pollution as a serious public health issue worldwide. According to the document, 40% of the population of EU countries was exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) during daytime; the corresponding figure for night-time was 30%. Taking all exposure to transportation together, the WHO estimated that approximately 50% of EU citizens lived in zones of

TABLE 4.1 Legislation Regulating Noise at Source in the EU

Noise Source	Related EU Legislation
Automobile	• Directive 70/157/EEC on the approximation of the laws of the Member States relating to the permissible sound level and the exhaust system of motor vehicle; • Directive 97/24/EC on certain components and characteristics of two- or three-wheel motor vehicles; • Directive 92/23/EEC relating to tyres for motor vehicles and their trailers and to their fitting; • Regulation No. 661/2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore; • Regulation No. 1222/2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters
Aircraft	• Directive 89/629/EEC on the limitation of noise emission from civil subsonic jet aeroplanes; • Directive 2006/93/EC on the regulation of the operation of aeroplanes covered by Part II, Chapter 3, Volume 1 of Annex 16 to the Convention on International Civil Aviation, second edition (1988); • Regulation 216/2008/EC on common rules in the field of civil aviation and establishing a European Aviation Safety Agency; • Directive 2002/30/EC on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Community airports
Railway	• Directive 2008/57/EC on the interoperability of the rail system within the Community; • Commission Decision 2002/735/EC concerning the technical specification for interoperability relating to the rolling stock subsystem of the trans-European high-speed rail system; • Commission Decision 2002/732/EC concerning the technical specification for interoperability relating to the infrastructure subsystem of the trans-European high-speed rail system; • Commission Decision 2011/229/EU of concerning the technical specifications of interoperability relating to the subsystem 'rolling stock – noise' of the trans-European conventional rail system
Outdoor equipment	• Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors
Recreational craft	• Directive 2003/44/EC amending Directive 94/25/EC on the approximation of the laws, regulations and administrative provisions of the Member States relating to recreational craft
Household appliances	• Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products; • Commission Regulation No. 206/2012/EU implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans;

Continued

TABLE 4.1 Legislation Regulating Noise at Source in the EU—cont'd

Noise Source	Related EU Legislation
	• Commission Regulation No. 1016/2010/EU implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers; • Commission Regulation 643/2009/EC implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigerating appliances; • Commission Regulation 1015/2010/EU of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines

acoustical discomfort. Just a few years later, the *6th Environmental Action Programme of the European Community* was adopted by the Council and the European Parliament specifically targeted the problem of environmental noise. The Programme stipulated that future environmental noise policy should aim at 'substantially reducing the number of people regularly affected by long-term average levels of noise, in particular from traffic…' as well as 'developing and implementing instruments to mitigate traffic noise' (European Commission, 2002, 10, 12).

At the EU level, these policy documents together with academic research on noise and health relationships have been instrumental in the development of a legislative framework for the management of environmental noise in Europe. In response to a rising evidence base suggesting health effects associated with excessive noise pollution, the EU passed Directive 2002/49/EC, also known as the END (EU, 2002). Recognising the potential public health concerns, it sought to develop a common approach towards the avoidance, prevention and reduction of the harmful effects of exposure to environmental noise using a strategic noise mapping process. This will be discussed in detail in the next section.

Since the END, there have been some policy documents specifically focussing on environmental noise and its reduction. Of particular note is the recent WHO *Night Noise Guidelines for Europe* (2009) which effectively updated *Guidelines for Community Noise* (1999). It not only sets out the health effects of night-time noise exposure but also offers guidance on how to reduce the harmful effects of night noise in the EU. As mentioned previously (Chapter 3), that document recommended a non-binding limit value of 40 dB(A) $L_{\text{night,outside}}$ if authorities are to prevent their citizens from being exposed to harmful effects of environmental noise pollution. But it also recognised that some authorities might not be able to adopt that limit value initially and suggested an interim value of 55 dB(A) $L_{night/outside}$ until it becomes more feasible for individual authorities to adopt the recommended limit value. This was followed up by the *Burden of Disease from Environmental Noise* document in 2011 which quantified for the first time the nature and extent of the disease burden from environmental noise exposure across the EU.

The most recent policy document focusing on environmental noise is *Towards a Comprehensive Noise Strategy* (Guarinoni et al., 2012). It attempts to expand the discussion beyond the relationship between noise and health in a more pragmatic manner. It critically assesses existing noise policy and legislation at the EU level by focusing on specific complementarities and disparities. In particular, it points toward the urgent need for more stringent source-based noise legislation than exists at present by reducing permissible noise levels for the manufacture of transport vehicles. The document points out that for the END to be successful into the future, there must be a complementary focus on reducing permissible noise levels at the source if serious noise reductions are to be achieved at the point of the receiver. In the absence of such reduction, the document concludes that the END is likely to only have a limited effect in terms of reducing noise levels across the EU and the cost of doing so will likely fall on the public purse rather than on private manufacturers. One worrying trend over the last decade is that permissible noise levels for road traffic vehicles have not been reduced nearly as aggressively as in previous decades. In fact, rather than decreasing permissible noise levels for vehicle manufacturers, there have actually been some regressive steps in this area including the introduction of special permissible noise limits for 'super cars' which, counter intuitively, are now higher than those for regular automobiles. It is hard to believe that this change, in particular, is anything other than a legislative response to lobbying from high-end European car manufacturers. It ultimately implies that those able to afford highly expensive motor cars are also permitted to produce more negative environmental externalities in terms of environmental noise. Despite this, the general trend has been for the European authorities to be proactive in terms of tackling the problem of environmental noise across Europe with a series of policy and legislative innovations that are beyond compare in other jurisdictions.

4.3 THE ENVIRONMENTAL NOISE DIRECTIVE

The overall objective of the END is to identify a common EU approach aimed at avoiding, preventing or reducing the negative and harmful effects caused by environmental noise. Environmental noise is defined as unwanted or harmful outdoor sound created by human activity, such as noise emitted by means of transport, road traffic, rail traffic, air traffic and industrial activity. The END indicates a series of actions that need to be implemented progressively by Member States in order to achieve the objectives of the END. These are (Guarinoni et al., 2012):

- Monitoring of environmental noise – Member States must develop strategic noise maps in order to estimate the level of population and/or building exposure to environmental noise in priority areas in their jurisdictions;
- Managing environmental noise issues – on the basis of the developed strategic noise maps, Member States must adopt action plans containing measures designed to address noise issues, including noise prevention/reduction and preserving sound quality where it is deemed to be good;
- Public information and consultation – strategic noise maps, action plans and relevant information about noise exposure, its effects and measures considered to address environmental noise issues should be made available to the public or developed in consultation with the public;
- Development of a long-term EU strategy – with a view to reduce noise emitted by the major sources (in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery), the EU and Member States should cooperate in order to provide a framework for EU policies addressing environmental noise issues.

In terms of scope, the END applies to environmental noise affecting humans particularly in residential or industrial areas as well as public parks and other quiet areas in agglomerations and the open countryside. However, the END does not apply to noise caused by the exposed person, noise created by domestic activities or neighbours, noise at the work place or inside means of transportation. Member States are obliged to designate competent national authorities responsible for the implementation of the END which is many cases tends to be the national Environmental Protection Agency. Overall, the END is concerned with four core areas that are considered vital for the assessment and management of environmental noise across the EU. These include (1) strategic noise mapping, (2) population exposure estimation, (3) noise action planning and (4) dissemination of results. Each of these areas is now discussed in more detail.

4.4 STRATEGIC NOISE MAPPING

Although there had been some modest efforts to produce noise maps in the mid-1990s (de Vos and Licitra, 2013), the practice of strategic noise mapping became a standard approach used across EU states as a result of the passing of the END. Defined broadly, noise mapping is simply a means of presenting calculated and/or measured noise levels in a representative manner over a particular geographic area (Murphy and King, 2010). In the END, noise mapping is defined as 'the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator'. From this, it can be seen that under the END, noise maps are considered to be multi-dimensional because they incorporate not only measured/calculated noise levels for a geographic area but also include information about potential breaches of national statutory limits as well as the number of people and number of dwellings exposed to environmental noise.

Within the END, 'strategic noise mapping' is defined somewhat differently than 'noise mapping'. A strategic noise map is defined as 'a map designed for the global assessment of noise exposure in a given area due to different noise sources or for overall predictions for such an area'. In other words, while 'noise mapping' is focussed primarily on the presentation of noise data, 'strategic noise mapping' is primarily concerned with the assessment of noise exposure under the terms of the END. Indeed, the mapping requirements of the END are concerned primarily with 'strategic noise mapping'. Assessment of exposure to environmental noise is to be achieved using 'strategic noise maps' for major roads, railways, airports and agglomerations using the harmonised noise indicators L_{den} and L_{night} that were developed specifically for the END. L_{den} is an annual noise indicator which describes the average day-evening-night-time A-weighted equivalent sound pressure level over a complete year, while L_{night} describes the night-time A-weighted equivalent sound pressure level over a complete year. L_{den} is given by the following equation:

$$L_{den} = 10\log\frac{1}{24}\left(12^{*}10^{L_{day}/10} + 4^{*}10^{L_{evening}+5/10} + 8^{*}10^{L_{night}+10/10}\right) \qquad (4.1)$$

The day period is generally taken to be from 07.00 to 19.00 while evening and night-time periods are taken to be from 19.00 to 23.00 and 23.00 to 07.00, respectively. The weighting factors in the above equation are designed to account for the increase in annoyance at different periods throughout the entire day, hence the addition of 10 to the value for L_{night} and 5 to the value of $L_{evening}$ meaning that escalations in night-time noise are more punitive with respect to limit values. However, the END also allows for additional supplementary indicators to L_{den} and L_{night}. During the first phase of noise mapping, the use of supplementary indicators was rare; in cases where they were used, L_{max} or L_{eq} were the supplementary indicators of choice. However, many different indicators exist and their use may maximise the value of strategic noise mapping. Possible additional examples include perceived noise level, sound exposure level (SEL) or even % highly annoyed (%HA) and % highly sleep disturbed (%SD).

On the basis of L_{den} and L_{night}, Article 7(1) of the END requires Member States to produce strategic noise maps for all major roads, railways, airports and agglomerations on a 5-year basis, starting from 30 June 2007. In the first phase (June 2007), strategic noise maps were compiled for: all agglomerations with more than 250,000 inhabitants; all major roads with more than 6 million vehicle passages a year; railways with more than 60,000 train passages a year; and major airports with more than 50,000 movements a year within the territories. The results of this process have recently been made available via a noise observation and information service for Europe (NOISE) which is maintained by the European Environment Agency (EEA),[1] while a preliminary European-wide analysis of the results has already been attempted (van den Berg and Licitra, 2009). The second phase (June 2012) requires that strategic noise maps are produced for all agglomerations with a population in excess of 100,000 individuals and also sees a reduction in the thresholds for major roads (to 3 million vehicle passages) and railways (to 30,000 vehicle passages). The strategic maps must satisfy minimum requirements as listed in Annex IV of the END and should be reviewed every 5 years.

Figure 4.1 presents a standardised schematic of best practice steps involved in the strategic noise mapping process. During the first phase of the END, these steps were applied in a rather variable way by each nation and, therefore, the results of the process were also variable. The standardised approach has a series of components: data collection; noise calculation; validation and mapping; estimation of population exposed; noise action planning; and public dissemination. This process is elaborated upon in the following section.

4.4.1 Data Collection/Input Data

Perhaps the most important part of the process is data collection; it is crucial that accurate data are available in order to acquire accurate calculation levels at noise receiver points. Generally, the main data required for noise mapping are information relating to traffic flows on the links/routes to be assessed which are representative of traffic flow for individual sources (road, rail, air and industry) for a full year for the area under consideration. Building height and geometry information is also needed as this affects the path of sound waves in the built environment. In addition, depending on the calculation method being utilised, local meteorological and topographical information may also be required including relative

[1] See http://noise.eionet.europa.eu/ for more information.

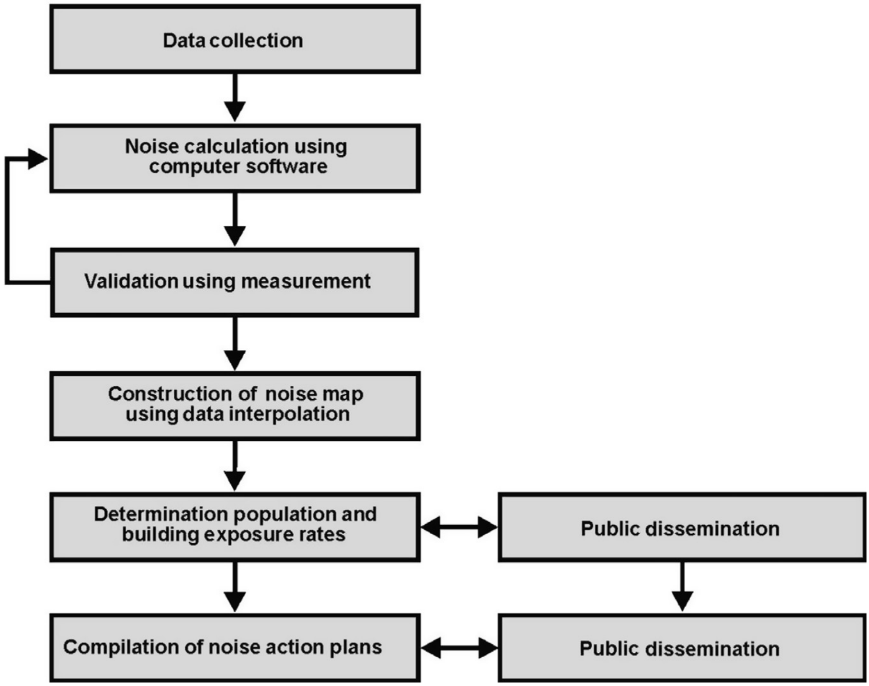


FIGURE 4.1 Schematic of the noise mapping process.

humidity, wind speed and temperature. For road traffic noise, for example, data related to the sound power characteristics of vehicles are generally standardised within calculation software on the basis of typical characteristics of light and heavy vehicles. An outline of the main data needed for noise modelling calculations is provided in Table 4.2.

4.4.2 Calculation Methods for Noise Mapping

Numerous calculation methods exist for predicting noise levels at specific receiver points. Similarly, the results obtained from calculations may be expressed using a variety of noise indicators. For noise studies, both issues are problematic because these difficulties make comparison between studies extremely difficult. One objective of the END was to establish a uniform approach to the assessment and management of environmental noise. In this regard, the END has addressed the latter issue relating to noise indicators through the introduction of the L_{den} noise indicator. However, in relation to the former issue, a standardised noise calculation model has yet to be fully developed but is currently in the process of being completed (see Box 4.1).

TABLE 4.2 Overview of Main Data Sources for Noise Calculations

	Parameters				
Data	**Road Traffic**	**Railway Traffic**	**Aircraft Traffic**	**Industry**	**Acoustical Data**
Sources and Emissions	Road geometry Gradient Curvatures Surface cover Speed Volume of traffic Heavy vehicle percentage Type of traffic flow Traffic lights	Number and types of trains Average speed Sirens Railway structure (in cuttings, level or elevated) Type of rails, ballasts and ties Bridge structures	Airport plan Runway configuration Flight operations (daily, yearly, etc.) Types of aircrafts	Layout plan for open air activities Factory buildings Manufacturing process Indoor–outdoor equipment Operation modes (hourly, daily, weekly)	Sound power levels in L_W, dBA and the spectral values Source directivity Reference sound pressure levels with temporal and spectral variations For complex sources: contributions from individual parts

	Parameters				
Data	**Ground Cover and Woodland**	**Buildings**	**Obstacles**	**Meteorological Factors**	**Acoustical Data**
Physical Environment	Type of surface (sound absorption coefficient) Width of surface under sound path Surface area configuration of different surface types Type of plants Configuration of trees (deciduous, evergreen, etc.)	Location Geometry Façade shape (ba lconies, etc.) Number of floors (or total height) Function Façade cover (sound reflection properties)	Natural (topography) or built barriers Location (distance from source) Thickness Length Height Surface type Top profile of screens Surface cover Constructional material	Wind gradient Temperature gradient Humidity (air absorption) (Short-, mid- and long-term average values) Favourable conditions increasing noise levels	Effects of physical factors on immission values caused by wave divergence absorption, diffraction, refraction, scattering of sound Total sound attenuation

	Parameters				
Data	**Land Use Information and Applicable Noise Limits**	**Population Structure**	**Building and Usage**	**Future Plans About Area**	**Acoustical Data**
Demographic	Urban residential Suburban and rural Health care buildings Educational buildings Administrative area Shopping centres Industrial and mixed zones Touristic area (hotels, motels) Recreational and entertainment area Parks and cemeteries	Total population Number of residents for each building Social, educational and economical characteristics of community Seasonal activities (in touristic areas)	Sensitivity to noise Indoor noise limite Times of occupation (daily, yearly) Open/closed windows Existence of AC equipment Indoor noise sources (background noises) Layout of rooms Building construction	On-going and future constructions Extension or modification of noise sources. Existing noise action plans	Noise – dose and response relationships for various types of land uses Noise levels and performance effects Outputs from noise maps: Number of people and buildings exposed to various noise levels Number of buildings having quiet façades

Source: *Kurra and Dahl (2012).*

For the first round of noise mapping, the END recommended several standards to be used by countries with no national standard or by those who wished to change computation methods. These standards were envisioned to be interim standards for use until a standardised European method was developed by the EU, although Member States were free to use alternative methods in the development of strategic noise maps. For road traffic noise, the chosen standards were the French national computation method 'NMPB-Routes-96 (SETRA-CERTU-LCPCCSTB)', referred to in 'Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, Article 6' and in the French standard 'XPS 31–133'. For input data concerning emission, these documents refer to the 'Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR 1980'. For railway noise, the Netherlands national computation method published in 'Reken- en Meetvoorschrift Railverkeerslawaai '96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 20 November 1996' was selected as the recommended interim method while for aircraft noise ECAC.CEAC Doc. 29 'Report on Standard Method of Computing Noise Contours around Civil Airports', 1997 was selected. Of the different approaches to the modelling of flight paths, the segmentation technique referred to in Section 7.5 of ECAC.CEAC Doc. 29 was to be used. For industrial noise ISO 9613-2: 'Acoustics - Abatement of sound propagation outdoors, Part 2: General method of calculation' was to be used. Each of these methods is discussed in more detail in Chapters 5 and 6.

While the interim methods have been widely implemented in their country of origin, it was deemed appropriate to publish additional guidance on the implementation of the standard for noise mapping under the END. Indeed, Annex II of the END commits the Commission to publish guidelines on the interim methods along with providing emission data for aircraft noise, railway noise and road traffic noise, on the basis of existing data. In August 2003, the Commission issued recommendations concerning the emission data of the interim computation methods, taking cognisance of the universal noise indicators L_{den} and L_{night} (European Commission, 2003). Additionally, in 2002, European Commission DG Environment engaged the service of Wölfel to develop adaptations and revisions of the interim methods for the purpose of strategic noise mapping in Europe (Wölfel Group, 2003).

In situations where a Member State chose to use a calculation method other than the recommended interim method, that Member State was required to demonstrate that the adopted method produced equivalent results. This requirement was designed to ensure comparability of results across member states. Yet, the manner by which to determine equivalence was not described in the END which led to considerable confusion among competent authorities in Member States. In order to assist Member States in determining equivalence in their mapping methods, a number of technical protocols were developed by the Joint Research Centre (JRC) of the European Commission (JRC, 2008). These protocols were made available to each Member State who was asked to report back about the results of the equivalency exercise. However, only a few Member States participated in this exercise. It was noted that this could be 'eventually attributed to the fact that Member States were reluctant in facing discussions concerning equivalency' (JRC, 2008, 6). In the responses received by the JRC, one communication noted 'As the EU Directive does not call for identical results it should not become necessary to demonstrate equivalence by means of a parallel computation of specific cases' (JRC, 2008, 13), while another observed that applying the equivalence protocol could 'prove a costly and time-consuming task just at the stage when Member States are working hard to meet the very challenging timetable for action planning', stating that 'it will be difficult to determine what deviation from the interim method will be acceptable' (JRC, 2008, 32). The result of this was that despite interim methods being recommended, most nations used their national calculation methods where one was available. This has had a significant impact of the efficacy of comparing noise mapping results across Europe.

Each national calculation method was originally developed to the specific conditions or legislation as applied in each nation (long before the END was conceived). Thus, the Dutch prediction method for railway noise is tailored for Dutch trains travelling on typical Dutch railway tracks. The UK CRTN method for road traffic noise predicts noise levels over 18 h of the day because this time period was enshrined in the legislation which preceded CRTN. One must also consider the time period in which these calculation methods were developed; CRTN (UK) was developed in 1988, the French Guide du Bruit was developed in 1980; the US Federal Highway Authority's Traffic Noise Model (TNM) Version 1.0 was released 1996; in 1990, the German RLS 90 calculation method revised a 1981 version; and in 1993, the Acoustical Society of Japan developed the ASJ Method for road traffic noise. While most methods have been revised in recent years (or accompanied by good practice documents), they are all based on methods that were developed prior to the advent of the personal computer and data-logging sound level meters. Furthermore, no calculation method was ever developed with the intention of producing strategic noise maps on a national scale. In fact, calculation methods (of the 1970s, 1980s and 1990s) were developed for implemention via hand calculation (Hepworth, 2006).

Table 4.3 shows the wide range of calculation methods used for each type of noise source in the first phase of the END; more or less identical approaches were also used for the second round. This highlights the variety of acoustical standards currently in use across the EU. The only way to ensure that a consistent approach is adopted across Europe is for every Member State to implement the same calculation method which is why the EU are now on the brink of establishing a common standardised prediction methodology for noise mapping in the EU – referred to as CNOSSOS-EU (Kephalopoulos et al., 2012).

BOX 4.1

COMMON NOISE ASSESSMENT METHODS IN EUROPE (CNOSSOS-EU)

Article 6(2) of the Directive states that '. . .Common assessment methods for the determination of L_{den} and L_{night} shall be established by the Commission. . .'. CNOSSOS-EU is a common noise calculation method for road, railway, aircraft and industrial noise across the EU (Kephalopoulos et al., 2012). Indeed, CNOSSOS-EU also develops a methodology for assigning receiver points to the façades of buildings and assigning population data to the receiver points at the façades of buildings. The methodological framework underpinning CNOSSOS-EU is based on noise assessment methods that are in existing use in some Member States (e.g. Austria, Denmark, Finland, France, Germany and Sweden). Following its adoption, CNOSSOS-EU is to be used by the Member States for the purpose of strategic noise mapping as required by Article 7 of the END. The introduction of the new methodology is a welcome development because it offers a solution to the inconsistent noise mapping undertaken in the past. For the first time it will allow a direct comparison of noise exposure at the EU level. Indeed, historical comparability of noise maps may be maintained by undertaking back calculation for the first two rounds of noise mapping if Member States choose to do so.

The development of CNOSSOS-EU was co-ordinated by the Directorate-General for the JRC on behalf of the Directorate-General for the Environment. It involved collaboration between the European Commission, European Environment Agency, European Aviation Safety Agency, the WHO and nearly 150 noise experts from across Europe. Following the development phase (Phase A) of CNOSSOS-EU, the Commission will amend Annex II of the END during the implementation phase (Phase B) of the project from 2012 to 2015. The ultimate objective is to have the common noise assessment methodology implemented and operational for the third round of strategic noise mapping in 2017.

However, it remains to be seen how European Member States will interpret the CNOSSOS-EU method. Aspects of the method have already been questioned and some experts appear reluctant to embrace it. The method

TABLE 4.3 Noise Calculation Methods Utilised Across the EU During the First Round of Strategic Noise Mapping

Road	Rail
RVS 3.02	RMR (SRM 11)
NMPB/XPS 31–133	NBT85
Temanord 525	Temanord 524
RLS90	NMPB/XPS 31–133
CRTN	Schal03
RMW 2002 (SRM I+II)	CRN
StL 86	SEMIBEL
Industry	**Air**
OAL 28	OAL 24
ISO9613	ECAC DOC 29
Nordforsk 32	AzB
Handleiding Industrielawaai	INM
BS5228	RLD/BV-01 and RLD/BV-02
	FLULA

is still in preliminary format, but the current release gives some indication of the proposed detail. If it is to be a successful endeavour, it will have to be finalised in an open, clear and logical manner with input from all relevant stakeholders. To date, this has been achieved with the establishment of the CNOSSOS-EU Technical Forum of Experts. This technical forum has brought CNOSSOS-EU to its current stage, but it is not yet complete. The final step requires validation of the methods, and it is likely that this will have to be completed in each Member State in order to ensure widespread adoption.

As well as the inherent differences associated with the use of different calculation methods, different commercial software packages (Box 4.2) are being used for fulfilment of the terms of the END together with unknown spatial interpolation techniques and different colouring display methods. As well as this, the END contains a number of unclear phrases and missing provisions. For example, noise maps have to be developed near major roads but what constitutes 'near' is not explicitly defined (McManus, 2009). Taken together, all of these issues produce results which make comparison of strategic noise mapping results across EU states extremely difficult. The recent *Good Practice Guide for Strategic Noise*

Mapping and the Prediction of Associated Data on Noise Exposure (WGAEN, 2006) has attempted to provide a toolkit of practical workaround solutions for the various obstacles encountered during the noise mapping process as well as offering a uniform interpretation of the Directive itself. Indeed, it is envisaged that CNOSSOS-EU will iron out many of these difficulties.

BOX 4.2

SOFTWARE PACKAGES AND NOISE MODELLING

Research has uncovered that different commercial software packages may yield different results while applying the same national computational method. A study conducted in the United Kingdom outlined the extent of variation between several commercial packages implementing the CRTN standard (Hepworth, 2006). Results obtained from the commercial software were compared over a 1-km^2 calculation area. The greatest mean difference was 2 dB(A), and the greatest individual difference at a single calculation point was 11 dB(A). These results indicate that the use of different software packages implementing the same standard, with the same input data, will have a significant effect on the resulting noise map. Other research has reported variances of up to 6 dB(A) due to different interpretations of the Dutch national calculation method RMV2 (Nijland and Van Wee, 2005), while similar problems have been highlighted by Arana et al. (2010). Indeed, King and Rice (2009) argue that to truly achieve standardisation in noise studies, competent authorities should be required not only to apply the same calculation procedures but also to employ the same calculation software. In this context, Guarinoni et al. (2012) have recently recommended that an open source noise calculation software package is produced by the EU to be utilised by all nations for the CNOSSOS-EU method.

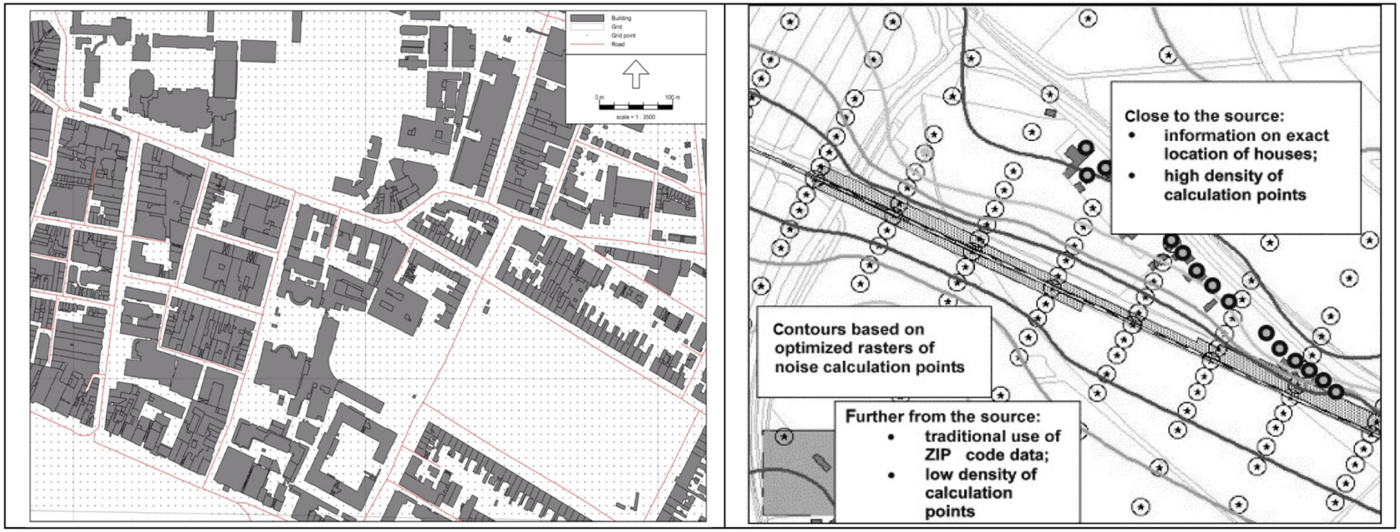
4.4.3 Producing a Noise Map

In order to produce a strategic noise map, the process proceeds by calculating noise levels at receiver points on uniform grids placed over the study area using the input data and noise modelling approaches described in the previous sections. All calculations are performed at the standard receiver height of 4 m above the ground according to the terms of the

END. These calculations are normally undertaken using commercial software programs which have embedded algorithms for national noise source and propagation standards for nations across the EU. After calculations have been undertaken in commercial software, it is best practice to validate modelling results using sound level meter measurements to ensure that the model provides an accurate representation of the true sound environment. Validation measurement should be performed according to ISO 1996-1 (ISO, 2003) and should adhere to international best practice for undertaking noise measurement described in Section 2.5, Chapter 2.

In terms of representation, grid sizes for noise calculations can range from 5 to 20 m^2 resolutions. In open areas outside agglomerations, larger grid resolutions may be adequate whereas in urban areas a grid spacing of less than 10 m is desirable. Indeed, it is also possible to use a variable grid spacing which declines in resolution away from the noise source (see De Kluijver and Stoter, 2003; see Figure 4.2) in order to reduce the overall number of receivers and speed up calculation time. Normally, noise maps are then produced using a process of spatial interpolation within a Geographic Information System (GIS) as presented in the noise map of Dublin, Ireland (Figure 4.3). Spatial interpolation is a mathematical method of constructing new data points within the range of a discrete set of known data points across a geographic area. The main interpolation methods available within a GIS framework are nearest neighbour, kriging, spline and inverse distance weighting. Murphy et al. (2006) have pointed out that the choice of interpolation method in noise mapping studies can be important due to different spatial interpolation methods producing slightly different mapping results both in a quantitative and in a qualitative sense. While most commercial noise mapping programs have an embedded mapping component allowing users to produce maps without the need for a GIS system, they are extremely limited in terms of their functionality. For example, the mapping component in commercial software does not usually provide the user with a choice of spatial interpolation method. In fact, many of them do not specify the method being utilised in the mapping process at all (Murphy and King, 2013). Overall, commercial packages do not compare positively with the mapping techniques available in commercial GIS packages. In particular, the ability of GIS packages to deal with numerous types of spatial data far outweighs that available within commercial noise mapping packages. As a reflection of this, some commercial software packages offer import/export functionality in an attempt to take advantage of the greater ability of GIS to manipulate spatial data in a more sophisticated and customised manner.

The absence of a standardised colour scheme makes it difficult to compare maps from different EU states. Very often, noise maps are produced with different colour codings despite the fact that an ISO standard exists for the presentation of acoustics graphics (ISO 1996-2). However, this



(a) (b)

FIGURE 4.2 Uniform (a) and irregular (b) receiver grids for noise calculation purposes. *Source: Panel (b): De Kluijver and Stoter (2003).*

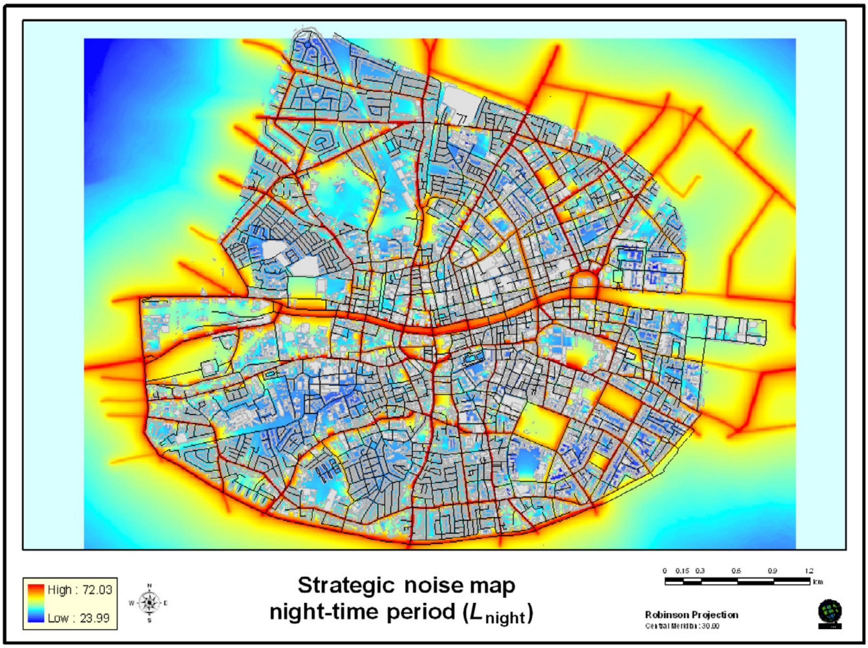


FIGURE 4.3 Noise map of Dublin, Ireland. *Source: Murphy and King (2011).*

standard has since been revised and includes no specifics on colour coding. Indeed, the recent best practice document from the WGAEN (2008) does attempt to deal with the issue of colour coding by providing more specific guidelines for relevant authorities. Moreover, the question of whether results should be presented using graduated colouring techniques or specifically delineated colour contours remains unclear. In comparative terms, this could prove to be problematic given that different methods affect the visual impact of noise mapping results when they are presented to the general public.

4.4.4 Estimating Population Exposure

The second key element of the END is the determination of levels of exposure to environmental noise using the common indicators L_{den} and L_{night}. The END requires competent authorities in each Member State to provide estimates of the number of people living in dwellings that are exposed to values of L_{den} and L_{night} in various categories[2] at the most

[2]The categories stated in the Directive are 55-59, 60-64, 65-69, 70-74 and >75 for L_{den} and 50-54, 55-59, 60-64, 65-69 and >70 for L_{night}.

exposed building façade and separately for road, rail, air traffic and industrial noise (EU, 2002, 24). In addition, where it is deemed appropriate and where the information is available, people living in dwellings that have special insulation against environmental noise or have a quiet façade[3] should also be reported. Thus, strategic noise maps must be accompanied by relevant assessment data detailing the level of exposure for each area under consideration. However, the END does stipulate that strategic noise maps can take the form of graphical plots or numerical data in table or electronic form.

In procedural terms, approaches aimed at estimating the exposure of people to environmental noise must consider three issues (Brambilla, 2013):

1. Assignment of receiver points to the building façade
2. Assignment of population to buildings
3. Assignment of population data to the receiver points at building façades

In the first instance, in order to estimate population exposure to noise separate calculations must be undertaken placing receiver points at the building façade – these are often referred to as 'façade calculations'. This is highlighted in Annex VI of the END. It is important also to point out that when noise levels are calculated at receiver points at façades, the noise level refers to the incident sound level – also known as the 'free field' sound. This means that reflections from the façade under observation are excluded from the calculation of noise levels. However, if external façade levels are required, a suitable correction factor can be applied. As demonstrated in Figure 4.4, façade calculations involve using separate receiver points from those used for the development of strategic noise maps. It is good practice to place receiver points at 0.1 m in front of the façade with spacing of 3 m between individual calculation points and at a height of 4 m (as for strategic noise mapping grids). While a height of 4 m is stipulated in the END, it is unlikely to be representative of the actual exposed population, particularly in urban areas. Specifically, a 4-m height is adequate in suburban of low-density areas where buildings are a few stories high, but is likely to be inaccurate in central city areas where building heights run to many stories. For example, Law et al.'s (2011) noise mapping study of Hong Kong demonstrates the inadequacy of 4 m receivers points for the high rise nature of buildings in that city.

The recently published CNOSSOS-EU report suggests a common approach for assigning receiver points to buildings based largely on the

[3] A quiet façade refers to the façade of a dwelling at which the value of L_{den} is more than 20 dB(A) lower than at the façade having the highest value of L_{den}.

FIGURE 4.4 Example receiver placing for calculating noise at building façades.

German method. Using that method, the following approach is used to calculate exposure (Kephalopoulos et al., 2012, 115):

- façades are split up every 5 m from the start position onwards, with a receiver position placed at the half-way distance;
- the remaining section has its receiver point in its mid-point;
- for buildings with floor sizes that indicate a single dwelling per floor level, the most exposed façade noise level is used directly for calculating exposure statistics and related to the number of inhabitants;
- for other buildings, exposure statistics use all receiver points in a weighted manner so that the sum of all receiver points represents the total number of inhabitants.

Once noise levels are known at the receiver points for each building façade, it is a rather straightforward process in a GIS to assign individual buildings with the noise level associated with the receiver point at the most exposed façade. This is normally undertaken using a procedure known as spatial joining in a GIS. Typically, population exposure is estimated by first determining the number of residential units for each building in the study area. Once determined, each residential unit is assigned an average household size value. For example, if there are 80 people residing in a building and the building has 32 residences (i.e. apartments), the average household size is 2.5. Given the number of residential units for each building in the study area and the average household size associated with each building location and the building noise level, it is possible to compute estimates of the residential population for each building exposed to environmental noise within a specific noise category. This is generally the approach that has been adopted thus far under the END although different procedures have been adopted depending on the availability of data (see Murphy and King, 2011; Murphy et al., 2009). However, if more detailed data are available in specific circumstances, then estimates of the residential population in individual units can be substituted with more precise data.

The foregoing approach is not without its flaws. In particular, it fails to account for the design of individual buildings and specifically whether the bedroom is located at the most exposed façade for individual residences within buildings. By counting individuals living in a particular household, the assessment method assumes, particularly during the night-time period, that all individuals living in a particular household are exposed to the noise level at the most exposed building façade. Thus, estimates of population exposure are likely to be overestimated to a significant degree if assessment is based at the individual level. Moreover, assessment of exposure to noise is based on the assumption that individuals reside in their dwelling and sleep there all year around, whereas in many EU cities, workers and students leave the city at the weekend to return to rural areas. Thus, the assessment method fails to account for transient populations when providing estimates of population exposure.

There are other methods of estimating population exposure to noise that have been used in specific national contexts. One of these is the German method – VBEB (Vorläufige Berechnungsmethode zur Ermittlung der Belastetenzahlen durch Umgebungslärm/Preliminary Calculation Method for Determination of the Number of Persons Exposed to Environmental Noise). The method assumes that the position, size, floor plan and number of residential units of a building are not generally known. Thus, the approach assumes that the total number of building inhabitants is distributed equally across receiver points located at the building façade. In this way, an 'inhabitant per assessment point' is determined (German Federal Gazette, 2007). The method generally produces much more conservative estimates of the population exposed to noise than the approach described previously. Other methods include the average-level exceedance (ALE) method and the 'nearest grid method' (NEAR). Licitra et al. (2009) applied the END, VBEB and ALE methods to the same area in Pisa, Italy. Their results showed that the END method was significantly more precautionary (in that it had higher estimates) than either the

ALE or VBEB method. In fact, their results found that at the exposure level of 60 dB(A) L_{den}, the END method estimated a population exposure rate of 47%, whereas the corresponding figures for the VBEB and ALE methods were 20% and 37%, respectively. This highlights the extent to which different estimation approaches can produce drastically different estimates of population exposure to environmental noise. Moreover, the results imply a potentially alarming overestimation of population exposure arising from the results of population exposure estimation across the EU as part of the END.

Very often, estimating population exposure can be a complex process for a number of reasons but mainly due to the fact that population data in individual buildings are not often known and therefore estimating the population associated with individual buildings can be difficult. Moreover, it is often not possible to know the orientation of the bedroom (i.e. whether it is at the most exposed façade or not) for large-scale noise mapping studies and this can often produce overestimates of exposure. In addition, in the first round of noise mapping in the EU, some nations (e.g. Ireland among others) produced estimates of population exposure based solely on strategic noise maps without undertaking façade calculations. When these issues are taken together, it can be seen that the results of exposure studies across the EU are likely to have a significant degree of error. Indeed, they are also difficult to compare across the EU because of the variation in the nature of the data and estimation procedure used across the continent.

For the first and second round of noise mapping, there has been no standardised method for estimating population exposure. It is likely that that will also be the case for the third round in 2017. In the END, emphasis is placed on providing information about the number of people living in dwellings that are exposed to various noise categories at the most exposed façade. The *Good Practice Guide* (WGAEN, 2008) makes a number of recommendations regarding the assessment of population exposure based on the type of data available within each Member State. However, the approaches suggested fall far short of a standardised methodological approach. Given these criticisms, standardised approaches have recently been developed for estimating population exposure under the CNOSSOS-EU methodology. The approach provides for estimating exposure both in cases where population information is available and unavailable for buildings in specific areas (see Kephalopoulos et al., 2012, pp. 111–115).

It is notable also that the END does not stipulate any guideline limit values for population exposure to L_{den} and L_{night}. The EU did not set common European-wide noise limit values. It was felt that this would be impossible given the large differences in scale and comprehensiveness of implemented noise measures throughout the different Member States (European Commission, 2000). Yet, as mentioned already, guideline limit values for environmental noise already exist in WHO policy documents (Berglund et al., 1999; WHO, 2009) which provides a framework for the establishment of dose–effect relations for environmental noise exposure. Looking to the future, and assuming that the more pressing methodological problems have been dealt with adequately, it would appear important that guideline limit values are set by the EU for both L_{den} and L_{night}. In its absence, it is extremely difficult to assess the extent of dose–effect relationships within and between Member States adequately. Indeed, a recent EU policy document recommends that while limit values should not be established immediately, their establishment as part of END revisions should be a key medium-term target for EU policymakers (Guarinoni et al., 2012).

4.4.5 Noise Action Planning

Chapter 7 provides a detailed account of existing noise mitigation approaches, including action planning measures and best practice case studies that assist with reducing noise exposure. As a result, the following discussion focuses only on the emergence of action planning under the terms of the END and subsequent implementation of action plans by Member States.

The END recognises that the development of strategic noise maps is simply a means to an end for improving public health across the EU. In this sense, noise maps are seen to be a precursor to implementing effective and sustainable noise reduction measures so that exposure to excessive noise can be reduced in agglomerations and within the vicinity of noise sources beyond city regions. Thus, based upon noise mapping results, Member States must prepare action plans containing measures addressing noise issues and their effects for major roads, railways, airports and large agglomerations (>100,000 people). According to Article 8.1(b), the plans should also aim to protect quiet areas against an increase in noise. However, the ENDs rather vague definition left ample discretion for Member States to subjectively interpret the concept of quiet areas. This subsequently led to a great deal of confusion surrounding how quiet areas should be defined for each nation and a considerable divergence in the approaches used for noise mitigation and sound quality preservation.

According to the END, action plans refer to 'plans designed to manage noise issues and effects, including noise reduction if necessary'. The END also requires that action plans are reviewed, if deemed necessary by the competent authority, when a major development occurs that may affect the existing noise situation including residential, commercial, retail or major infrastructure developments. In addition, action plans are to be reviewed every 5 years after the initial date of approval. Thus, noise action planning is process-oriented in the sense that it is constantly evolving and regularly taking account of major changes that are likely to affect the sound quality of a local area.

The END also introduces the notion of 'acoustical planning' which has direct relevance to the development of action plans for noise. 'Acoustical planning' refers to 'controlling future noise by planned measures, such as land-use planning, systems engineering for traffic, traffic planning, abatement by sound-insulation measures and noise control of sources'. In other words, the END points directly to the role that can be played by national planning systems in the future mitigation of environmental noise and recent research has demonstrated the impact that land use and traffic management measures can have on reducing noise pollution in cities (King et al., 2009, 2011a,b).

As outlined already, noise action planning is envisioned as a method for the management of noise issues and effects. In this regard, the END requires that noise mitigation measures are put in place to deal with areas considered to be of poor sound quality and suggestions have been made within the END about measures that could perhaps be utilised by the relevant authorities (Table 4.4). The difficulty with noise mitigation measures is trying to connect the correct mitigation measure with the appropriate problem. For example, a noise barrier may not be an

TABLE 4.4 Minimum Required Elements for Actions Plans and Potential Noise Mitigation Measures in the END

Minimum Required Elements for Action Plans	Potential Mitigation Measures
• Description of agglomeration, major roads, major railways or airports • The authority responsible • The legal context (national legislative compliance) • Limits values (if applicable) • Summary noise mapping results • Evaluation of human exposure; identification of problems potential improvements • Record of public consultation • Noise reduction measures in force or in preparation • Actions to be taken in next 5 years • Estimates of the reduction of the people affected • A long-term strategy • Financial information (cost-effectiveness assessments, etc.) • Provision for evaluation of action plan implementation and results	• Traffic planning • Land-use planning • Technical measures at noise sources • Selection of quieter sources • Reduction of sound transmission • Regulatory or economic measure or incentives

appropriate measure to be adopted within cities given the potential aesthetic consequences, but it may be appropriate for areas that are less visually sensitive. Similarly, reducing the speed limit on motorways may be less suitable than the erection of a noise barrier. Thus, the key to implementing noise mitigation measures is for decision makers to take account of the severity of the noise situation as well as the local context for implementing such measures.

Policymakers must also be careful not to lose sight of the need to preserve quiet areas of good sound quality under the terms of the END. There is a danger that areas of good sound quality will be neglected or simply ignored if they are considered to be 'unproblematic'. In this sense, action plans should be careful to clearly identify 'quiet areas' within the strategic noise mapping process which would allow for the ongoing monitoring of these areas and the evolution of the sound quality within them. Moreover, quiet areas are poorly defined in the END which fails to set a guideline decibel value below which quiet areas could be appropriately categorised. This is a further area for clarification in future legislative amendments which has been aided considerably by a recent UK policy document which assists in the definition of quiet areas (DEFRA, 2006).

A further element of this strand of the END relates to public consultation. Competent authorities are required to 'ensure that the public is consulted about proposals for action plans' and that they are 'given early and effective opportunities to participate in the preparation and review of the action plans'. Authorities are also required to ensure that 'the results of participation are taken into account and that the public is informed on the decisions taken'. To date, public consultation has been limited in many states. For example, public consultation has generally been limited to placing strategic noise maps on the internet while little attempt appears to have been made to inform the public of actions to be taken as a result of noise action planning. As it stands currently, public consultation is seen very much as an afterthought of the strategic noise mapping process where public communication and information dissemination is occurring in a rather *ad hoc* and tokenistic fashion.

4.4.6 Dissemination of Results to the General Public

The final major element of the END centres on the dissemination of information derived from the strategic noise mapping process to the general public. Indeed, one of the central objectives of the END is to ensure that 'information on environmental noise and its effects is made available to the public'. The END requires that strategic noise maps and action plans are not only made available to the public but also disseminated in accordance with Directive 90/13/EEC on the freedom of access of information to the environment. The availability of the information must also conform to the minimum requirements for strategic noise mapping and action plans laid down in Annexes IV and V of the END. Information presented to the general public is required to be 'clear, comprehensible and accessible'.

Member States are obliged to provide the Commission with information from their strategic noise maps, summaries of the action plan details and noise control programmes at regular intervals, as well as to update the Commission on competent bodies, noise limit values and designated roads, railways, airports and agglomerations. On the basis of this information, every 5 years the Commission publishes a summary report and sets up a database of strategic noise maps in order to facilitate the compilation of a report on the implementation of the END. The first implementation report was published by the Commission on 1 June 2011. The full reporting obligations set out under the END are contained in a number of provisions and are summarised in Table 4.5.

The core issue surrounding the dissemination of information to the public relates primarily to the method of dissemination of strategic noise mapping information to the public. At present, the methods used are primarily the online availability of strategic noise maps and associated noise actions plans. In addition to this, a recent European Environment Agency (EEA) document – *Presenting Noise Mapping Information to the Public* – highlights the need for the public to be informed about the use and limitations of the results of noise mapping so that their expectations for the action planning stage remain realistic (WGAEN, 2008). Indeed, numerous additional suggestions are offered for improving the presentation of noise mapping information to the public through the establishment of a central government website for national data, press releases, public forums and school education.

Most strategic noise maps are available only in two dimensions and are often difficult for a relatively uninformed public to understand clearly. Some scholars have attempted to present noise mapping results as a 3D representation of 2D information (Law et al., 2011; Murphy et al., 2006; Stoter et al., 2008). Such approaches offer better visualisation of noise mapping results than the more conventional approaches currently being adopted and have the potential to enhance public engagement with noise mapping and action planning exercises. More recent approaches have advocated the incorporation of strategic noise mapping results into virtual urban simulations (Law et al., 2011; Murphy et al., 2007). Such an approach would enable end users to experience strategic noise mapping results in a manner akin to that of an online gaming experience (see Drettakis et al., 2007; Tsingos et al., 2003). In this way, the end user is able to negotiate the surrounding environment and experience changes in environmental noise in a more realistic fashion. These changes would also

TABLE 4.5 Reporting Requirements of Member States Arising from the END

Implementation Deadline	Summary Description of Data Sets to Be Reported	END Provision	Updates by Member States
30 June 2005	Major roads, major railways, major airports and agglomeration designated by MS and concerned by first implementation step	Art. 7-1	Mandatory every 5 years
18 July 2005	Establishment of competent bodies for strategic noise maps, action plans and data collection	Art. 4-2	Possible at any time
18 July 2005	Noise limit values in force or planned and associated information	Art. 5-4	Possible at any time
30 December 2007	Strategic noise maps related data as listed in annex VI for major roads, railways, airports and agglomerations concerned by first implementation step • Per agglomeration ≥250,000 inhab. • Per major civil airport ≥50,000 movts/year • For overall major roads ≥6 million veh/year • For overall major railways ≥60,000 trains/year	Art. 10-2 Annex VI	Mandatory every 5 years
31 December 2008	Major roads, railways, airports and agglomerations designated by Member States and concerned by second implementation step	Art. 7-2	Possible at any time
18 January 2009	Noise control programmes that have been carried out in the past and noise measures in place • Per agglomeration ≥250,000 inhab. • Per major civil airport ≥50,000 movts/year • For overall major roads ≥6 million veh/year • For overall major railways ≥60,000 trains/year	Art. 10-2 Annex VI 1.3 and 2.3	No update
18 January 2009	Action plans-related data as listed in annex VI for major roads, railways, airports and agglomerations concerned by first implementation step + any criteria used in drawing up action plans	Art. 10-2 Annex VI + Art. 8-3	Mandatory every 5 years

TABLE 4.5 Reporting Requirements of Member States Arising from the END—cont'd

Implementation Deadline	Summary Description of Data Sets to Be Reported	END Provision	Updates by Member States
	• Per agglomeration ≥250,000 inhab. • Per major airport ≥50,000 movts/year • For overall major roads ≥6 million veh/year • For overall major railways ≥60,000 trains/year		
30 December 2012	Strategic noise maps related data as listed in annex VI for major roads, railways, airports and agglomerations concerned by second implementation step • Per agglomeration ≥100,000 and <250,000 inhab. • For overall major roads ≥3 million and <6 million veh/year • For overall major railways ≥30,000 and <60,000 trains/year	Art. 10-2 Annex IV	Mandatory every 5 years
18 January 2014	Noise control programmes that have been carried out in the past and noise measures in place • Per agglomeration ≥100,000 and <250,000 inhab. • For overall major roads ≥3 million and <6 million veh/year • For overall major railways ≥30,000 and <60,000 trains/year	Art. 10-2 Annex IV 1.3 and 2.3	No update
18 January 2014	Action plans-related data as listed in annex VI for major roads, railways, airports and agglomerations concerned by second implementation step + any criteria used in drawing up action plans • Per agglomeration ≥100,000 and <250,000 inhab. • For overall major roads ≥3 million and <6 million veh/year • For overall major railways ≥30,000 and <60,000 trains/year	Art. 10-2 Annex VI + Art. 8-3	Mandatory every 5 years

correspond to those incorporated within strategic noise mapping results. Certainly, such innovative approaches would assist in raising awareness about environmental noise in the future although they are likely to be the exception rather than the rule.

4.5 STRATEGIC NOISE MAPPING IN THE EU: RESULTS FROM THE FIRST PHASE (2007)

Under the terms of the END, the first phase of noise mapping was to be concluded by Member States by June 2007. However, only a handful of countries submitted the required data by the deadline. Almost all nations have since completed the first round. Because the first phase was in some respects experimental, there was some leeway in relation to the submission of results. At the time of this book going to press, submitted data for the second round, due for submission in October 2012, were not yet available to the general public.

From the data submitted under the END's 2007 reporting round, estimates have been generated of the number of EU citizens within each Member State that are exposed to noise levels above 55 dB(A) L_{den} and 50 dB(A) L_{night}.[4] Overall, 164 agglomerations were involved across the EU with 82,575 km of major roads (>6 million vehicle passages a year), 12,315 km of major railways (>60,000 train passages a year) and 76 major civil airports (>50,000 movements a year) mapped under the process (de Vos and Licitra, 2013). Although there are clearly problems with a lack of consistency in calculation, mapping method and approaches to estimating exposure, the data collected from the first round and made publicly available through the Noise Observation and Information Service for Europe database (NOISE),[5] provides an initial, albeit tentative, indication of existing levels of population exposure to environmental noise in the EU. Indeed, it is the largest noise exposure database ever assembled worldwide.

Table 4.6 summarises the main results arising from the estimation of population exposure for the first round of noise mapping within and outside agglomerations. The results suggest that approximately 56 million people across the EU are exposed to environmental noise above 55 dB (A) during daytime from road traffic within agglomerations, while 33 million are exposed to noise from major roads outside agglomerations.

[4]Strategic noise maps pursuant to annex VI were provided in the first round for: agglomerations ≥250,000 inhab., major civil airports ≥50,000 movts/year, major roads ≥6 million veh/year and major railways ≥60,000 trains/year.

[5]Noise Observation and Information Service for Europe database—N.O.I.S.E.: http://noise.eionet.europa.eu/.

TABLE 4.6 Population Exposure to Environmental Noise in the EU

Scope	Number of People Exposed to Noise Above $L_{den} > 55$ dB (Million)	Number of People Exposed to Noise Above $L_{night} > 50$ dB (Million)
WITHIN AGGLOMERATIONS		
All roads	56	40.2
All railways	7.8	6.2
All airports	3.4	1.9
Industrial sites	0.8	0.5
MAJOR INFRASTRUCTURE (OUTSIDE AGGLOMERATIONS)		
Major roads	33.4	22.7
Major railways	5.8	4.8
Major airports	1.3	0.4

Note: Based on data submitted from the first phase of strategic noise mapping (2007) by the Member States up to 30 June 2011.
Source: Noise Observation and Information Service for Europe (http://noise.eionet.europa.eu/)

Additionally, and more worrying from a public health perspective, is 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 sets 40 dB (A) night-time as the value above which health effects are noticeable (see Chapter 3), the results highlight the scale of potential health impacts across the EU. These figures are expected to be revised upwards as more noise mapping data are received and/or assessed and with further EU enlargement. Also, further increases in noise emissions and therefore exposure is also likely as road traffic volumes are expected to intensify in the future.

According to recent Eurostat data,[6] road-based passenger transport (measured as passenger kilometres travelled) accounts for 92.9% of overall ground travel in the EU-27, while railways (including trams, metro, etc.) accounts for only 7.1%. Despite this, the railway accounts for 14.9% of the number of people exposed to environmental noise from ground-based transportation sources during night-time and 13.2% during the

[6] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Passenger_transport_statistics.

day–evening–night period. So while road transport is overwhelmingly the main source of acoustical discomfort, the railway system plays an important role in this regard also.

The results from the process also show that there is significant variability in terms of exposure across the EU. Figure 4.5 shows that the proportion of the population within agglomerations exposed to road-based environmental noise above 50 dB(A) during night-time ranges from highs of 85% and 83% in Slovakia and Ireland, respectively, to lows of 9% and 21% in Estonia and the Netherlands, respectively. The average for the EU-27 is 40%. Turning to night-time noise from railways, Figure 4.6 shows that the average proportional exposure to noise above 50 dB(A) from rail sources is 6%. Once again there is significant variation across nations and the results are quite obviously biased in favour of those nations with little railway infrastructure. The results for exposure from rail-based sources range from highs of 35% and 16% in Slovakia and Austria, respectively, to lows of 1% in counties such as Bulgaria, Denmark, Ireland and Lithuania. The results for aircraft are displayed in Figure 4.7. They show that countries with the greatest proportional levels of exposure above 50 dB(A) are Portugal (14%), Belgium (4%) and Bulgaria (3%) with the EU-27 average lying at 1%. Overall, the results demonstrate a considerable pollution problem across Member States. However, they also highlight the significant degree of variability of exposure across nations, which is likely

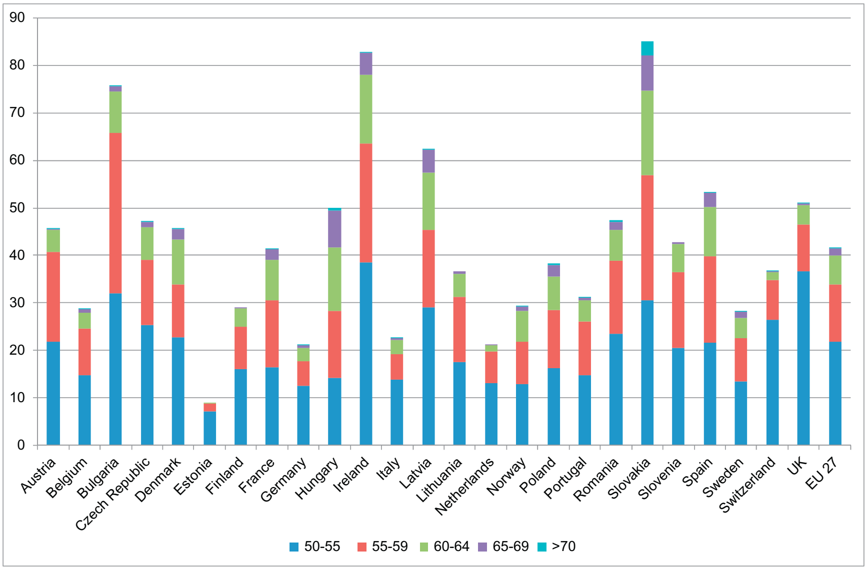


FIGURE 4.5 Proportion of inhabitants within agglomerations exposed to various categories of road-based environmental noise using the L_{night} indicator.

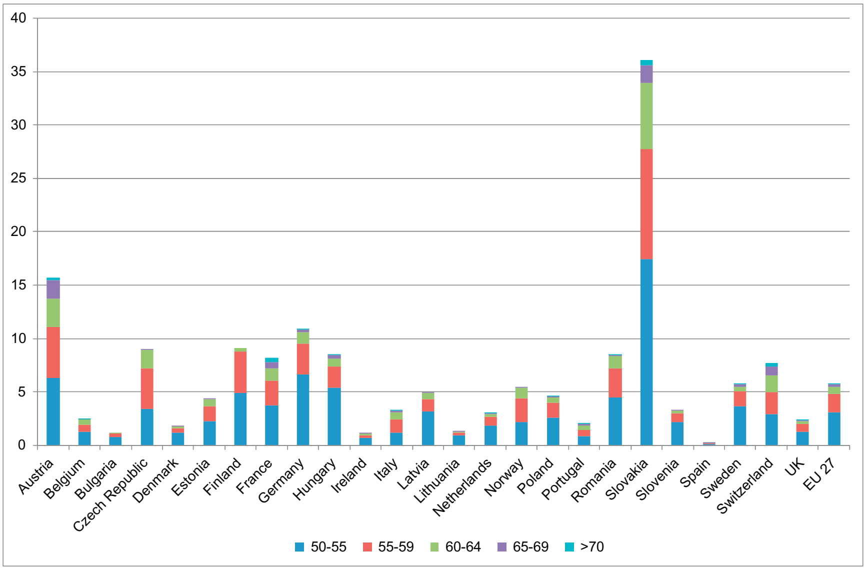


FIGURE 4.6 Proportion of inhabitants within agglomerations exposed to various categories of rail-based environmental noise using the L_{night} indicator.

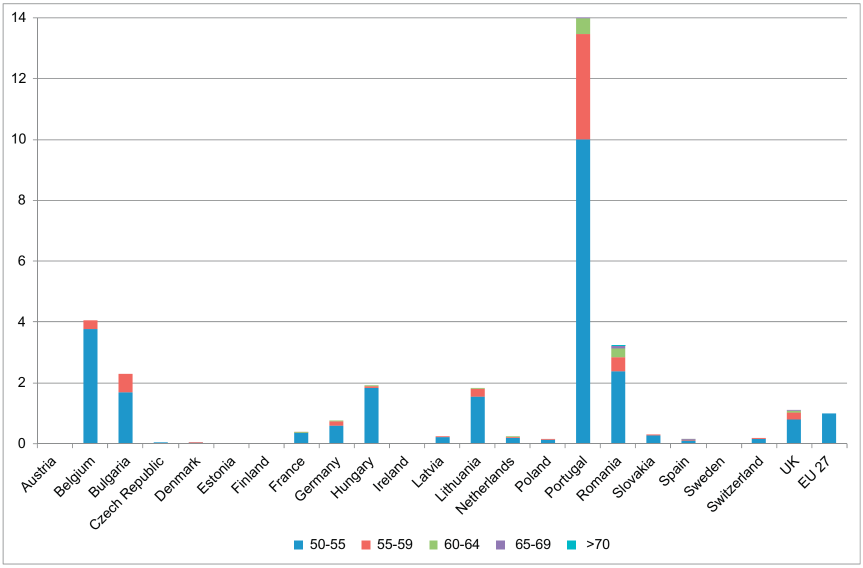


FIGURE 4.7 Proportion of inhabitants within agglomerations exposed to various categories of aircraft-based environmental noise using the L_{night} indicator.

to be linked to the imposition and adoption of different policies in relation to noise management and control.

While being highly innovative in policy and legislative terms, the strategic noise mapping process has not been without its challenges. Guarinoni et al. (2012) have highlighted some of the specific obstacles towards full implementation of the END. These include delays to implementation by Member States, non-enforcement of national noise limit values after the noise mapping process has been completed, the generally poor and highly variable quality of strategic noise maps, inconsistencies in calculation approaches, poor quality action plans, divergent approaches to identifying quiet areas and general administrative confusion among responsible bodies.

4.6 STRATEGIC NOISE MAPPING BEYOND THE EU

The signing into European law of the END has had a significant policy impact around the world. More than 10 years on from its signing into EU law, it has also been important for stimulating noise pollution exposure research which had been fairly scarce up until the beginning of the new millennium. Particular areas of research focus have included noise calculation and mapping approaches, methods of assessing population exposure as well as different approaches for noise mitigation through noise action planning. More broadly, however, the END has had a significant impact in terms of policy transfer throughout the world with not only scholars but also administrative authorities in countries beyond the EU applying strategic noise mapping approaches to their territories.

While not mandated in the United States (US), some academic studies have applied the EU strategic noise mapping process to locations in US states. A number of European-based commercial noise mapping software vendors offer the option to implement the Federal Highway Administration's (FHWA) TNM even though it has not been officially 'approved' by the FWHA; others have simply applied the EU calculation approaches to locations in the United States which has allowed a number of strategic noise mapping studies to be undertaken. To take some examples, researchers recently created strategic noise maps for roadways in Chittenden County, Vermont (Kaliski et al., 2007). Their research found that 30% of residents were exposed to road traffic noise levels above 45 dB(A) L_{eq} despite Chittenden being considered a rural county in US terms. More recently, Seong et al. (2011) undertook road noise mapping for Fulton County, Georgia, including noise mapping of downtown Atlanta. Their estimates of population exposure after constructing noise maps found that 48% of the resident population was exposed to noise levels of 55 dB(A) or higher during daytime with 32% exposed to 50 dB(A) or higher during night-time. Noise mapping approaches have also been applied in a

Canadian context albeit in a limited manner. Novak et al. (2009) created a noise map of the Huron Church Road (with approximately 32,000 vehicle crossings per day), the main transportation route leading to the Ambassador Bridge which the Windsor–Detroit border crossing relies heavily upon.

Beyond North America, a considerable volume of strategic noise mapping has been undertaken in Asia. In fact, beyond Europe, the vast majority of noise mapping research has been conducted in Asian countries. To take one example, Box 4.3 shows the recent development of innovative state-of-the-art 3D noise maps for Hong Kong. However, other noise mapping research has also been conducted there. Lam and Ma (2012) have conducted one of only a few longitudinal studies of the acoustic environment over time. They determined the noise environment of residential complexes built at different time periods using noise mapping at three spatial scales: the dwelling, the neighbourhood and the community. They provided evidence that overall noise levels in newly built developments are lower than those in older developments, suggesting slight improvements in the noise environment associated with newly constructed residential environments. There has also been noise mapping research undertaken comparing the high- and low-density cities of Wuhan, China and Manchester, UK, respectively, and the noise levels therein (Wang and Kang, 2011). Their results show the considerable effect that urban morphology has on the distribution of traffic noise in those cities. Additionally in a Chinese context, Sheng and Tang (2011) have undertaken noise mapping research in the Macao Peninsula. The authors found that 60% of traffic noise levels along the major pedestrian sidewalks in the evening peak hour exceed the National Standard of 70 dB(A) in China.

Furthermore, Ko et al. (2011a) created strategic noise maps of Youngdeungpo-gu, an administrative district of Seoul, South Korea. They found that 35% of the resident population was exposed to noise levels greater than 55 dB(A) during daytime, while approximately 80% was exposed to levels above 40 dB(A) during night-time as a result of combined exposure to road and rail noise. In a separate study, Ko et al. (2011b) also developed strategic noise maps for the city of Chungju, Korea. They developed an excess noise map by comparing road traffic noise maps with a standard noise map. As a result of the assessment, the exposed population was more accurately estimated, showing that 20% of the population is exposed to daytime noise above 55 dB(A), while 68% is exposed to noise levels above 40 dB(A) during night-time. Lee et al. (2008) also undertook noise mapping research in Seoul by utilising noise mapping for environmental impact assessment of a development site in the downtown area, while Cho et al. (2007) created a noise map of Pusan National University, Busan (South Korea's second largest city) using noise measurement and GPS data.

Also within an Asian context, Mehdia et al. (2011) produced noise maps of the entire city of Karachi, Pakistan. While they did not explicitly estimate population exposure for the city, by comparing population density maps with strategic noise maps, they concluded that a large number of people were at risk of excessive environmental noise exposure. Tsai et al. (2009) undertook strategic noise mapping and estimation of the exposed population in Tainan City, Taiwan. They found that more than 90% of the population is exposed to unacceptable noise levels and that the exposed population is greater in summer (ca. 97%) than in winter (ca. 90%).

In South America, the noise mapping process has been used in Brazil, Chile and Argentina. In a Brazilian context, Zannin and de Sant'Ana (2011) used measurement-based noise mapping to assess the evolving acoustic characteristics of a road-restructuring project at various stages of implementation in the outskirts of the city of Curitiba. In a more recent study, Zannin et al. (2013) once again undertook measurement-based noise mapping but this time for the educational campus of the Polytechnic Center of the Federal University of Parana (UFPR) also in the city of Curitiba. Their results found that 90% of the 58 measurement points recorded noise levels above 55 dB(A). Pinto and Mardones (2009) completed a noise mapping study of the Copacabana neighbourhood in Rio de Janeiro and found that noise levels exceed recommended limit values in the city. Dintrans and Préndez (2013) have recently utilised noise mapping techniques to model the impact of various noise control measures in Santiago, Chile, while Suárez and Barros (2014) recently produced a noise map for the same city using a simplified low-cost modelling technique. Their research was in line with previous similar research (Murphy and King, 2011) which suggests that it is possible to reduce environmental noise exposure through appropriate traffic management and mitigation measures in cities. Similar scenario analysis was also conducted in the city of Aracaju, Brazil (Guedes et al., 2011). Using a strategic noise mapping approach, the authors found that the physical characteristics of cities including building density, geometry and location and the existence of open spaces exert a significant influence on environmental noise. In Argentina, Ausejo et al. (2010) have also studied the uncertainty associated with strategic noise mapping in the Macrocenter of the Independent City of Buenos Aires.

Noise maps have also been utilised in the Middle East. Kurra and Dal (2012) used noise maps to determine the required façade insulation in Beşiktaş, a municipality of Istanbul, Turkey. The approach allows for the transformation of façade noise levels into insulation contours and proposes a categorisation scheme to facilitate the task of both acousticians and architects when designing building façades. Moreover, a recent Iranian study used the noise mapping concept to analyse environmental noise pollution from traffic noise in the city of Yazd (Nejadkoorki et al., 2010).

Overall then, it can be seen quite clearly that the scope of the impact of the EU's strategic noise mapping approach is significant. It has been successful at stimulating similar noise mapping studies and estimates of exposed populations in jurisdictions beyond the EU and on almost every continent. Indeed, the foregoing discussion highlights the innovative ways in which the strategic noise mapping process has been applied many of which were never the original intention of the END but have been made possible because of the development of commercial noise mapping software as a result of the adoption of the noise mapping process into legislation.

BOX 4.3

3D NOISE MAPPING IN HONG KONG

The Government of Hong Kong recently developed state-of-the-art 3D noise maps for the municipality of Hong Kong (see Law et al., 2011). Given the unique nature of the topography of the city and its density, traditional 2D noise mapping approaches were deemed to be unsuitable for accurately describing the noise environment. In Hong Kong, there are ca. 110,000 buildings within an area of around 1100 km^2. The approach utilised a combination of modelling, GIS and computer graphics technology to develop 3D noise maps. Users can visualise the results by flying through the city which makes it much easier for the general public to understand and experience the noise environment of the city, thereby enhancing public dissemination and engagement with the problem and potential solutions to environmental noise (Figure 4.8).

FIGURE 4.8 3D noise mapping in Hong Kong. *Source: Law et al. (2011).*

4.7 CONCLUSION

The emergence of strategic noise mapping as an approach to reduce the harmful effects associated with environmental noise has proven to be a highly innovative piece of environmental policy within the EU. The EU is one of the few jurisdictions around the world who are taking the problem of environmental noise seriously both as an environmental policy issue and as a public health problem. The introduction of the END has allowed for a quantification of the burden of disease resulting from excessive environmental noise exposure, and while such data are to be viewed somewhat tentatively, it has served to demonstrate the scale of environmental noise pollution as a major public health policy concern into the future. Indeed, the END has also served to stimulate awareness of environmental noise across the world with numerous researchers applying the principles of the strategic noise mapping process to other jurisdictions. Even more importantly is that EU noise policy and associated noise mitigation approaches are gaining interest from other nations who see environmental pollution as a serious concern for their citizens that needs to be addressed.

It should also be clear from the chapter that the strategic noise mapping process is not without its problems. There are some considerable methodological hurdles that need to be overcome in the process so that estimates of exposure are more robust and also that results of the process can be realistically compared across Member States. The key issues of developing a standardised noise calculation method across the EU as well as developing a common approach for estimating population exposure are currently being dealt with under CNOSSOS-EU which should help eliminate methodological problems for future strategic noise mapping rounds.

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