Environmental Research Plan of the

German Federal Ministry for the Environment,

Nature Conservation and Nuclear Safety

(Funding Code: 3708 51 103)

Strategies for the Effective Reduction of Aircraft Noise Exposure at Airports

Preparation of an integrated, effective and practice-orientated aircraft-noise reduction concept

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ON BEHALF OF THE
GERMAN FEDERAL ENVIRONMENT AGENCY
09/2012

Report Cover Sheet

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UBA-FB</td><td>2.</td><td colspan="2">3.</td></tr>
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<tr><td colspan="3" rowspan="4">5. Authors, Family Names, First Names
Friedrich, Rainer
Müller, Wolf
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Rokitansky, Carl-Herbert
Kubera, Barbara
Bergmann, Heidi</td><td>8. Report Date
28. September 2012</td></tr>
<tr><td>9. Publication Date</td></tr>
<tr><td>10. UFOPLAN-Ref. No.
3708 51 103</td></tr>
<tr><td>11. No. of Pages
111</td></tr>
<tr><td colspan="3" rowspan="2">6. Performing Organisation (Name, Address)
Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart, Heßbrühlstraße 45A, 70565 Stuttgart</td><td>12. No. of References
101</td></tr>
<tr><td>13. No. of Tables, Diagrams
54</td></tr>
<tr><td colspan="3">7. Sponsoring Agency (Name, Address)
Umweltbundesamt, Postfach 1406. 06813 Dessau-Roßlau</td><td>14. No. of Figures
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Exposure of the population to aircraft noise is still a severe problem. In this study, instruments and measures are investigated with which aircraft noise exposure might be reduced to a tolerable level. These investigations are carried out exemplarily for three types of airport: an airport with a large volume of freight and night-flight operations, a medium-sized airport and a regional airport. Initially, short- and long-term objectives for noise exposure are deduced. Measures for noise reduction are then identified and their impact (noise reduction and consequential decline in health risks and annoyance) and legal feasibility assessed. The measures are subsequently consolidated in strategies (that is, packages of measures). The efficiency strategy comprises measures that are easily implemented legally; namely, an increase in takeoff and landing charges, introduction of noise-optimized approach procedures and reduction of noise limits for establishment of protection zones in accordance with the German Aircraft Noise Protection Act (Fluglärmgesetz). In the effectivity strategy further measures are implemented, in particular a night-flight ban. Long-term noise abatement objectives cannot be achieved with the short- and also long-term measures under investigation. A possible solution could be a drastic reduction in permissible noise limits for new aircraft.</td></tr>
<tr><td colspan="4">17. Keywords
Aircraft noise, noise reduction measures, health-related impact of noise, noise annoyance, monetary assessment, noise reduction strategies, noise monitoring, control concepts</td></tr>
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Acronyms and Abbreviations

AzB	Instructions on the calculation of noise protection
AzD	Instructions on Acquisition of Data on Flight operations
BAF	*Bundesaufsichtsamt für Flugsicherung* – Federal Supervisory Office for (Civil) Air Traffic Control
BAnz	Federal Gazette
BGBl.	Federal Law Gazette
BGH	*Bundesgerichtshof* – Federal Court of Justice
BImSchG	Federal Immission Control Act
BImSchV	Ordinance Implementing the Federal Immission Control Act
BVerfG	*Bundesverfassungsgericht* – Federal Constitutional Court
BVerfGE	Decisions of the Federal Constitutional Court
BVerwG	*Bundesverwaltungsgericht* – Federal Administrative Court
BVerwGE	Decisions of the Federal Administrative Court
CDA	continuous descent approach
CI	Confidence Intervall
COM	European Commission
DALY	disability-adjusted life years
DFS	*Deutsche Flugsicherung GmbH* - German Air Traffic Control
EC	European Community
EPNL	effective perceived noise level
EU	European Union
EEC	European Economic Community
FAA	Federal Aviation Administration
FluLärmG	Aircraft Noise Protection Act
HA	highly-annoyed (by noise)
HSD	highly sleep-disturbed (by noise)
ICAO	International Civil Aviation Organization
ICCA	International Convention on Civil Aviation
IFR	Instrument Flight Rules
INM	Integrated Noise Model
LA	little-annoyed (by noise)
$L_{Aeq\ night}$	A-weighted (energy-) equivalent continuous sound level at night
$L_{Aeq\ day}$	A-weighted (energy-) equivalent continuous sound level during the day

L_{den}	day-evening-night sound level
LDLP	low drag low power
L_{Adn}	day-night sound level (A-weighted)
L_{Aeq}	A-weighted (energy-) equivalent continuous sound level
LOAEL	lowest observed adverse effect level
LuftVG	Air Traffic Act
LuftVO	Air Traffic Regulation
LuftVZO	Air Traffic Licensing Regulations
NAT	number above threshold
NOEL	no observed effect level
NVwZ	*Neue Zeitschrift für Verwaltungsrecht*
OLDLP	optimized low drag low power
PNL	perceived noise level
POD	Point of descent
SCDA	segmented continuous descent approach
SD	sleep-disturbed (by noise)
TEC	Treaty establishing the European Community
TFEU	Treaty on the Functioning of the European Union
VFR	Visual Flight Rules
VGH	*Verwaltungsgerichtshof* – Higher Administrative Court
WHO	World Health Organisation
ZFI	*Züricher Fluglärmindex* Zürich Aircraft Noise Index
ZLW	Zeitschrift für Luft- und Weltraumrecht

1 Introduction

1.1 Terms of reference

Exposure to aircraft noise continues to be a severe problem. Surveys undertaken by the Federal Environment Agency (*Umweltbundesamt, UBA*) confirm that people living in the vicinity of airports are considerably annoyed by aircraft noise and the resulting adverse effects on their quality of life (UBA, 2011a). Evidence of this is provided by numerous public protests against aircraft noise. Research into the impact of noise has proven that aircraft noise at levels occurring in many regions in the vicinity of German airports gives rise to health hazards.

Based on the findings of noise-impact research, noise abatement targets have been recommended by *inter alia* the Federal Environment Agency and the World Health Organization (WHO). The target values they recommend are, however, already greatly exceeded at large airports in Germany.

The question therefore arises of which strategies will enable compliance with noise abatement targets and in which time frame. Strategies in this study are understood to be packages of noise reduction measures.

The objective of this project is therefore recommendation of strategies for the reduction of present and future aircraft noise exposure in Germany. The focus is on medium-sized and regional airports. For the three largest German airports – Frankfurt/Main, Munich and, in future, Berlin-Brandenburg – numerous investigations into noise emission have already been carried out in connection with realized (Frankfurt) and rejected (Munich) airport expansion as well as with current construction (Berlin-Brandenburg), so that these airports are not further considered in this study.

1.2 Structure and approach

In Chapter 2, bases for the assessment of aircraft noise are explained, which comprise the description of applied indicators for characterization of sound, and a summary of findings on the impact of sound emanating from aircraft. On this basis, short- and long-term noise abatement targets are defined.

It is then investigated, in Chapter 3, to what extent noise exposure of the population at the end of this decade will exceed target levels. For this purpose, three airports of different types are defined: a large airport with a large volume of freight traffic and unrestricted night-flight operations, a medium-sized airport with wide-ranging night-flight restrictions as well as a regional airport with expansion potential. In order to facilitate realistic appraisal, data from existing airports forms the basis for description of flight movements at the three reference airports and population distribution in the vicinity of the airports. Basic flight operation data is provided by forecasts of flight operations (so-called 'DAS' – data acquisition system – data) prepared for the years 2017 and 2020 in accordance with the First Ordinance implementing the Aircraft Noise Protection Act.

In order to determine the noise levels that arise as a result of flight operations for the base scenario (predicted case excluding additional noise reduction measures) and with application of measures and strategies at the selected reference airports, a noise calculation model is utilized. This calculates noise exposure on the ground that arises from the total of individual flight movements as noise contours (noise level isolines). A model system is used comprising the Integrated Noise Model (INM 7.0 (2007)) and the air traffic simulator NavSim. NavSim processes available data on forecast flight movements is such a way that it can be used as input for INM. For this purpose, NavSim has had to be considerable expanded and adapted. Health risks and the number of annoyed persons and persons affected by disturbed sleep are then computed on the basis of the noise contours. These effects are subsequently converted into a common unit of measurement – initially to 'disability-adjusted life years' (DALYs) – and, additionally, into a monetary value (in euros).

In Chapter 4, measures for reduction of aircraft noise are identified, analysed and assessed. Most of the analysed measures can be implemented within just a few years and are therefore quickly effective. Assessment of these measures relates to their degree of intervention, administrative cost, legal realization and effectivity. Effectivity – that is, noise reduction achievable through introduction of the particular measure – is calculated using the noise propagation model described above. Since a number of years will pass before the measure is fully effective and, moreover, an increase in the number of flight movements is also expected in the coming decade, effectivity of the measure is calculated for a scenario of flight movements for the years 2017 and 2020.

There are two further measures – namely, reduction of noise emissions of aircraft and the displacement of air traffic to newly-constructed airports in sparsely populated areas – whose effect will be apparent only after several decades. A rough estimation of the effects of these measures is provided in Chapter 5. A more detailed analysis is neither sensible nor possible, since fleet composition and the number of flight movements are not predictable over a period of several decades. Based on the assessment of individual measures, strategies – packages of noise reduction measures – are consolidated in Chapter 5. These comprise an efficiency strategy and an effectivity strategy that would produce further noise reductions, but would be also difficult to realize from a legal point of view, as well as a concept for achievement of long-term targets.

In Chapter 6, the monitoring and control concept for the strategies is explained, with which it should be examined whether noise abatement targets are achieved. The procedures are also discussed with which the achievement of targets can be ensured.

2 Effects of noise and deduction of target values for noise abatement

Noise abatement is essential, since noise gives rise to considerable health risks, sleep disturbance and annoyance effects. Research findings on the effects of noise are initially compiled, in order to be able to deduce noise abatement targets.

2.1 Overview

Aircraft noise can lead at four different levels to adverse effects on persons exposed to it:

a. Psychological level (annoyance): From a particular intensity (noise level and frequency) aircraft noise leads to considerable annoyance on account of

- disturbance of indoor and outdoor communication,
- adverse effects on recreational and leisure activities,
- disturbance of learning and work processes,
- sleep disturbance (falling asleep, uninterrupted sleep) and
- possible anxiety states (above all, with rapidly-increasing, loud noise events; for instance, flyovers at a low height).

b. Physiological damage (illness and death): Noise can induce measurable vegetative and endocrine (hormonal) changes, which in the long term can result in metabolic disorders, organ dysfunction and death. For instance, the above-mentioned primary sleep and sensitivity disturbances can induce secondary disorders and long-term damage to health such as cardiovascular diseases and high blood pressure. The transition from considerable annoyance to health impairment is therefore fluent and individualized.

c. Sociological level: Besides psychological and physiological damage, noise can also have sociological effects. Few scientific studies have, however, been devoted to the social or socio-psychological effects of noise. It has been established that social disparities exist between quiet areas and areas exposed to aircraft noise [Wirth (2004)]. There are indications of a certain degree of social segregation alongside noise-polluted transport infrastructure, in particular with regard to economic status. Some studies show that aircraft noise is the cause of migration from affected areas, and can thus bring about a change in settlement structure [Wirth (2004), Oliva (2005), Mediationsgruppe Flughafen Frankfurt/Main (2000)]. Since quantitative exposure-response relationships for sociological effects are not available, they are not quantified or considered in this study.

d. Economic level: Aircraft noise can lead to adverse economic effects, and, in particular, to a decline in property values as a result of noise exposure. As a rule, this is a consequence of the annoyance effect. It is assumed that this loss of value is already considered in the monetary assessment of the annoyance effect, which indicates the readiness to pay for avoidance of annoyance. This assumption is also supported by the fact that a number of studies deduce the monetary value of annoyance from changes in house prices in noisy areas (cf. Batemann et al. (2000)). Declining property values are therefore not considered in the assessment of damage from aircraft noise.

Annoyance and physiological damage can be converted into a common unit, so-called 'disability-adjusted life years' (DALYs). Further remarks on this unit of assessment are to be found in Section 3.3.

Such damage can also be assessed monetarily (in euros) and consolidated as the cost of noise damage (see Section 3.3). This comprises *inter alia* the cost of treatment in the case of damage to health as well as the loss of productivity as a result of lost working days and loss of quality of life arising from impaired health or annoyance. This loss of quality of life represents – irrespective of costs – aversion to the risk of becoming ill or annoyed; in other words, unease about suffering distress and pain. In order to determine this loss of quality of life, the readiness to pay for avoidance of a health risk or an annoyance is determined by means of surveys. In the case of health risks, the costs of treatment and loss of productivity are added to the amount that people are willing to pay. The cost of noise damage can be subsequently applied in cost-benefit and cost-effectivity analyses in order to facilitate comparison of reduction measures and strategies.

2.2 Sound level indicators

The methods used for quantification of sound intensity are briefly described below [cf. Isermann & Schmid (2000), Hofmann (2000), Wirth (2004)].

Energy-equivalent continuous sound level L_{eq}

The *energy-equivalent continuous sound level* is a measure of average noise exposure over a particular period of time, for which the symbol L_{eq} is used. The energy-equivalent continuous sound level is calculated under consideration of frequency, level and duration of single sound events. Energy-equivalent means more or less 'containing the same energy' or 'corresponding to the same energy'. L_{eq} therefore corresponds to constant sound level with the same sound energy, such as the average sound energy of a fluctuating sound event. This definition is a convention that is mainly based on the assumption that the impact of noise is primarily dependent on sound energy quantity.

L_{eq} (unit: dB) is defined physically as:

$$L_{eq} = 10 * \log[\frac{1}{T}(\sum t_i * 10^{\frac{L_i}{10}})]$$

with T = measuring duration; L_i = level during period t_i; t_i = period of level L_i

The main advantage of energy-equivalent continuous sound level is that a sound event that varies with time can be characterized with a single assessment variable. Tones of varied frequencies are perceived – with the same sound pressure – at different degrees of loudness. In the case of traffic noise, and in this study, weighting of frequencies of a broadband sound signal is therefore generally carried out on the basis of a certain filter (mostly of type 'A'). Based on an auditory level with 1000 Hz as reference, the level of other frequencies are changed according to their auditory level, and very high and low frequencies, in particular, are lowered. The resulting, so-called 'A-weighted' continuous sound level is stated in dB(A). There are a number of different forms of A-weighted **energy-equivalent continuous sound level**, which variedly assess the effects of noise at different times of the day:

$L_{Aeq,day}$ (daytime noise level): $L_{Aeq,day}$ is applied for daytime noise between 6 a.m. and 10 p.m. (16 hours).

$L_{Aeq,night}$ (night-time noise level): The night-time noise level $L_{Aeq,night}$ is determined for the period between 10 p.m. and 6 a.m. (for example, in the Aircraft Noise Protection Act).

L_{den} (day-evening-night noise level): With L_{den}, the attempt is made to represent noise exposure over a 24-hour period in a single continuous sound level, under consideration of varied noise intensity at different times of the day. With L_{den}, the noise level share averaged over the evening (as a rule, 4 hours from 6 p.m. to 10 p.m.), is weighted with + 5 dB. The noise level share averaged over the 8 night-time hours (as a rule, from 10 p.m. to 6 a.m.) is weighted with 10 dB. L_{den} is applied, for example, in the EU Environmental Noise Directive.

L_{dn} (day-night noise level): The day-night noise level L_{dn} is very similar to L_{den}. L_{dn} is composed of daytime noise level and night-time noise level. As with L_{den}, night-time noise is weighted with an 'adjustment' of +10dB.

2.3 Adverse effects on health of aircraft noise

Noise can have an adverse effect on health of the following kinds:

1. Damage to hearing in the case of very loud noise events.
2. Cardiovascular diseases: Exposure to traffic noise increases the risk of high blood pressure, heart attack and cardiovascular diseases.
3. Damage to health through sleep disturbance: Aircraft noise at night can lead to wake-up reactions and a diminished proportion of deep sleep. As a secondary effect, this can result in increased tiredness, reduced memory performance and secretion of stress hormones. Sleep disturbance can also be an indirect cause of long-term damage to health such as cardiovascular diseases.

Dose-response curves derived from epidemiologic studies display a statistically significant relationship between noise exposure and the risk of cardiovascular diseases. While at the beginning of the 21st century the relationship between traffic noise and cardiovascular diseases was not regarded as verified or statistically significant (cf. UBA (2000)), this relationship is viewed in recent studies as scientifically substantiated, particularly in the case of night-time noise [*inter alia* Greiser & Greiser (2010), Babisch & van Kamp (2009), Jarup et al. (2008), Haralabidis et al. (2008), Babisch (2006)].

Even if the causality is no longer disputed, research findings differ, however, regarding the strength of the relationship. There are differences concerning, in particular, the threshold value, above which adverse health effects are verifiable.

According to previous research findings, for cardiovascular illnesses the threshold value with daytime noise was around $L_{Aeq,day}$ 60-65 dB(A) outdoors. New studies indicate, however, an effects threshold of 60 dB(A) or even lower (55 dB) [for example: Babisch & van Kamp (2009) and Babisch (2006)]. In the case of night-time noise, cardiovascular illnesses – for example, high blood pressure – occur already with lower noise exposure. The threshold value lies in the range $L_{Aeq,night}$ = 45-55 dB(A) outdoors, and according to the most recent studies even somewhat lower, namely at 40 dB(A) [Jarup et al. (2008), Greiser & Greiser (2010), WHO (2009)].

Scientific studies of the German Aerospace Center (DLR) show a significant relationship between noise exposure and sleep disturbance [Quehl (2005), Basner, Samel and Isermann (2006); see also WHO "Night Noise Guidelines" [WHO (2009)]. From a certain noise threshold, significantly more cases of sleep disturbance occur that are manifested by wake-up reactions and reduced regeneration capacity, the latter being triggered by shortened deep and REM sleep stages, longer time required to fall asleep as well as a stress-related increase in blood pressure and hormone release.

According to WHO Night Noise Guidelines [WHO (2009)], initial effects of night noise such as increased body movements and wake-up reactions can be observed from a threshold of 30 dB(A) $L_{Aeq\ night}$. The consequences, however, are still moderate. 30 dB(A) night noise is therefore designated as 'no observed effect level' (NOEL). According to the WHO Guidelines, above 40 dB(A) $L_{Aeq\ night\ outdoors}$ adverse health effects are to be expected in those affected. This applies particularly for risk groups (children, the ill and elderly persons). The WHO therefore designates a night-noise level of 40 dB (A) as 'lowest observed adverse effect level' (LOAEL).

According to the current state of knowledge, in order to avoid damage to health a continuous sound level in excess of 55 dB(A) during the day and 40 dB(A) at night should be avoided.

The relationship between aircraft noise and damage to health is more pronounced with night noise than with daytime noise. Furthermore, with night noise the average continuous sound level is less relevant; decisive is the number and intensity of single noise events, which increase the likelihood of wake-up reactions due to aircraft noise [WHO (2009), Miedema & Vos (2003), Baser et al. (2004), Boguhn (2007), Schreckenberg et al. (2008)]. Particularly critical for persons exposed to noise are, besides the night-time hours, the shoulder hours (10 p.m. to midnight and 5 a.m. to 6 a.m.), since at this time a considerable proportion of the population seeks recuperation or is sleeping.

2.4 Annoyance effect

In contrast to sound level, subjective noise annoyance cannot be physically measured; it has rather to be determined by surveys of the population. Different degrees of annoyance are applied. In practice, four to eleven categories of annoyance are applied, which are underlaid with verbal marks on a scale from 'not at all annoyed' to intolerably annoyed'. In the interest of standardization of measurement, one has committed oneself to a five-stage verbal and an eleven-stage numerical rating [ISO 15666, Fields et al. (2001)].

In order that investigations involving different categories of annoyance can be compared, these are assigned to an annoyance scale ranging from 0 to 100. Within this scale, the thresholds of 72 points for "highly annoyed" (HA) and 50 points for "annoyed" (A) have become generally accepted. Below these thresholds there is also the category of "little annoyed" (LA). For comparable representation of different studies, the percentage of persons exposed to a particular continuous sound level who feel highly annoyed (% HA), annoyed (% A), little annoyed (% LA) or not annoyed is generally stated. Here, the four-stage scale is used, since for these categories exposure-response relationships between sound level L_{den} and number of exposed persons per annoyance category exist.

The degree of noise annoyance is at least partially dependent on the degree of physical noise exposure, that is, on noise level. The relationship between noise exposure and noise annoyance is generally represented in dose-response curves.

Increased annoyance (noise-related impairment of performance and psychic effects) on the part of those exposed to aircraft noise is to be expected from a continuous sound level of approximately $L_{Aeq\ day\ outdoor}$ 40 to 50 dB(A) [Miedema & Vos (1998), Miedema & Oudshoorn (2001), European Commission (2002), Wirth (2004), Schreckenberg et al. (2008), Stansfeld et al. (2005)]. The feeling of severe or very severe noise annoyance (for instance, startle and anxiety responses) corresponds among other factors with the number of very loud and low flyovers (noise > 100 dB(A)) and, above all, with the number of low-level military flights with rates of increase in noise levels in excess of 60 dB(A) per second [UBA (2000)].

The relationship between noise exposure and individually-perceived noise annoyance differs according to time of day and means of transport. In the case of air transport, average noise level gives rise to greater annoyance than the same average noise level with road transport [European Commission (2002)].

The annoyance effect depending on noise level differs markedly between daytime and night noise. Surveys confirm that the annoyance effect begins at night at a lower noise level than during the day [Wirth (2004)9. During the day, the highest perceived annoyance with constant noise exposure is observed in the early morning, at mid-day and in the evening, whereas those questioned were less sensitive to aircraft noise in the late morning and in the afternoon [Wirth (2004)]. The reason for this is that noise effects are always dependent on the type of disturbed activity. Noise-sensitive activities are more frequently undertaken in the evening (relaxation) and at night (sleep). In individual cases – shift work and concentrated mental activity, for instance – perceived annoyance can, however, be quite different.

The perception and assessment of noise annoyance has changed during the last two or three decades. The sensitivity of the population to aircraft noise, in particular, has noticeably increased [Janssen & Vos (2009), Babisch (2010)]. This is confirmed by the result of research, namely that with aircraft noise the continuous sound level at which 25% of the population feels highly annoyed has decreased since the 1970s by around 10 dB (from around 65 dB to around 55 dB [Guski (2006)]). Not only average noise level is relevant for annoyance, but also other aspects, such as the number of flight movements (above all during the shoulder hours) and plans for airport expansion, and the related negative expectation that noise pollution will increase and that one is exposed to this development without having the possibility to exert influence or to take protective measures.

2.5 Noise abatement objectives

2.5.1 Recommendation on target values in literature

Target values for noise exposure can be deduced on the basis of scientific studies. Various research surveys, expert reports and noise guidelines provide recommendations for such target values. A number of important recommendations are shown below. They form the basis for the targets formulated for this study in the following section. The Federal Environment Agency has published noise levels, above which health risks and annoyance arise, *inter alia* UBA (2000), UBA (2006), UBA (2009), UBA (2011b), UBA (2011c), Myck (2011) and Babisch (2011). Babisch (2011) names – based on UBA (2006) – the following environmental targets:

- Short term: avoidance of health hazards

  $L_{Aeq\ day}$ = **65 dB(A)**, $L_{Aeq\ night}$ = **55 dB(A)**

- Medium term: curtailment of significant annoyance

  $L_{Aeq\ day}$ = **60 dB(A)**, $L_{Aeq\ night}$ = **50 dB(A)**

- Long term: avoidance of significant annoyance:

  $L_{Aeq\ day}$ = **55 dB(A)**, $L_{Aeq\ night}$ = **45/ 40[1] dB(A)**

These values are recommended, in particular, as trigger criteria for noise action planning, which is required by the EU Environmental Noise Directive [EU 2002/49/EC (2002)].

WHO "Night Noise Guidelines", NNGL [WHO (2009)]: The WHO recommends in its guidelines as long-term target a maximum continuous sound level for **night noise of 40 dB(A)** ($L_{Aeq\ night\ outdoor}$) [WHO (2009)]. As interim target a night-time noise exposure **55 dB(A)** ($L_{Aeq\ night\ outdoor}$) should be aimed at.

The German Advisory Council on the Environment (SRU) makes the following recommendation in its Environmental Report 2008 [SRU (2008)]: "It is essential for effective protection of human health that daytime outdoor noise levels be reduced in residential areas in the **short term to 65 dB(A),** in the medium term to 62 dB(A) and in the **long term to 55 dB(A).** At night, efforts should be made to reduce noise levels to **45 dB(A)**."

DLR "Night Noise Study": Regarding night-time aircraft noise, the authors of the DLR Night Noise Study [Basner et al. (2006), Basner et al. (2004), Basner, Isermann & Samel (2005), Basner, Samel & Isermann (2006); Schreckenberg et al. (2009)] recommend the following protection targets:

- On average, less than one additional wake-up reaction per night should be caused by aircraft noise [Basner, Isermann and Samel (2005)].[2] Wake-up reactions are not always identically defined in different studies. In DLR studies, for instance, one already speaks of a wake-up reaction when a change from deep-sleep phase to the lightest sleep stage S1 occurs. In the DLR night noise study a wake-up reaction is defined as follows: One speaks of a wake-up reaction when a change from sleep stage REM. S4, S3 or S2 to a waking state or to sleep stadium S1 occurs [Basner et al. (2004), Quehl (2005)]. Occurring to the DLR, transition to stage S1 is also regarded as a wake-up reaction, since sleep stage S1 does not contribute, or hardly contributes to the recovery function of sleep. Whether or not one can remember waking up on the following day has no influence on this definition. In an undisturbed night an average of 24 'natural' wake-up reactions are observed, which occur within the scope of the natural sleep cycle, during which deep- and light-sleep phases alternate [Basner, Isermann and Samel (2005)]. An isolated additional wake-up reaction as a result of noise exposure can, however, represent great annoyance when one is suddenly woken up out of a deep sleep. With an average of less than one additional wake-up reaction, however, it is assumed even with long-term exposure that health impairment is not to be expected from aircraft noise [Basner, Isermann and Samel (2005)]. For calculation of the Frankfurt Aircraft Noise Index merely 0.5 additional wake-up reactions per night applies for the demarcated noise protection zone [Schreckenberg et al. (2009)].

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[1] The second value was added by Babisch under reference to the WHO night noise guidance threshold [WHO (2009)].

[2] In an undisturbed night, an average of, 24 'natural' waking reactions are observed, which occur during the natural sleep cycle through alternating deep- and light-sleep phases [Basner, Isermann und Samel (2005)]. A single, additional waking reaction as a result of noise exposure can already be highly-annoying if one is suddenly woken out of a deep sleep.

With less than one additional waking reaction, however, an adverse effect on health from aircraft noise is not to be expected, even in the case of long-term exposure.

- Recallable awakening induced by aircraft noise should be avoided as far as possible. With maximum noise levels in excess 65 dB(A) ($L_{max\ indoor}$) in bedrooms the risk of wake-up reactions that are recalled the following day is considerably increased. A maximum level in excess of 65 dB(A) ($L_{max\ indoor}$) in bedrooms is therefore permitted at the most once a night.[3]

2.5.2 Target indicators and target values for aircraft noise

Based on the findings of noise impact research and the above-mentioned studies on possible environmental quality targets, the indicators and target values are now deduced that form the basis for compilation of aircraft noise reduction strategies. The proposed measures and packages of measures are judged and their contribution to target achievement assessed in the light of these target values.

The basic objective of the aircraft noise reduction strategies compiled in this study is the protection of human health and the reduction of annoyance resulting from aircraft noise.

The **primary noise abatement objective** is the **protection of public health**. Through determination of appropriate indicators and noise limits, damage to human health should be reduced to a tolerable level and, in the long term, avoided altogether. The most important sub-objective in connection with health protection is the **avoidance of the consequences of night noise**, since here the relationship between aircraft noise and damage to health is strongest (Greiser, 2010). The second health protection objective relates to the consequences of daytime noise, where the substantiated relationship between noise and high blood pressure is of particular importance.

As mentioned in Section 2.3, recent studies show that health risks can already occur with a continuous sound level above 55 dB(A) during the day and 40 dB(A) at night. These values are therefore recommended as long-term target values. In the short term, these values are not attainable with existing measures (see Chapter 4). As a minimum requirement for avoidance of major health hazards, short-term target values of 65 dB(A) during the day and 55 dB(A) at night are therefore proposed. This is in line with the recommendations of the Federal Environment Agency and the German Advisory Council on the Environment (SRU) mentioned in Section 2.5.1.

The **secondary noise abatement objective** is the **protection of the public against annoyance**. Annoyance is a further adverse effect of aircraft noise that is based, however, on subjective perception and, in contrast to noise exposure, is therefore not physically measurable. The number of persons annoyed by noise is very much higher than the number of persons whose health is impaired by noise. Many of those affected regard the annoyance effect together with sleep disturbance as the main problem arising with aircraft noise (see Sections 3.3 and 3.4). It follows that measures should be taken that reduce the number of persons annoyed by noise as far as possible, and ideally to zero. However, the avoidance of any annoyance whatsoever is not an absolute objective that has to be met without regard to reduction possibilities and cost, especially since annoyance effects occur even with very low continuous sound levels (from $L_{den\ outdoor}$ of about 35 dB(A), see

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[3] An $L_{max\ indoor}$ of 65 dB (A) corresponds with tilted window to an outdoor maximum noise level ($L_{max\ outdoor}$) of around 80 dB (A). This means that the difference in level between indoor and outdoor noise with tilted window is around 15 dB. This science-based value, which is also applied in jurisdiction, is recommended as input variable for conversion of outdoor to indoor noise or *vice versa* [Basner et al. [2006], [Schreckenberg [2009)]. With closed window the difference is greater, depending on type of window. Basner et al established a level difference of 25 dB between indoor and outdoor noise with closed window [Basner et al (2006)].

Section 3.3). While in the case of health risks, relatively reliable noise levels can be identified, by which lower deviation does not gives rise to damage to health, this is not the case with annoyance effects. In order to completely avoid annoyance effects, single noise events would have to be so quiet that they would be hardly perceivable. Consequently, no practicable target values for annoyance effects can be deduced for this study. It is therefore recommended that annoyance be reduced to an extent that is regarded as reasonable in terms of cost-benefit considerations. In other words, it is recommended that all measures be taken by which the benefit – the reduction of the annoyance effect – outweighs the cost of the measure (hereafter: 'insofar as is possible efficiently ').

The number of highly-annoyed persons (abbreviated to HA, see Section 3.3) is applied as an indicator for annoyance effect. This indicator is also applied in other studies that quantify the annoyance effect; for example, the Frankfurt Noise Index (Schreckenberger et al., 2008). The annoyance effect also covers annoyed persons (A) and little-annoyed persons (LA) who also indicate a considerable readiness to pay for avoidance of annoyance, and cannot therefore be ignored. However, as the analyses in Chapter 4 show, a reduction in the number of HA also leads to a corresponding reduction in the number of A and LA, so that the number of HA is sufficient as an indicator of annoyance effect. It should be mentioned, however, that in the monetary assessment of the benefit of a measure the reduction in the number of annoyed persons of all categories is taken into account. This is described in more detail in Section 3.3.

The number of highly-annoyed persons is calculated, as described in Section 3.3 from L_{den}. The number thus calculated is a computational value based on a defined procedure. It does not necessarily reflect the number of highly annoyed persons at a particular airport at a given time, which depends, for example, on whether airport expansion is planned, and is also influenced by survey methodology and the questions put. Furthermore, the results of surveys within the scope of a case study such as this are not appropriate as target values, since in this study forecast scenarios are considered.

The following table summarizes the indicators and target values that should be achieved in this project.

Table 1: Target indicator and target values

	$L_{Aeq\ night}$	$L_{Aeq\ day}$	Number of HA (highly-annoyed persons)
Long-term values	40 dB(A)	55 dB(A)	Reduction insofar as is possible efficiently
Short-term values	55 dB(A)	65 dB(A)	

The short-term targets should be achieved as soon as possible; that is, within a few years. The long-term targets can be achieved, as explained in Section 5.3, only after around 2060.

3 Base scenario

3.1 Short description of the reference airports

3.1.1 Airport with large volume of freight and night-flight operations

At the reference airport with a large volume of freight and night-flight operations around 131,000 flight movements took place in 2011. In the process 9.6 million passengers and 740,000 tonnes of freight were handled. While passenger transport has stagnated in recent years, the volume of freight has constantly increased. The forecast for 2017 foresees a 34% increase in the number of flight movements compared to 2011.

The airport disposes of three runways and unrestricted night-flight permission until 2030. More than 27% of commercial flight movements take place at night. The landing charge includes a noise-related component. A takeoff charge is not levied.

3.1.2 Medium-sized airport

The medium-sized airport has one runway, and the construction of additional runways is not planned. Traffic volume at this airport has greatly increased: the number of passengers rose from 6.5 million in 1996 to 9.6 million in 2011. The number of flight movements increased from 109,000 in 1996 to 136,500 in 2011, of which 21% were with propeller-driven aircraft and 4% with helicopters. Around 6.6% of flight movements take place between 10 p.m. and 6 a.m. In 2011, the volume of freight was 21,000 tonnes; in addition, 10,000 tonnes of airmail were transported. A 55% increase in the number of flight movements is assumed in the forecast for 2020.

At the medium-sized airport, aircraft may not land between midnight and 6 a.m., and may not takeoff between 11 p.m. and 6 a.m. Exceptions are made *inter alia* for airmail transport as well as emergency and diversion flights.

Landing and takeoff charges have a noise-related component.

3.1.3 Regional airport with expansion potential

The regional airport disposes of one runway, and expansion of the terminal is planned. 1.13 million passengers and about 600 tonnes of freight were transported in 2011. Annual flight movements amounted to 45,000. The forecast for 2020 sees an increase in flight movements of more than 70%.

Between 11 p.m. and 6 a.m. the airport is closed. In exceptional cases, landings and takeoffs are permitted during this period. Landing and takeoff charges are based on takeoff mass, and only with propeller-driven aircraft is there a noise-related component.

3.2 Calculation of noise contours

Modelling of aircraft noise is undertaken with the Integrated Noise Model (INM) software tool, which was developed by the US Federal Aviation Administration (FAA). The INM has been applied since 1978 by the

FAA as standard method for noise assessment, and is used in more than 1,000 organizations in over 65 countries [INM 7.0 (2007)].

With the INM, different sound level indicators can be calculated at the points of a raster that is laid over the area surrounding an airport. For this study, the daytime equivalent continuous sound level ($L_{Aeq\ day}$), night noise level ($L_{Aeq\ night}$) and 24-hour sound level (L_{den}) are each provided as noise contours (isolines of equal levels of noise).

For calculation of noise contours an interface was developed that produces INM-readable data from input data. Input data in DAS format is charted using NavSim, an air traffic simulation tool developed by the University of Salzburg, and communicated as XML data flow to the interface. Measures and strategies for efficient aircraft noise reduction at German airports can be thoroughly investigated using NavSim and INM, and the effects of different measures on noise exposure deduced and reproduced.

For calculation of noise levels in the base scenario – that is, without introduction of additional measures – DAS (data acquisition system) data for all three types of airport under investigation was applied. The airport operator and Air Traffic Control are required under the First Ordinance implementing the Protection against Aircraft Noise Protection Act (*FluLärmG*) to describe in detail flight movements of the respective airport for a forecast year. These DAS data sets contain for every approach and departure data on the noise category of the aircraft, approach and departure routes as well as the times of takeoffs and landings for the six months of the forecast year with the heaviest traffic. This data is applied for calculation of noise exposure on the ground; it is available for the freight airport for forecast year 2017 and for the other two airports for 2020. In order to be able to use this data, approach and departure routes have first to be simulated with the NavSim air traffic simulator and converted into a format that is readable by INM. Noise contours are then calculated with INM. Whereas for base scenarios DAS data sets are directly applied, for measure and strategy scenarios these data sets are modified in accordance with the measures that are to be simulated. Noise levels are then calculated with the modified DAS data.

In DAS data, flight movements are not stated for every type of aircraft; instead the aircraft are grouped in noise categories, namely in so-called *AzB* categories (*AzB: Anleitung zur Berechnung von Lärmschutzbereichen AzB* (2008); that is: Instructions on calculation of noise protection zones). Since the INM applies individual aircraft types, a representative aircraft type was selected for each *AzB* aircraft group. Representative aircraft types are understood to be those that in each group have the greatest share of flight movements at the selected airport.

Flight track dispersion is also stated in DAS data, and can be reproduced in the INM using sub-tracks. In order to avoid manual adaptation of these sub-tracks for all flight tracks, the additional tracks are generated by NavSim and then converted with the interface programme into an INM-compatible format.

Further adjustments were necessary, since the standard approach procedures used in the INM are not always the approach procedures that are used by the aircraft under consideration in the base scenario for the reference airports. For this purpose, the procedures applied at the reference airports were ascertained through evaluation of radar tracks. Insofar as these procedures were not identical with those stored in the INM, corresponding adjustments had to be made in the INM.

Two measures concern the modification of approach procedures, and these new approach procedures have also to be reproduced in the INM. The basis for this is provided by so-called *LanAb* profiles (*LanAb: Lärmoptimierte An- und Abflugverfahren*; that is noise-optimized approach and departure procedures), which have been developed and tested by the German Aerospace Centre (DLR) for the A320 aircraft (DLR (2007)).

On this basis, different additional approach profiles were created that have a varied effect on the noise situation; in particular, low drag low power (LDLP), optimized LDLP (OLDLP) and segmented continuous descent approach (SCDA) (see Section 4.3).

An example of the input and result of calculation with INM is displayed below. Figure 1 shows approach and departure routes for the airport with a large volume of freight and night-flight operations (approach red, departure blue).

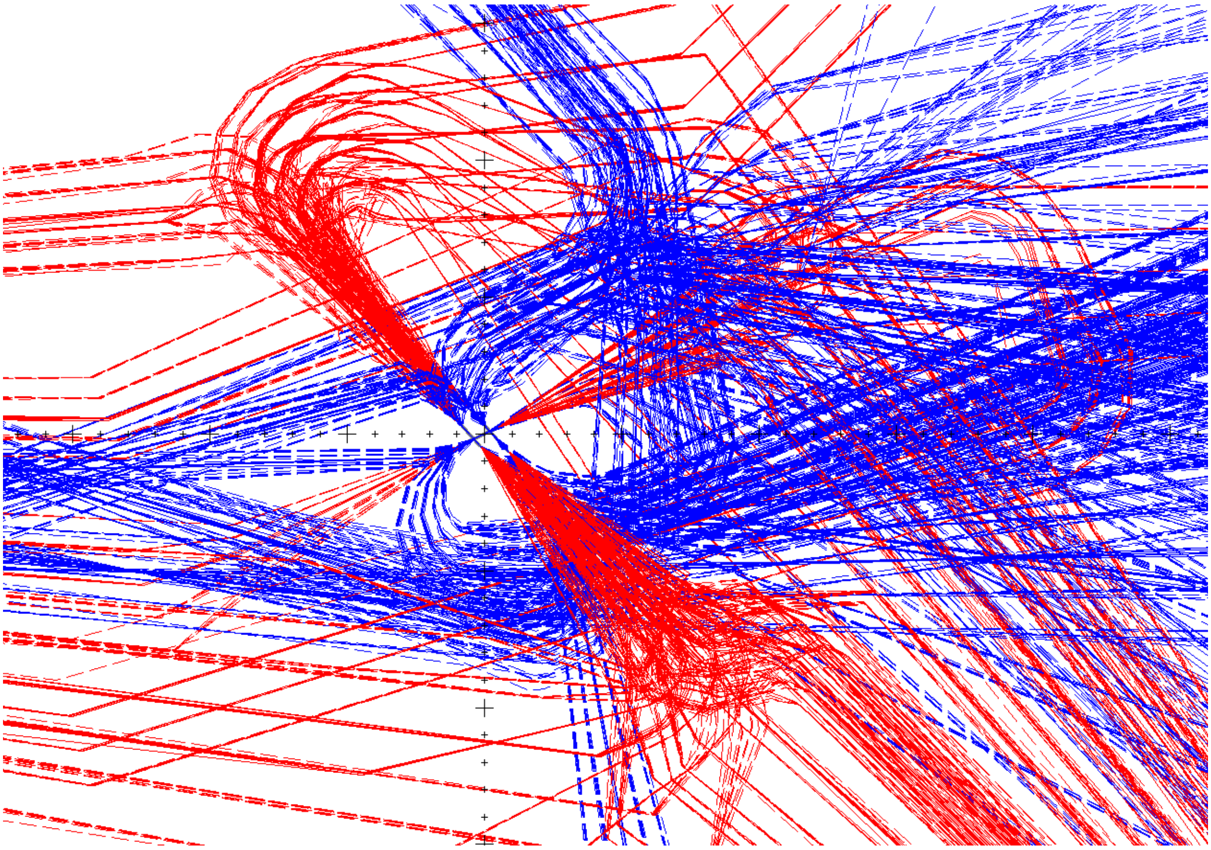

Figure 1: Flight tracks and sub-tracks of the airport with the largest volume of freight and night-flight operations

The result of calculations with INM is noise contours. These are displayed in Figure 2 for L_{den} and the airport with a large volume of freight and night-flight operations. The isolines are calculated in 1 dB(A) steps, but shown here in 5 dB (A) steps for greater clarity.

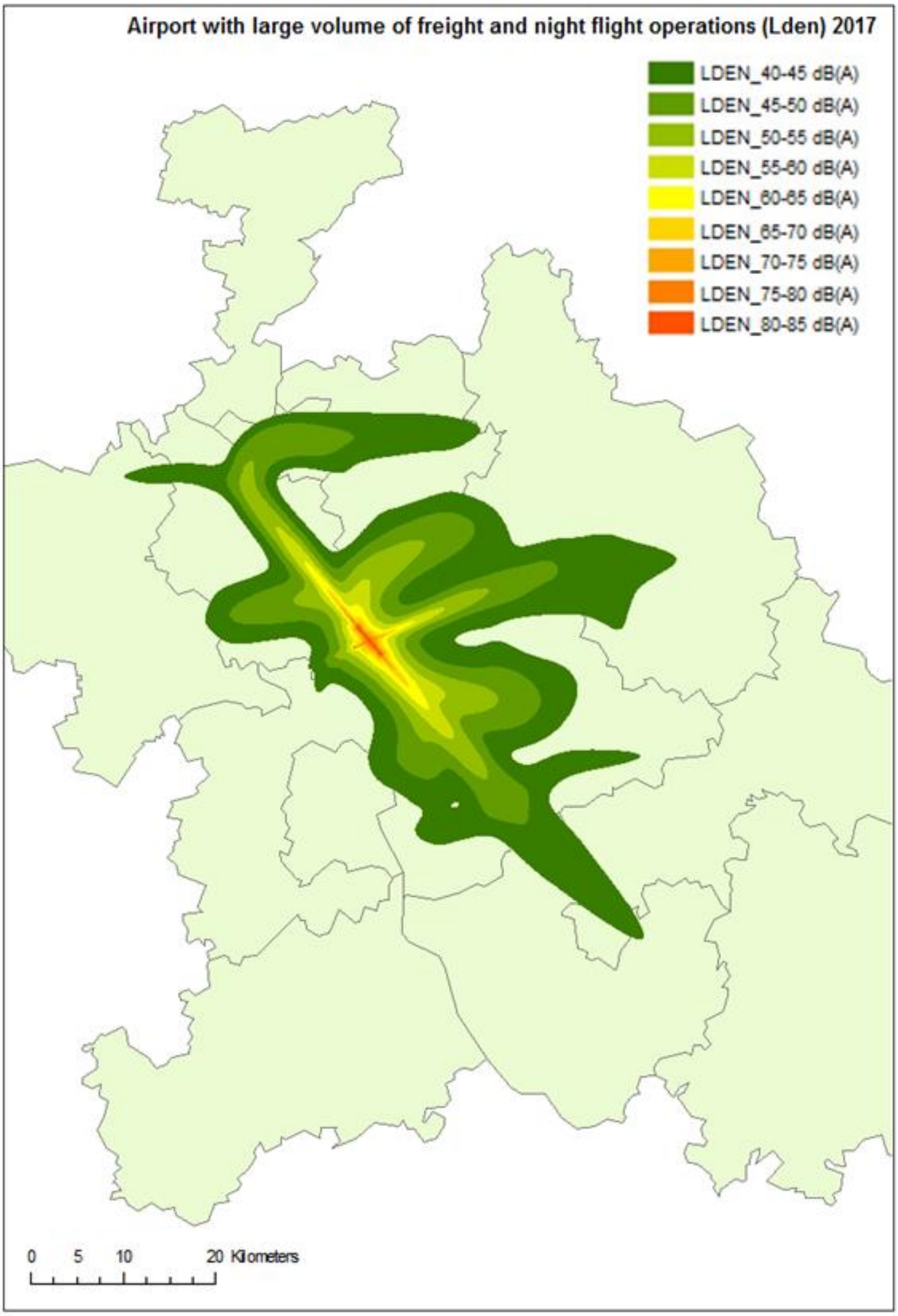

Figure 2: Aircraft noise contours for the airport with a large volume of freight and night-flight operations, base scenario 2017

3.3 Quantification and assessment of the impact of aircraft noise

3.3.1 Overview

In the following sections 4 and 5, scenarios are developed for each of the three types of airport, which describe flight movements in the year 2017 and 2020. These scenarios comprise the base scenario (without measures), the measure scenarios, in which in each case a measure is applied, as well as two strategy scenarios, in each of which a package of measures is applied. Different exposure levels ($L_{Aeq\ day}$, $L_{Aeq\ night}$, L_{den}) on the ground are calculated for all noise levels that are 35 dB(A) or higher with the model described in Section 3.2.

In this section, it is described how effects can be estimated on the basis of noise contours.

To determine noise exposure of the persons affected, the area around each airport is divided into grid elements of 100m*100m. For each element the number of inhabitants is determined on the basis of Eurostat population data for the year 2006, which, with the aid of additional statistical forecast figures, is projected for the respective reference year (2017 or 2020). For each scenario the grid element is then intersected with the noise contour (isoline of noise level) using a geographic information system; so that for each element the noise level ($L_{Aeq\ day}$, $L_{Aeq\ night}$, L_{den}) as well as the number of inhabitants are ascertained.

Further appraisal proceeds as follows:

- For each scenario and each airport type maximum noise levels ($L_{Aeq\ day}$, $L_{Aeq\ night}$, L_{den}) are determined from the values for the grid elements in which people live. These maximum noise values are compared with the target values (see Section 2.3).
- In addition, health risks, cases of sleep disturbance and annoyance effects are estimated for each grid element. These effects are then converted into disability-adjusted life years (DALYs) and added together to produce a single number. Independent of that, the effects are then converted directly into monetary values. The applied equations and parametric values are described below.

3.3.2 Estimation of adverse effects on health, sleep disturbance and annoyance effects

The effects for the ascertained number of persons affected in individual sound level ranges are estimated using the exposure-response relationships described below. The recommended procedure largely corresponds to the approach mentioned in "Good practice guide on noise exposure and potential health effects" [EEA (2010)]. Merely in the calculation of high blood pressure resulting from aircraft noise is more recent knowledge concerning exposure-response relationships applied.

Annoyance effects

For determination of annoyance effects the 'Position paper on dose-response relationships between transportation noise and annoyance' of the European Commission provides an overview [European Commission (2002)].

For conversion of sound levels into the three annoyance categories used here the results of a study by Miedema & Vos (2004) are applied. These relationships are also applied in other recent studies (for example, in the WHO study 'Burden of disease from environmental noise' [WHO (2011)], and they are recommended for use by the European Environment Agency [EEA (2010)]. They are thus an established standard throughout the European Union. Three categories of annoyance are distinguished, which are defined as follows:

- proportion of the little-annoyed population in % LA,
- proportion of the annoyed population in %A and
- proportion of the highly-annoyed population in %HA.

In Miedema & Vos (2004) relationships are deduced that include affected persons of the highly-annoyed category: the number of annoyed persons (A) therefore also includes the number of the highly-annoyed (HA), while the number of little-annoyed (LA) also includes the annoyed (A) and highly-annoyed HA. To avoid double counts in the assessment, this is corrected with equation 1, where the number of the annoyed (A) represents only these and not also the highly-annoyed (HA).

The proportion of those annoyed per annoyance category is calculated from the sound level as follows:

Equation 1: Dose-response relationships for persons annoyed by aircraft noise

Air transport (source: EEA, 2010)

Applicable for sound level L_{den} from 32 dB(A) for LA, 37 dB(A) for A and 42 dB(A) for HA:

$$\%HA = -9.199 \times 10^{-5} (L_{den} - 42)^3 + 3.932 \times 10^{-2} (L_{den} - 42)^2 + 0.2939 (L_{den} - 42)$$

$$\%A = 8.588 \times 10^{-6} (L_{den} - 37)^3 + 1.777 \times 10^{-2} (L_{den} - 37)^2 + 1.221 (L_{den} - 37) - \%HA$$

$$\%LA = -6.158 \times 10^{-4} (L_{den} - 32)^3 + 3.410 \times 10^{-2} (L_{den} - 32)^2 + 1.738 (L_{den} - 32) - \%A$$

Sleep disturbance

In a study of the European Commission (2004) the following dose-response relationships for sleep disturbance are deduced through evaluation of available data sets [see also Miedema & Vos (2003) and Miedema & Vos (2004)]. These relationships are applied, for instance, in the WHO study 'Burden of disease from environmental noise [WHO (2011)].

Here, two categories of sleep disturbance are distinguished:

- Sleep-disturbed (%SD) and
- Highly sleep-disturbed (%HSD).

Equation 2: Dose-response relationships for the number of persons sleep-disturbed by aircraft noise

Air transport (Source: Miedema & Vos (2004)), for $L_{Aeq\ night} > 40$ dB(A)

$$\%HSD = 18.147 - 0.956 * L_{Aeq\ night} + 0.01482 * (L_{Aeq\ night})^2$$

$$\%SD = 13.714 - 0.807 * L_{Aeq\ night} + 0.0\ 1555 * (L_{Aeq\ night})^2 - \%HSD$$

Heart attacks

Existing epidemiological studies on the relationship between road traffic noise and the risk of cardiovascular diseases are evaluated in (Babisch (2006)). From these, an exposure-response relationship was deduced for occurrence of a heart attack depending on an equivalent continuous sound level during the day (6 a.m. to 10 p.m.). The application of this equation for aircraft noise has the disadvantage, however, that night-time noise is only indirectly considered; namely, insofar as it is present in a relationship of daytime and night-time noise that is typical for road traffic. In applying the equation, differences in night flight operations between different airports were therefore not considered; a reduction of night-time noise would change the risk of heart attack. It would be better to use an indicator that covers daytime and night-time noise; that is, L_{dn} or L_{den}. Moreover, the exposure-response relationship must be correspondingly converted. For this purpose, in its "Good practice guide on noise exposure and potential health effects" the EEA made a proposal for an exposure-response relationship that applies the L_{den} for road transport noise [EEA (2010)]. In this study, it is assumed that this relationship can be transferred to aircraft noise:

Equation 3: Exposure-response relationships for the risk of a heart attack

Risk of heart attack through noise (Source: EEA (2010), own modifications)
To be applied for 59.5 dB (A) ≤ L_{den} ≤ 79.5 dB (A)
Odds ratio (OR) per 10 dB(A) = 1.17 (CI=0.87-1.57)

A recent study by Huss et al. established an odds ratio (OR) of 1.3 for the risk of a fatal heart attack through aircraft noise [Huss et al. (2010)]. This was derived from the ratio of risks for persons over 30 years of age who are subject to noise exposure of L_{dn} >60 dB(A) compared to persons subject to noise exposure of L_{dn} < 45 dB(A), with a 95 % confidence interval of 0.96 to 1.76. In the case of persons who have lived in noisy areas for 15 years or longer, the hazard risk (HR) was 1.48. The detailed findings also show, however, that up to an L_{dn} of about 55 dB(A) there is merely a very slight increase in the risk (HR = 1.02); the risk increases markedly only above 1.02. Moreover, it is not stated how high the levels > 60 dB(A) are; for instance, scaled in 5 dB(A) categories. Derivation of a precise exposure-response relationship is therefore not possible without additional evaluations. Depending on related assumptions, the risk of fatal heart attacks is somewhat higher compared to the exposure-response relationship in Equation 3.

Since validated conversion of the results of Huss et al. into an exposure-response has not yet been carried out, the above-mentioned exposure-response relationship of Babisch (2008) and EEA (2010) is applied, as a conservative estimation, for air traffic.

High blood pressure

In the WHO study (2011) and in Babisch (2010), a meta-analysis is presented, which evaluates the results of five studies that investigate the relationship between aircraft noise and high blood pressure. The results vary widely. If one takes the average value of all five studies, however, the following connection arises [Babisch & van Kamp (2009)]:

Equation 4: Exposure-response relationships for the risk of occurrence of high blood pressure

Risk of high blood pressure through aircraft noise (source: Babisch & van Kamp (2009))
To be applied for 47.5 dB (A) ≤ L_{dn} ≤ 67.5 dB (A)
Odds ratio (OR) per 10 dB(A) = 1.13 (CI=1.00-1.28)

In two studies for the Federal Environment Agency, high blood pressure and other cardio-vascular diseases – and thus increased consumption of medicinal products – occur with continuous sound levels ($L_{Aeq\ night}$) above 40 dB(A) [Greiser et al. (2007) and Greiser & Greiser (2010)]. It has also been established that particularly with women the risk of depression is significantly increased; a factor, which has previously not been considered in noise assessment. In the case of exposure in the range 46 to 61 dB(A) continuous sound level at night, between 3 a.m. and 5 a.m., there is an increase in the prescription of medicinal products that lower high blood pressure of 24% for men and 66% for women. Only with women was an effect in the noise level range of 40 to 45 dB(A) verifiable, namely 27%.

For the assessment of noise reduction measures in this report, however, an exposure-response relationship is required that indicates the effect (odds ratio for high blood pressure) as a function of continuous sound level. Deduction of such a function from Greiser's findings provides no consistent results [Wichmann et al. (2006)], and can therefore not be applied. On the other hand, from the results of Greiser et al. (2007) it can be assessed that application of Equation 4 for high blood pressure results in considerable underestimation of cases of high blood pressure when there is heavy air traffic between 3 a.m. and 5 a.m. This is the case with the airport with a large volume of freight and night flight operations.

Greiser et al. also investigate other cardio-vascular diseases, in particular cerebral blood flow disorders, stroke, cardiac insufficiency, heart attack and coronary heart disease [Greiser et al. (2007)]. With low aircraft noise (40 to 45 dB(A)) at night between 3 a.m. and 5 a.m. there is an increase in the prescription of medicinal products for the treatment of the above-mentioned diseases of 14% for men and 22% for women. With greater aircraft noise (46 to 61 dB(A)) the figures are 27% for men and 116% for Frauen. Here, a consistent exposure-response relationship with sound level as continuous variable cannot be deduced. Moreover, there is a strong association between aircraft noise and the prescription of medicinal products only when the different diseases are considered together, whereas for the assessment disease-specific data is required.

In studies other than that of Greiser e al. there is little evidence of a connection between aircraft noise and cardio-vascular diseases (apart from heart attacks and high blood pressure) [see Greiser et al. (2007)). Diseases other than heart attack and high blood pressure are accordingly not considered in calculations of health risks from aircraft noise. This should be rectified in future studies.

3.3.3 DALYs

DALYs are 'disability-adjusted life years'. All diseases, annoyance effects and premature deaths can be converted into DALYs and added, producing an aggregate value that covers all health risks. In the case of premature deaths, DALYs correspond to the sum of the years of "healthy" life that are lost. In the case of diseases, the number of DALYs arises as the sum of the duration of the disease (in years or fractions of years) multiplied by a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead).

Sources for the applied DALY factors are EEA (2010), HEIMTSA (2011) and WHO (2011). For the highly-annoyed (HA) a degree of severity of 0.02 is applied, and for the "highly sleep-disturbed" (HSD) a factor of 0.07. It is, however, not clear whether the DALYs caused by annoyance effects and the DALYs caused by sleep disturbances can be aggregated. As an example, it is to be expected that consciously perceived sleep disturbances are included in the annoyance effects. Following the recommendation of the WHO (2011), DALYs of both categories will be aggregated in this study, which might lead to an overestimation of the number of DALYs. On the other hand, if annoyance effects and sleep disturbances affect the same person, synergistic effects might occur, i.e. the sum of DALYs for a combination of effects which exceeds the number of DALYs for the single effects. Additionally, DALYs are only available for highly annoyed and highly sleep disturbed persons; they are not available for the other levels of annoyance and sleep disturbance. This leads to an underestimation of the number of DALYs. For future analysis, it would be useful for DALY degrees of severity to be compiled also for the categories of "annoyed" (A) and "sleep-disturbed" (SD), in order to include these in calculations of DALYs.

It is further assumed that a fatal heart attack results in the loss of an average of 8 years of healthy life. For non-fatal heart attacks a degree of severity of 0.405 with a duration of one year is assumed.

High blood pressure, provided it is detected, can be well controlled by drugs. A DALY factor of 0.35 per year is recommended by the WHO [WHO (2011)]. This value would appear to be too high, and is only applied for moderately-high to severely-high blood pressure.

The following table displays a summary of the applied DALY assessment approach.

Table 2: DALY values for different human health endpoints

Health effect	Unit	DALY
Medium and severe high blood pressure	Year	0.35
Fatal heart attack	Case	8
Non-fatal heart attack	Case	0.405
Highly sleep-disturbed	Year	0.07
Sleep disturbance (SD)	Year	Not considered
Highly-annoyed (HA)	Year	0.02
Annoyed and little-annoyed (A & LA)	Year	Not considered
Little-annoyed (LA)	Year	Not considered

3.3.4 Monetary values

With DALYs, effects on human health can be compared and aggregated. Comparison with other advantages and disadvantages, particularly costs, is not possible. In order to carry out a quantitative assessment of variations in health risks and the resulting costs, the respective values have to be converted into a common factor, at best a monetary value. This enables assessment of avoided health risks and annoyance effects as well as costs. Effects must therefore be converted into monetary values.

One way to do this would be on the basis of DALYs, as determined in Section 3.3.3. This would, however, increase the uncertainty of results, since two steps fraught with great uncertainties would be undertaken successively; namely, conversion of effects into DALYs, and conversion of DALYs into monetary values. For this reason, in this study effects are converted directly into monetary values – that is, the costs of adverse effects – without the use of DALYs.

The loss of quality of life emanating from a health risk or annoyance is assessed by determining the value to the person affected – expressed in money terms – of avoidance of a health risk or noise annoyance. The monetary value of an adverse effect is therefore generally determined by raising the question of the readiness to pay for avoidance of such damage. In the case of diseases, there are additionally the costs of treatment and the loss of productivity on the part of employers. These factors are much less important, however, than the readiness to pay for avoidance of a disease. The latest meta-analysis of the assessment of monetary value per case of illness was carried out within the scope of the EU HEIMTSA project [HEIMTSA (2011)]. The determined values (for 2010 in $euros_{2010}$) are shown in Table 2:

Table 3: Range of monetary values for the weighting and comparison of mortality and morbidity risks as well as of severe sleep disturbance

Adverse effect	Lower value of the range	Average value of the range	Upper value of the range	Unit
Reduction of the risk of loss of 1 year of life expectancy	37,500	60,000	215,000	$Euros_{2010}$/person*year
Risk of heart attack	4,675	86,200	436,200	$Euros_{2010}$/case
High blood pressure	880	950	1,110	$Euros_{2010}$/person*year
High sleep disturbance	480	1.240	1.570	$Euros_{2010}$/person*year

Source: HEIMTSA (2011)

The range of given values is taken from various studies. The average value is applied in the evaluations below. No values are available for the valuation of sleep disturbances; only high sleep disturbance can be valued. However, it is assumed in this study that annoyance effects, which annoyed persons are exposed to, at least partially also include sleep disturbances. Thus, it is here assumed that the following monetary values for annoyance effects include sleep disturbance, except the high sleep disturbances which can be valued explicitly.

Only a few surveys have been conducted concerning the monetary assessment of degrees of annoyance; these include Lambert et al. (2001) for the Rhône-Alpes Region, Bue Bjorner et al. (2003) for Copenhagen and HEATCO (2006) for several European countries. No figures are available for Germany, but it is assumed that those for Copenhagen can most likely be applied to Germany. Converted to the three-stage annoyance scale used in this study and the monetary value $Euros_{2010}$, the values shown in Table 3 arise.

Table 4: Readiness to pay for avoidance of high annoyance, annoyance and slight annoyance per person and year

Degree of annoyance	Monetary value
High annoyance	670 $euros_{2010}$/(person*year)
Annoyance	470 $euros_{2010}$ /(person*year)
Slight annoyance	200 $euros_{2010}$/(person*year)

Source: Bue Bjorner et al. (2003) and authorial calculations

It should be noted that the readiness to pay has been determined for persons who have been exposed to noise for a relatively long period. This means that persons who are very willing to pay for avoidance of noise are not taken into account, since they have either already moved out of, or have not moved into the noisy area under consideration. This could mean that the willingness to pay of persons exposed to a noticeably increased noise level – for instance, in the case of airport expansion – would be greater. This is not of relevance to this study, since the measures discussed below reduce noise exposure.

There are many more studies that for assessment apply not degrees of annoyance but rather noise levels directly, mostly L_{den}, as indicator. With the aid of 'hedonic pricing' (see the following paragraph) or analyses of willingness to pay, a monetary value per decibel, person and year is determined. Apart from the above-mentioned survey studies of Navrud (2010) and Navrud & Strand (2011) there are further meta-studies by Navrud (2002), Navrud (2004), ExternE methodology update (2005) and HEATCO (2006) on determination of average values.

Average values (factor costs, without value-added tax) of 10 $€_{2010}$ per dB (A) L_{den} and person arise for analyses of willingness to pay and 23 $€_{2010}$ per dB(A) L_{den} and person for hedonic pricing studies. Hedonic pricing studies analyse how housing prices decrease in areas with high noise exposure. To determine these values, the results of studies in other European countries are converted using average income per capita in Germany. These values are taken into account from a threshold of 50 dB(A) to 70 dB (A) and applied for road traffic. In order to take account of the different characteristics of noise impact with air traffic, the values for road traffic are adapted on the basis of differences in annoyance curves according to Miedema & Oudshoorn (2001) [HEATCO (2006)]. For air traffic, the result is a factor of 1.55. That is, in the case of hedonic pricing, a value of 1.55*23 $€_{2010}$ per dB(A) = 36 $€_{2010}$ per dB(A) above 50 dB(A), and in the case of analyses of willingness to pay 15.50 $€_{2010}$ per dB(A) above 50 dB(A).

Such assessment approaches that assess linear the continuous sound level are not applied in this study. On the one hand, assessment only applies above a level of 50 dB(A), although annoyance occurs also at lower noise levels (for example, high degrees of annoyance from 42 dB(A)). Moreover, the annoyance effect increases non-linear with noise level. Both are better represented in the assessment of degrees of annoyance. The results are therefore also noticeably higher with assessment using degrees of annoyance than with direct noise level assessment.

In following table the monetary values for different health effects are summarised.

Table 5: Monetary values for different human health endpoints

Health effect	**Unit**	**$€_{2010}$**
Medium and severe high blood pressure	Person*year	950
Fatal heart attack	Case	86,200
Non-fatal heart attack	Case	86,200
Highly sleep-disturbed (HSD)	Person*year	Included in values for HA/A/LA
Sleep-disturbed (SD)	Person*year	Included in values for HA/A/LA
Highly-annoyed (HA)	Person*year	670
Annoyed and little-annoyed (A+LA)	Person*year	470
Little-annoyed (LA)	Person*year	200

3.4 Effects of aircraft noise exposure in the base scenario

For airport types described in Section 3.1 noise contours are initially calculated for the base scenario for the reference years 2017 and 2020, as described in Section 3.2. These are then applied, as explained in Section 3.3, to estimate annoyance effects, sleep disturbance and health risks. The result is shown in Table 4. As mentioned in Section 3.3.2, the number of persons suffering from high blood pressure, particularly at the airport with a large volume of freight and night-flight operations, is probably clearly underestimated. Furthermore, health risks that arise through aircraft noise, for which, however, there are no exposure-response relations suitable for assessment, could not be quantified. These are primarily cardio-vascular diseases with the exception of heart attack and high blood pressure.

Table 6: Maximum equivalent continuous sound level in built-up areas and the number of persons suffering from noise-related annoyance, sleep disturbance, high blood pressure and heart attack per year in the base scenario

Annoyance and health effects		**Airport with a large volume of freight and night-flight operations**	**Medium-sized airport**	**Regional airport**
Maximum value in residential areas	L_{den}[dB(A)]	72	67	61
	$L_{Aeq\ day}$ [dB(A)]	63	65	58
	$L_{Aeq\ night}$ [dB(A)]	66	56	51
Number of persons annoyed	1000 HA	30.9	10.2	0.7
	1000 A	116.5	42.5	4.4
	1000 LA	214.7	97.0	15.6
Number of persons with disturbed sleep	1000 HSD	11.0	1.4	0.05
	1000 SD	18.4	2.3	0.09
Number of heart attacks		2.9	0.5	0.005
Number of persons with high blood pressure		4.490	530	84

Note: HA = highly annoyed, A= annoyed, LA = little annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed (see Section 3.3)

Table 6 shows the maximum equivalent continuous sound level in built-up areas around the respective airport. What is noticeable is the high $L_{Aeq\ night}$ arising from intensive night-time air traffic at the airport with a large volume of freight and night-flight operations. At the other airports, flight movements at night are restricted to the shoulder hours. Noise exposure causes the annoyance and health effects specified. The very great differences in health risks and annoyance effects between the airport with a large volume of freight and night-flight operations and the medium-sized airport are caused by more intensive night-flight operations at the freight airport. This shows that the reduction of night noise is of increased significance. The number of heart attacks is very low. These are therefore considered below in the calculation of DALYs and the costs of noise damage, but are not specifically stated.

In order to better assess the extent of the effects, and to enable comparison with the costs of measures, they are converted to a common unit, namely a monetary value; in other words, the costs of damage are calculated. The result is shown in the final line in Table 7. The most significant proportion of the cost of damage from noise is caused by annoyance effects and sleep disturbance.

Table 7: DALYs/a and damage costs caused by noise per year in the base scenario

Annoyance and health effects	**Airport with a large volume of freight and night-flight operations**	**Medium-sized airport**	**Regional airport**
Sum of damages in DALYs	2,439	663	37
Sum of damage costs cause by noise in mill. $€_{2010}$/a	188	62	7.0

4 Measure scenarios

4.1 Criteria for the assessment of noise measures

In this chapter various measures for the reduction of noise are analysed. To begin with, the measures are described. Their primary areas of impact are then explained. The following areas of impact are distinguished:

- Sound emissions of aircraft: Sound emissions are reduced through technical measures in aircraft.
- Passive noise abatement: The effectivity of noise control between outdoor and indoor areas is enhanced; for example, through installation of sound-proofed windows. The objective of the measure is reduction of the noise level to which persons in indoor areas are exposed.
- Approach and departure procedures: Noise exposure is reduced through modification of approach and departure procedures and routes.
- Aircraft fleet mix: Noise exposure is reduced by fleet renewal with introduction of progressively quieter aircraft types (without changes in the number of flight movements or schedules).
- Number of flight movements: Noise exposure is reduced through a reduction in the number of flight movements (throughout the day, or at specific periods of time, and particularly at night).

Following the description and categorization of measures, they are assessed on the basis of the criteria stated in Table 8. Presentation of the respective legal framework as well as assessment of individual measures regarding their depth of intervention and administrative cost is to be found in each section following description of the measures. Quantification of the effectivity of all measures is dealt with in Section 4.8.

Table 8: Criteria for overall assessment of measures

Criterion	Description	Characteristic
Effectivity	To what extent does the measure reduce the maximum equivalent continuous sound level in built-up areas and the number of persons suffering sleep disturbance and annoyance?	The reduction is quantified for all measures in Section 4.8
Depth of intervention	To what extent does implementation of the measure involve intervention in the market mechanism?	High: direct intervention in the market mechanism Medium: change in general market conditions Low: changes in general conditions that can be avoided with technical measures
Administrative cost	How high is the administrative cost of measures from the points of view of those exposed to noise and public authorities?	High: in some cases, very high initial costs and / or significant running costs Average: implementation of the measure requires smaller additional measures (for example, auxiliary differentiations in controls) or extensive preliminary negotiations. Low: Easily-controllable prohibitions and technical measures
Legal realization	Can the measure be legally implemented? Are legislative changes necessary?	Discussion of this aspect is to be found in each section for specific measures

4.2 Movement and noise quotas

4.2.1 Description of movement quotas

Objective and modality of the measure

Movement quotas are intended to limit aircraft noise through restriction of the number of flight movements. The airport operator is then required to ensure that at his airport a certain quota is not exceeded. On the one hand, it is conceivable that movement quotas be allocated free of charge to individual airlines together with slots.[4] On the other hand, the auctioning of 'movement certificates' is another option. Unused 'movement certificates' would then have to be returned to the issuer; alternatively, they could be freely traded among aircraft operators. It would also be conceivable, within the scope of an overall strategy, for movement quotas to be separately defined for night and daytime hours. In this section, however, the impact of overall quotas is analysed.

Impact mechanisms

A movement quota primarily defines the number of flight movements. Taking off and landing at the airport can also have an effect on aircraft fleet mix. In the defined form it has to be expected that due to the reduction in the number of total movements night-flight movements also decrease.

Table 9: Areas of impact of movement quotas

Direct impact	**Sound emissions of aircraft (technical)**	**Sound-proofed windows and sound-insulated ventilators**	**building bans and resettlement**	**Approach and departure procedures**	**Fleet mix**	**Number of movements**
Day					(x)	X
Night					(x)	X

Note: x: main effect; (x): additional effects

With a decrease in the permitted number of flight movements, the benefit that an airline receives through a flight movement will be generally higher with large aircraft than with smaller aircraft. The likely result is that airlines will be more likely to reduce flight movements with small aircraft rather than with larger aircraft. Depending on the overall level of movement quotas, this would initially mean that general aviation[5] would be shifted to small airports without movement quotas. Where displacement of general aviation is insufficient to comply with declining quotas at an airport, the question arises as to the extent to which flight movements of remaining aircraft decrease, and to what extent airlines attempt to retain current transportation capacity through the replacement of relatively small aircraft with larger aircraft. On the one hand, the desire to maximize turnover suggests that small aircraft would be replaced by larger aircraft. On the other hand, with decreasing quotas the number of flight connections would then decline. For passengers this would represent a loss of quality, and could lead to reduced demand for flight tickets.

[4] The allocation to airlines of takeoff and landing times – so-called slots – governs the right of an airline to takeoff or land at a particular airport within a certain time window with a particular type of aircraft (dependent, above all, on the size of the aircraft, which is decisive for separation distances).

[5] Civil aviation, with the exception of scheduled air services and charter transport (for example, taxi flights, private flights, flights of leisure pilots and rescue flights).

Modelling assumptions

In modelling, it is assumed that movement quotas are 20% under movements in the base scenario. Since there is little empirical evidence on conceivable impact mechanisms, two possible effect scenarios are computed:

a) Movements of all types of aircraft are reduced proportionally.

b) General aviation is displaced. With the remaining flights transportation capacity is retained at a constant level. This means that small aircraft are replaced with large aircraft until such time as the movement quota is exhausted, provided that at the airport in question the share of civil aviation exceeds 20%.

The two scenarios reproduce the lower (scenario b)) and higher (scenario a)) impact range of the measure.

4.2.2 Description of noise quotas

Objective and modality of the measure

The objective of noise quotas is the restriction of noise exposure to a pre-determined level in the vicinity of an airport. In contrast to flight movement quotas, noise quotas are aimed directly at noise exposure. There are two types of noise quota:

a) Starting point: overall control of noise reduction. Noise quotas as control mechanism for all noise reduction measures, including settlement control.

b) Starting point: airport. 'Cap and trade' noise quota for the airport (specification of the maximum noise exposure that may be caused by the airport and its flight movements.

With the first type of noise quota, noise contours are specified that may not be exceeded. Alternatively, the number of households or persons that may be exposed to noise is defined, as well as the level of noise to which they may be exposed. The airport operator is required to comply with such specifications. The specifications can be defined as maximum level or can include, if need be, further elements of annoyance (for example, the number of persons or households that are highly annoyed by noise). In order to ensure observance of noise contours, actual noise exposure is reviewed regularly, for example once a year. If the specified level is exceeded, the airport has to take measures that lead to a reduction of noise contours. Should this not be possible, or if it is disproportional, other spatial-planning measures may be taken (cf. Section 4.7). This type of noise quota is a superior control instrument, which is applied within the scope of an overall strategy, but it does not constitute an individual measure. Application of this instrument for implementation of strategies is discussed further in Chapter 6.

The second type of noise quota is based on cap-and-trade logics. The specified noise exposure or pre-determined number of households or persons exposed to noise ('cap') is distributed over a certain number of noise certificates. Every aircraft that takes off or lands requires, depending on its sound emissions, a certain number of noise certificates. In order to take account of greater damage to persons exposed to night noise, a larger number of noise certificates can be demanded for flight movements at night than for daytime movements. Noise certificates can be allocated to airlines together with slots, or auctioned. In this sense, these mechanisms are comparable with movement quotas. Noise certificates could also be traded between airlines ('trade'). Public authorities or airport operators could be responsible for implementation of the cap and trade system. Were the certificates to be auctioned, the proceeds could flow into a 'noise fund', with which noise abatement measures could be financed. A noise quota on a cap-and-trade basis is essentially a noise-related movement quota.[6]

Impact mechanisms

A cap und trade system has a direct effect on aircraft fleet mix and the number of flight movements.

Table 10: Impact areas of noise quotas

Direct impact	Sound emissions of aircraft (technical)	Sound-proofed windows and sound-insulated	building bans and resettlement	Approach and departure procedures	Fleet mix	Number of movements
Day					X	x
Night					X	x

Airlines basically have the following reaction options to specification of a quota at a particular airport:

a) Operation of low-noise aircraft.

b) In cases where a flight movement with a large aircraft requires fewer noise certificates than two smaller aircraft, flights with small aircraft can be substituted with fewer flights with large aircraft.

c) Reduction in the number of movements combined with lower transportation capacity.

It is understandable that airlines, as an initial reaction, optimize their fleet mix, since it is assumed that this is economically more beneficial than the purchase of additional certificates. This reaction corresponds to the reaction to takeoff and landing charges (see Section 4.5). Should this be insufficient, the measure has a similar effect to a movement quota. The difference compared to a movement quota is that the incentive to replace relatively small aircraft with larger aircraft is lower, since with comparable technology large aircraft are generally louder than small aircraft and therefore require a greater number of noise certificates. On the assumption that for each 3 dB(A) increase in the noise emission level of an aircraft the number of required noise certificates doubles, the replacement of relatively small aircraft with larger aircraft is not to be expected.

Modelling assumptions

An optimum allocation of noise quotas would be the result of iteration based on target noise contours, and raises the question as to which changes in flight movements and fleet mix are necessary. Since this is not possible within the scope of the present study, assumptions on reactions are made and parameters set in such a way that the objective of compliance with target values (noise limits) can be more or less achieved. The following assumptions apply the system of division of aircraft into 12 noise categories that is used at

[6] See also Piehler (1994)

Frankfurt Airport; whereby Category 1 comprises the quietest and Category 12 the loudest aircraft [FRAPORT (2011)]. The following assumptions are made:

- 30 % of Category 3 aircraft are replaced with aircraft of Category 2.
- Short- and medium haul aircraft of noise categories higher than Category 3 are replaced with aircraft of Categories 2 and 3 (each to the extent of 50%).
- 50% of long-haul aircraft that are louder than Category 5 are replaced with aircraft of Category 5. For the remaining 50%, airlines prefer to pay higher noise charges, due to higher transportation capacity.
- Finally, flight movements of all types of aircraft are reduced by 40%.

4.2.3 Legal framework[7]

Movement quotas and noise quotas are measures of active noise abatement, and are applied not only for protection against night noise, but also as general quotas. In essence, allocation of quotas always implies a prohibition. With movement quotas, for instance, the absolute number of flight movements (related to a specific period) is limited, and when this limit is reached no further flight movements may take place. In the case of noise quotas, upper limits for noise exposure are set, which prohibit additional noise exposure.

Quotas become legally binding by means of an administrative act. Those wishing to build an airport require, under current German law, planning approval and authorization (Articles 6 and 8 Air Traffic Act (*LuftVG*)). Through planning approval the permissibility of the project is established, including necessary follow-up action at other facilities in respect of all public interests affected by the project (cf. Article 75 (1) of the Administrative Procedures Act (*VwVfG*). Operating restrictions can be made legally binding by means of conditions pursuant to Article 8 (1) Air Traffic Act in connection with Articles 6 (1) and (4) Air Traffic Act. Quotas are part of officially prescribed operating regulations for protection against aircraft noise.[8] Modification of an operating regulation does not require planning approval (Article (8) Air Traffic Act), but rather a change in authorization pursuant to Article 6 (4) Air Traffic Act. Movement quotas therefore become legally binding with planning permission or notification of permission. The competent state (*Länder*) authorities are responsible for issuing the respective permit.

For approval of an airport, current law requires that public and private interests that are touched upon by the project be weighed up against and among one another. Protection against aircraft noise – in particular at night – is of particular importance; whereby neither active nor passive noise abatement measures enjoys priority. Whether and to what extent flight restrictions in the form of quotas are prescribed, can only be decided on the basis of a correct, discretionary planning trade-off. A decision can, however, be revised: Quotas contained in notifications can be updated and adapted for the respective airports by means of notifications of change. Only such notifications will stand up in court, which are based on facts that justify the assumption that public safety or order is endangered (cf. Articles 6 (2) and (4) Air Traffic Act).

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[7] A more comprehensive presentation of the legal framework is provided in the Annex (German version only).

[8] Cf. Decisions of the Federal Administrative Court: BVerwGE 87, p. 332.

According to established case law, this covers only aircraft noise that as a health hazard is of constitutional relevance (Article 2 (2) of Basic Law for the Federal Republic of Germany (hereafter: German Basic Law).[9]

Instruments for protection against aircraft noise such as quotas, but also a ban on or restriction of night flights, have the problem that the legal criterion for protection of persons exposed to noise is not specified in administrative law. The Air Traffic Act does not authorize the issuance of ordinances that render terms that are subject to interpretation – such as 'threat to public safety and order' in the sense of Article 6 (2), or 'the public good' and 'dangers and disadvantages', in the sense of Article 9 (2) – manageable by means of limit values. [10]

Operating restrictions by means of movement and noise quotas always involve decisions taken in specific cases related to a particular airport site and the local noise situation. The Federal Administrative Court ruled that the decision on whether "operating restrictions are imposed, or the airport operator is obliged to extend passive noise abatement and to additionally inform persons exposed to noise of the right to compensation, in order to avoid, on the grounds of proportionality, more stringent intervention for the airport,"[11] is at the discretion of the planning approval authority. The planning freedom of public authorities also covers the decision on one of several options for realization of active noise abatement, such as the design of the airport project, operating regulations or determination of flight tracks.[12]

The central regulation on passive protection against aircraft noise in Germany – the Aircraft Noise Protection Act (*FluLärmG)*) – does not impede quotas, but neither does it demand them. The Environment Committee of the *Bundestag* established that "Aircraft Noise Protection Act contains no provisions on active noise abatement such as, for example, night flight restrictions, operating restrictions for particularly loud aircraft and noise quotas."[13]

Questions of capacity touch basically on the provisions of Article 27a Air Traffic Act; whereby the provision on airport co-ordination makes reference to EU legislation. Amongst the duties of the Federal Ministry for Transport, Building and Urban Development (*BMVBS*) is determination of the number of slots that can be planned in advance, at "commercial airports declared to be co-ordinated" (that is, falling under the supervision of the Federal Ministry) (cf. Article 27a (1) Air Traffic Act). The EU Regulation on common rules for the allocation of slots at Community airports[14] is binding, concerning which a new proposal has

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[9] Cf. Decision of the Federal Administrative Court (BVerwG) of 20.04.2005, BVerwGE 123, p. 261, margin no. 35; Federal Constitutional Court, decision of 15.10.2009 - 1 BVR 3474/08, margin no. 48.

[10] For a critical comment on this cf. Environmental Report 2008 of the German Advisory Council on the Environment (*Sachverständigenrates für Umweltfragen (SRU)*), Vol. 2, p. 627 f., with further references.

[11] Decisions of the Federal Administrative Court: BVerwGE 123, p. 261, margin no. 35.

[12] Decisions of the Federal Administrative Court: BVerwGE 87, p. 332, margin no. 28.

[13] Committee for the Environment, Nature Conservation and Nuclear Safety, Public Hearing on the Federal Government Bill on Improvement of Protection against Aircraft Noise in the Vicinity of Airports 08.05.2006, *Bundestag* Doc. 16/508, p. 37.

[14] Regulation (EEC) No. 95/93 of the Council of 18.01.1993 on common rules for the allocation of slots at Community airports (in the updated 2004 version).

recently been published by the European Commission.[15] The Federal Ministry of Transport (that is, the airport co-ordinator appointed by the Ministry pursuant to Article 6 (1) of Regulation (EEC) 95/93 in the updated version Regulation (EC) 793/2004) has to observe capacity restrictions provided for in the permit issued in accordance with air traffic law. The Federal Administrative Court called attention to the fact that "Article 6 (1) of Regulation (EEC) N0. 95/93, in the version of Regulation EC 793/2004, states explicitly that in determining parameters for allocation of slots, all relevant technical, operational and environmental-protection-related restrictions are to be considered. These include capacity restrictions stipulated on noise-abatement grounds in the operating licence."[16]

There is basically no requirement in international law that requires unrestricted access of aircraft at any time to commercial airports in Germany and represents an obstacle to quotas. The Chicago Convention, in particular, knows no such requirement, and general international law (with the exception of contractual agreements) also allows restrictions. Finally, in bilateral agreements of the Federal Republic there is no right to unregulated access to German airports.

As far as concerns operating regulations within the scope of aircraft noise protection, the EU Operating Restrictions Directive[17] has always to be considered. The standards set in the directive have been implemented on German law in Article 48a ff. of Air Traffic Licensing Regulations (*LuftVZO*). The "balanced approach" according to Article 48a No. 6 of Air Traffic Licensing Regulations applies, under which the aviation authority examines possible measures to resolve the noise problem at an airport, in particular the foreseeable effect of a reduction in aircraft noise at source, land-use planning and administration, noise-reducing operating procedures and operating restrictions. Noise-related operating restrictions are permissible pursuant to Article 48b (3) of Air Traffic Licensing Regulations, when under consideration of the balanced approach all possible measures to resolve the noise problem at the respective airport have been examined. The conditions for quotas could change as a result of the Proposal of the European Commission for a regulation on rules and procedures regarding introduction of noise-related operating restrictions at Community airports within the scope of a balanced approach, as well as through repeal of Directive 2003/30 EC[18] – should the proposal become law.[19]

In conclusion, it should be mentioned that an operating restriction need not necessarily be imposed by public authorities. Besides allocation of quotas on the basis of an administrative order, an operating restriction on a self-commitment basis is also conceivable.

4.2.4 Assessment

To begin with, it should be noted that a flight movement that has the effect that small, quiet aircraft are replaced by larger aircraft can have a negative impact on noise. A cap-and-trade system with auctioning of

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[15] Cf. COM (2011), 827 final 2011/0391 (COD) of 01.12.2011

[16] Federal Administrative Court decision of 18.08.2005 (BVerwG 4 B 20.05),: http://www.bverwg.de/media/archive/3419.pdf.

[17] Directive 2002/30/EC of the European Parliament and of the Council of 26.03.2002 on the establishment of rules and procedures with regard to noise-related operating restrictions at Community airports, OJ EC 2002 No. L 85 of 28.03.2002, p. 40 ff.

[18] Cf. *Bundesrat* Doc. 799/11 of 01.12.2011.

[19] Cf. the detailed comments in the Annex of this study (German version only).

all movement rights could lead to displacement of small aircraft, since with such a system alone the willingness to pay per flight movement is relevant. In the case of airports that are already approaching their capacity limit, small aircraft have generally already been replaced by larger aircraft. Capacity limit represents a 'natural' movement quota.

Table 11: Assessment of the movement quota measure on the basis of selected criteria

Measure	Depth of intervention	Administrative cost
Allocated movement quota	High	low to mid-range

Were movement rights to be awarded on the basis of historic circumstances, the measure could have an anti-competitive effect. Access to the market on the part of new stakeholders would become more difficult. With this form of implementation, the depth of intervention is therefore estimated to be high. A reserve quantity of movement rights for new market participants would alleviate this problem somewhat.

The administrative cost would be low to mid-range. Movement rights would have to be awarded and controlled. Since, however, movements can be easily counted, this would not represent a great challenge.

The noise-quota measure is assessed as follows:

Table 12: Assessment of the noise quota measure on the basis of selected criteria

Measure	Depth of intervention	Administrative cost
Noise quotas based on cap and trade	mid-range	High

The depth of intervention is mid-range. With noise quotas, the number of flight movements of a given technical status is indirectly limited. Noise reduction then occurs via the market mechanism (increasing prices, decreasing demand).

The administrative cost of noise quotas based on cap and trade is estimated to be high. Experiences with the European trading system for CO_2 show that the administrative cost of trading with emission rights and of monitoring environmental impact can be considerable [INFRAS (2009)].

Simulation of measures is conducted in such a way that a meaningful effect can be recognized. Since for this purpose, massive reductions in flight movements of around 20 to 40 per cent are required, legal implementation of this measure appears, at least in this form, to be difficult.

4.3 Restriction and prohibition of night flights

4.3.1 Description

Objective and modality of the measure

The restriction and prohibition of night flights[20] are aimed at protecting the inhabitants in the vicinity of airports against aircraft noise during the particularly sensitive night-time hours. Night is here defined as the period between 10 p.m. and 6 a.m.

In the case of night-flight restrictions, only those aircraft may take off and land at night that satisfy certain noise criteria. In Germany, some airports – for instance, Cologne/Bonn – apply the so-called 'Bonus List'[21] for determination of permissible aircraft. Other airports allocate aircraft to noise categories, which are compiled on the basis of noise measurements at the respective airport. In this study, the noise categories used at Frankfurt Airport are applied (see Section 4.2.2).

The question initially arises as to why flights take place at night. Basically, there are four reasons for night flight movements:

a) Unplanned landings: These can be aircraft that arrive late or emergency landings due, perhaps, to technical defects.

b) Hub for express cargo flights: The handling of time-sensitive goods (for example, food and flowers) is mostly carried out at night. This guarantees that the goods reach recipients during business hours.

c) Intercontinental flights: With intercontinental flights it is sometimes difficult to plan flights in such a way that they neither take off nor land at noise-sensitive times. Generally, flights that terminate in another continent are planned so that aircraft land in the early morning, to guarantee continental connecting flights, and take off in the late evening.

d) Low-cost holiday charter flights: Slots during the less attractive and low-traffic night-time hours are more likely to be available than during the day. Moreover, aircraft capacity utilization can then be increased.

With bans on night flights, unplanned landings during the night are at least occasionally tolerated. This applies without restriction in the case of emergencies. In the case of late arrivals, the number of flight

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[20] According to the systematics of the relevant EU Directive on noise-related operating restrictions at Community airports, there are merely "restrictions" that can be differentiated on the basis of time or emissions. In the Directive, a "ban on night flights" is described as a particularly restrictive operating restriction, which permits no planned takeoffs and landings during the night.

[21] In ICAO Annex 16, aircraft are allocated to different Chapters according to their noise emissions. Through relatively moderate tightening-up of the progression, the situation arose that in Chapter 3, which was valid until 2006, widely-differing aircraft types were covered with respect to noise emissions. In order that airports could continue to offer airlines an incentive for operation of the most modern and quietest aircraft, the Federal Ministry of Transport, Building and Urban Develop (BMVBS) drew up in 1994, together with the German Airports Association (*ADV*), a 'Bonus List' for differentiation of charges in Chapter 3. According to this procedure, which is based on noise measurement at airports, aircraft that are particularly quiet on takeoff and landing are compiled and regularly updated and published by the BMVBS (most recently in 2003). In the meantime, the 2003 update is obsolete.

movements can be limited and / or restricted to the beginning of the night-flight period (for example, 10 p.m. to midnight).

Displacement of low-cost charter aircraft from night-time hours has considerably fewer economic consequences than displacement of intercontinental or cargo flights from the night, since there are no structural reasons that require charter aircraft to take off or land at night. In the case of intercontinental or cargo flights, however, the cost of displacement is generally higher, and the consequence of night flight restrictions is therefore more likely to be operation of quieter aircraft rather than a shift to daytime flight movements.

Impact mechanisms

Whereas night flight restrictions primarily affect fleet mix during the night, night flight bans affect the number of flight movements. Direct reactions on the part of airlines and airport operators can lead to the shifting of flight movements to the shoulder hours.

Table 13: Direct impact of a ban on or restriction of night flights

Direct impact	**Sound emissions of aircraft (technical)**	**Sound-proofed windows and sound-insulated**	**building bans and resettlement**	**Approach and departure procedures**	**Fleet mix**	**Number of movements**
Day					(x)	(x)
Night					X	x

Note: x: Main impact; (x): additional effects

With the introduction of a ban on night flights with existing night flight movements the reactions are as follows:

- Shifting of movements to the shoulder hours,
- Displacement to other airports,
- Annulment of a particular flight.

So long as the ban on night flights is not imposed nationwide, it is assumed that cargo flights and low-cost charter flights switch to other airports. In this respect, intercontinental flights are less flexible due to hub systematics. Since restrictions on flight scheduling in Asia are less stringent, it appears likely that takeoffs and landings of such flights are shifted to the shoulder hours. The annulment of flight connections due solely to a night flight restriction is less plausible, as long as displacement options exist.

In the case of night flight restrictions the following reactions exist:

- Renewal of the fleet,
- Shifting to the shoulder hours,

- displacement to airports that have no night flight restrictions.

The possibility of displacement of flights to airports without night flight restrictions is conceivable if the night flight restriction is not introduced nationwide. Should this option not exist, the question arises as to the proportion of affected flights that are shifted to the daytime period, and to the proportion of flights of airlines that prefer renewal of the aircraft fleet. In the process, airlines would weigh up the additional costs of shifting to the daytime movements compared to the cost of fleet renewal.

Modelling assumptions

In modelling, a distinction is made between cargo and passenger flights. The following assumptions are made:

Night flight bans:

- All cargo flights are switched to other airports. Unfortunately, differentiation of flight movements in the years 2017 or 2020 according to cargo and passenger flights is not available. It is assumed that the share of cargo flights in all flights in 2017 and 2020 corresponds to that in the year 2010.[22] In the base scenario, 50 % of all cargo flights take place at night.
- All short- and medium-haul passenger flights are shifted equally to daytime and evening hours; that is, 75% to daytime hours (6 a.m. to 6 p.m.) and 25% to evening hours (6 p.m. to 10 p.m.).
- 80 % of long-haul passenger flights are switched to daytime (75%) and evening (25%) hours, and 20% to airports with less stringent night flight conditions.

Night-flight restrictions:

- All cargo flights are conducted with quieter aircraft (short- and medium-haul flights: noise categories 1 and 2; long-haul flights: noise category 5[23]). It is assumed that the share of cargo flights in all flights in 2017 and 2020 corresponds to that in the year 2010. In the base scenario, 50 % of all cargo flights take place at night.
- One third of long-haul, continental passenger flights with aircraft of noise categories 6 to 12 are switched to the daytime and evening hours, and of this third, 75% are conducted during the day (6 a.m. to 6 p.m.) and 25% in the evening. 10% switch to other airports, and with the remaining 57% the fleet is optimized.[24]
- 50% of continental passenger flights that are conducted with aircraft of noise category 2 are switched to daytime (75%) and evening (25%) hours and 40% are conducted with aircraft of noise category 2.

[22] According to EuroStat, the share of cargo flights in 2010 at the airport with a large volume of freight and night-flight operations amounted to 19%, at the medium-sized airport 2% and at the regional airport 4% [EUROSTAT (2012)].

[23] See Fraport (2011) for a definition of noise categories.

[24] In modelling the increase of noise charges (see Section 4.5) it is assumed that 50% of airlines optimize their aircraft fleets. With this measure, the costs of fleet renewal have to be compared with higher noise charges. With a restriction on night flights, the costs of fleet renewal have to be compared with the costs of altering flight schedules. It is assumed that the alteration of flight schedules represents a greater challenge that the payment of higher noise charges.

With the remaining 10% it is assumed that due to very high price sensitivity of this passenger segment they no longer take place or are displaced to other airports.

- Unplanned flight movements are not considered due to their irregularity.

4.3.2 Legal framework

There is no legal regulation on the required introduction of bans or restrictions on night flights. There is also no specification concerning the period of time for which night time is to be applied. Nevertheless, night-flight regulations are among the usual instruments of noise abatement, and due to their far-reaching consequences for all parties they regularly give rise to litigation proceedings.[25]

Case law of the Federal Administrative Court is based on the assumption of a night-time core period (the period between midnight and 5 a.m.) and night-time shoulder hours, which are to be applied between 10 p.m. and midnight as well as between 5 a.m. and 6 a.m. As justification for air traffic in the night-time core period the court demanded proof of a "site-specific night-flight need". In the case of night-time shoulder hours, the Court demanded explicitly that "plausible evidence" o be submitted as to "why a particular traffic demand or a particular traffic segment cannot be satisfactorily processed during daytime hours".[26]

According to the current legal situation, restrictions or bans on night flights are always the result of a decision in an individual case. Within the scope of planning approval and authorization to operate an airport, protection against unacceptable noise as well as particular regard for peace at night represent a legislative order (cf. Article 29b Air Traffic Act). The authority responsible for planning approval and authorization of airport operation under air traffic law decides, by virtue of its discretionary planning powers, on the choice of available noise abatement measures based on the results of the planning trade-off process. Article 8 (2) of the Air Traffic Act requires that in planning approval proceedings public and private interests affected by the respective project, including environmental compatibility, be considered within the scope of a weighing-up process. In so doing, Article 8 (1) Air Traffic Act requires that "for the protection of the general public and the neighbourhood against adverse environmental effects from aircraft noise, the applicable limit values of Article 2 (2) of the Act on Protection against Aircraft Noise are to be complied with". Which noise abatement measures have to be taken must be stipulated in official notification of planning permission. There is no legally regulated order of priority governing active and passive noise abatement, which would require that measures at the source of emission be first implemented.

Those exposed to noise have a subjective right under public law to fair and equitable consideration of their interests. This entitlement covers also the right to protection against aircraft noise at night. Protection against unacceptable noise, and particular consideration of peace at night for the general public, is a legislative order pursuant to Article 29b Air Traffic Act, which cannot be disregarded by the planning approval authority. Behind the protection order is ultimately the obligation of the state to protect and promote elementary, legally-protected rights (such as "life" and "health" in terms of Article 2 (2) of German Basic Law) and, in

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[25] See, for example Decisions of the Federal Administrative Court: BVerwGE 131, p. 316 –Halle/ Leipzig Airport; BVerwG Decision of 12.04.2012 – Frankfurt Airport

[26] Decisions of the Federal Administrative Court: BVerwGE 131, p. 316, 326 (margin no. 39).

particular, to protect such rights against illegal intervention by third parties.[27] The Federal Administrative Court has conferred the quality of a specification on the order to consider concerning weighing up of the interests of inhabitants exposed to aircraft noise.[28] The Federal Administrative Court laid down further that it cannot be inferred from this that Article 29b (1) of the Air Traffic Act could lead to general prohibition of night-time flight movements.

New regulation of existing night-flight options at an airport is basically possible by way of modification of authorisation for airport operation under air traffic law.[29] The issuance of conditions for night-flight operations at an authorized airport can be achieved by way of partial revocation of authorization under air traffic law pursuant to Article 6 (2) Air Traffic Act and Article 3 of Air Traffic Licensing Regulations. Such revocation requires, in the judgement of the highest administrative court, health-threatening noise exposure on the part of inhabitants.[30]

A general ban on night flights (or night flight restrictions) at all German airports would be an innovation compared to the current legal situation. Under air traffic law, night-flight regulations are ordered at the executive level (the respective state authority) on a case-by-case basis, and since the situation of every single airport has to be considered and assessed individually, the regulations laid down can vary. A general abstract night flight ban would have to be anchored in law; whereby exceptions have to be permitted, in particular, when the protection of the public does not necessitate a night-flight ban. Otherwise, such a ban would be disproportional. In the case of a ban, two constitutional rights stand face to face: The right of freedom of those who allowedly offer air transport services and those who travel by means of air transport confronts the right of inhabitants in the vicinity of airports to be protected against the effects of air traffic noise on their body, health and property. The rights of air transport users and air transport providers are safeguarded under constitutional law to the same extent as the rights of local residents. The protection of life and health pursuant to Article 2 (2) of German Basic Law can and must have particular importance, but it does not permit the disregarding of other constitutional rights. With a statutory night-flight ban applicable at all airports, the decision would be shifted from the executive to the legislative level.

4.3.3 Assessment

The night flight restriction and night flight ban measures are assessed as follows:

Table 14: Overall assessment of the measure 'Prohibition or restriction of night flights'

Measure	Depth of intervention	Administrative cost
Night flight restriction	mid-range	mid-range
Night flight ban	high	Low

[27] Decisions of the Federal Constitutional Court: BVerfGE 56, p. 54, 73 with further references.

[28] Giemulla (2011) in Giemulla/ Schmid, LuftVG Kommentar, Art. 29b margin no.2, with further references.

[29] In April 2012 the Government of the State of North Rhine-Westphalia presented a ban on passenger flights between midnight and 5 a.m. at Cologne/Bonn Airport, whose legal admissibility is disputed; http://regionales.t-online.de/landesregierung-will-nachtfluege-in-koeln-bonn-teilweise-verbieten/id_55690698/index.

[30] Cf. Decision of the Federal Administrative Court, BVerwG of 20.04.2005 - 4 C 18.03 -, NVwZ 2005, 933 ff.

The depth of intervention of a night-flight ban is high, since flight movements in a particular time window at an airport are banned completely. A night-flight ban can, in particular, impair the function of an airport as freight hub or as a hub for intercontinental passenger transport of one or more airlines. The depth of intervention of a night-flight restriction, on the other hand, is less drastic and is estimated to be mid-range. Night flights are still permitted, but not with all types of aircraft.

A ban on night flights is relatively easy to implement from the administrative point of view. Following issuance of a night-flight ban there is hardly any further administrative expense. With a restriction on night flights, on the other hand, it has to be verified that only those aircraft take off and land that are licensed for night flights. The administrative costs is estimated to be 'low-range'.

4.4 Noise-reducing approach procedures and flight route optimization

4.4.1 Approach procedures

Approach and departure procedures define the flight route, the propulsion and the configuration of the aircraft during the landing and takeoff phase. Through the choice of appropriate procedures, noise on the ground can be noticeably reduced. In particular, lateral guidance of the ground track over sparsely populated areas, higher flight height/altitude over built-up areas as well as lower thrust, delayed landing gear extension and further configuration adjustments reduce noise level on the ground.

There are also low-noise departure procedures (Neise, 2009) – for example, MODATA-FLEX (modified air transport association procedure with adapted (reduced) takeoff thrust) and MODATA-TOGA (maximum takeoff thrust) – which differ regarding the timing of changes in thrust and flap deflection settings. Noise-reducing departure procedures have not been investigated in this study.

With approach procedures a distinction can be made between procedures with intermediate approach segment (for example, low drag low power: LDLP) and without intermediate approach segment (for example, continuous descent approach: CDA). To that end there are then sub-variants, which are characterized in Figures 3 to 5. These are taken from DLR (2007) and show height/altitude profiles of the approach of an A 320.

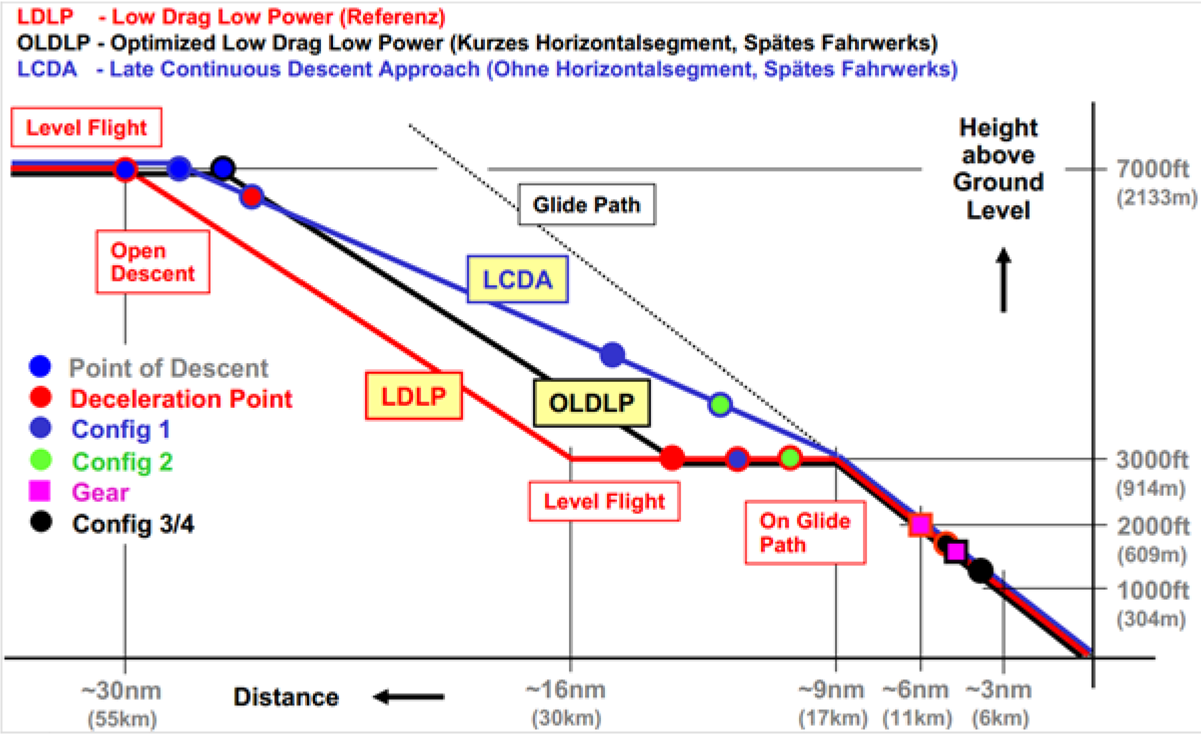

Figure 3: Height/altitude profile of different approach procedures, Part I. Source: DLR (2007)

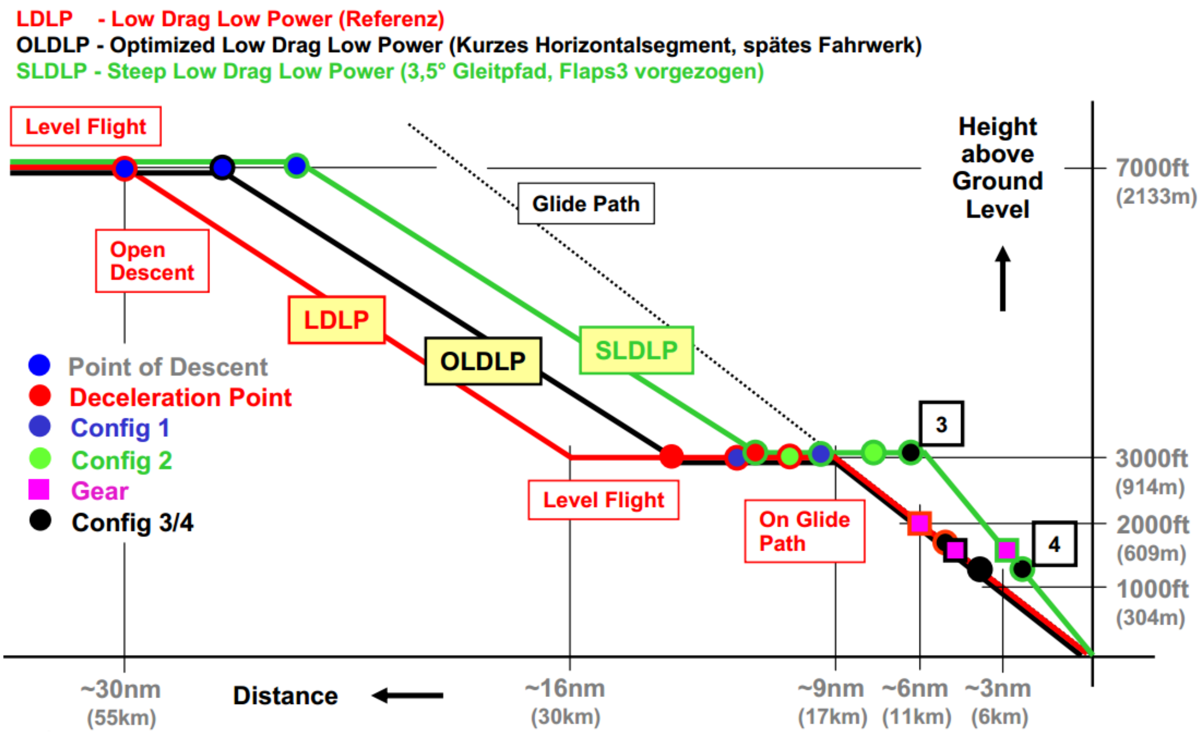

Figure 4: Height/altitude profile of different approach procedures, Part II. Source: DLR (2007)

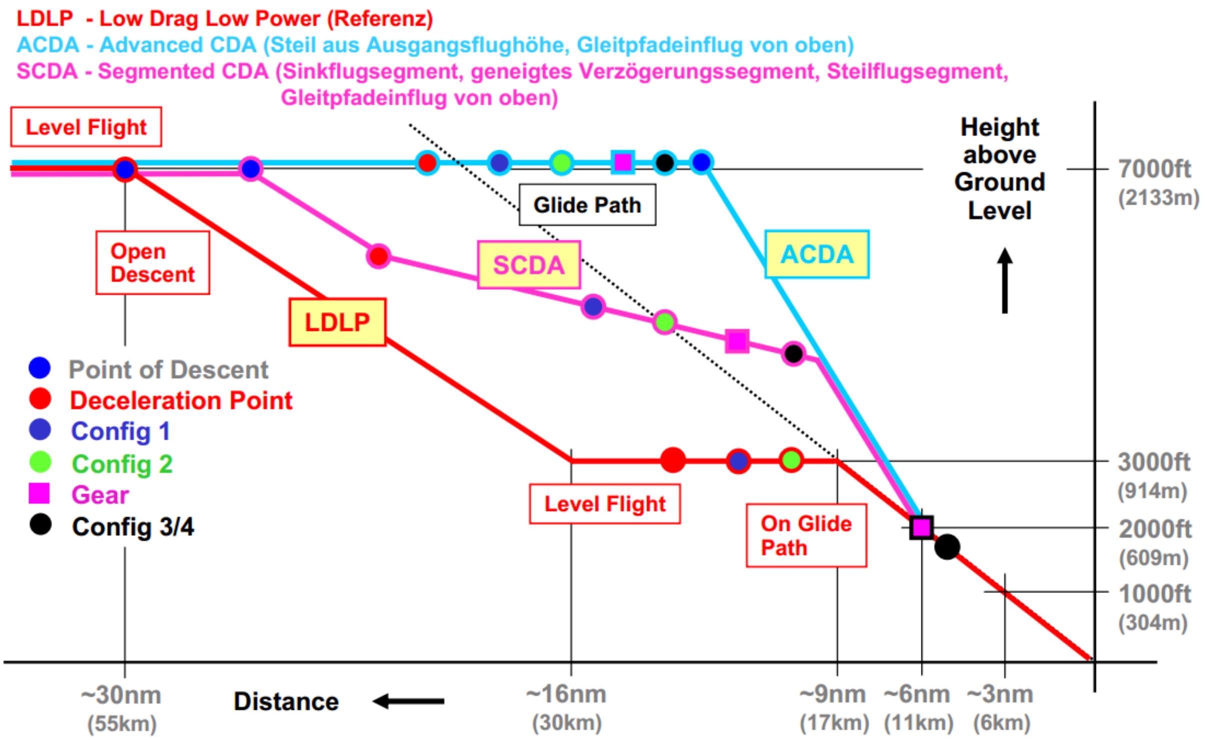

Figure 5: Height/altitude profile of different approach procedures, Part III. Source: DLR (2007)

The displayed approach profiles were employed in the INM sound propagation model and, in each case, an approach at an airport with an Airbus A 320 simulated. The resulting noise contours are displayed in Figure 6.

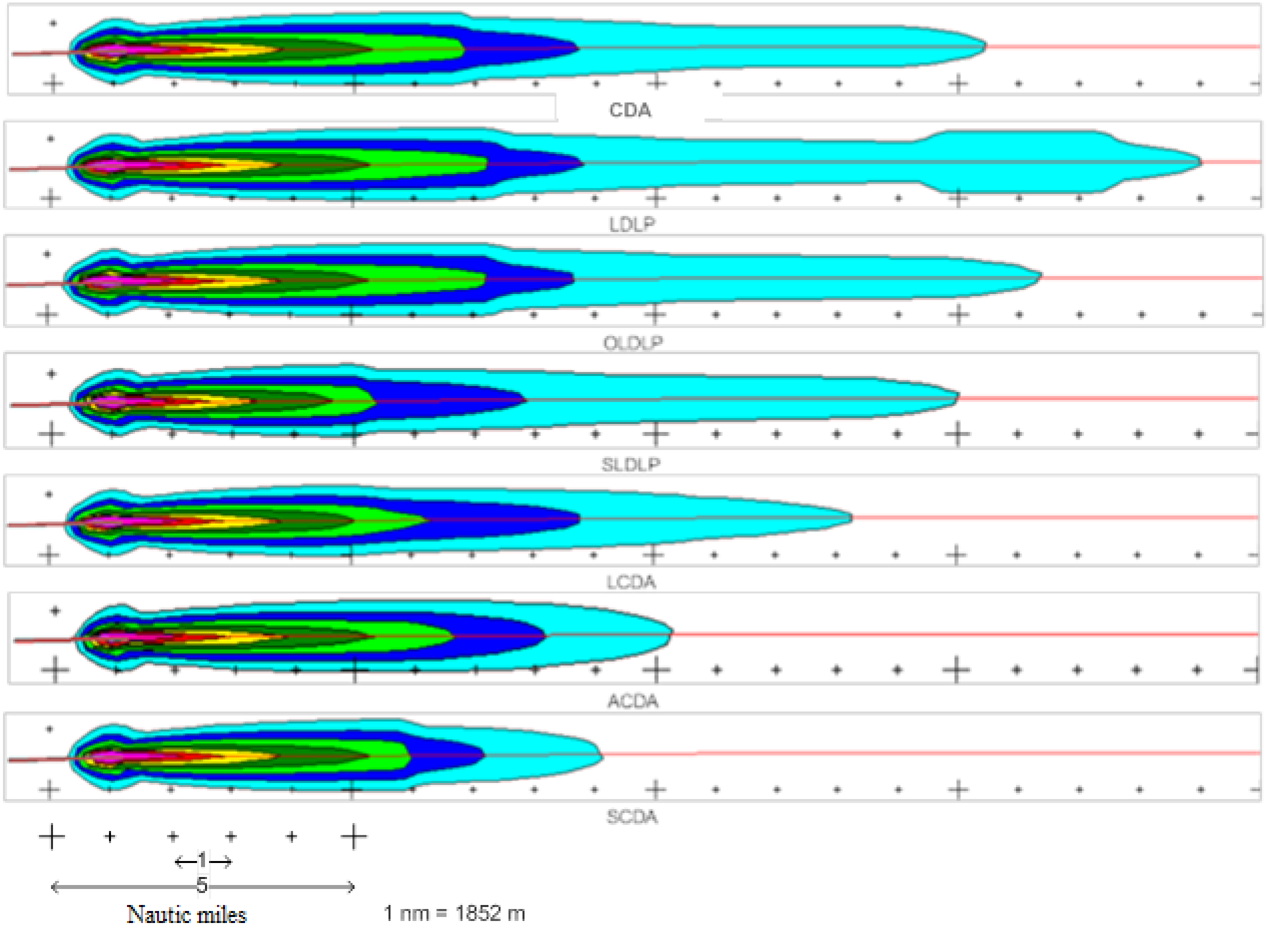

Figure 6: Noise profiles for different approach procedures for the Airbus A 320

To begin with, one notices that the noise contours hardly differ during the last few kilometres before the runway. This is because the approach route using different approach procedures is more or less the same. An exception is the steep low drag low power procedure (SLDLP), which provides for a steeper approach. Even here, however, the closer the aircraft to the runway, the smaller the difference becomes. Larger differences arise at greater distances to the runway. A change in approach procedure thus contributes, above all, to a reduction in noise level at a certain distance to the airport.

For this reason, the measure is more appropriate for reduction of the number of persons that are highly annoyed by aircraft noise, than for the reduction of the maximum permanent sound level in residential areas in the immediate vicinity of the runway. As Figure 6 shows, the segmented continuous descent approach (SCDA) is best suited for reduction of noise levels at mid-range noise levels. Flight height is first reduced during descent with constant speed and idle thrust. There follows a segment with lower bank angle for reduction of speed. In this deceleration phase the aircraft is fully configured for landing and then enters the vertical flight segment. At a height of about 2,000 ft. the aircraft descends to glide path and rapidly stabilizes, since landing gear and flaps are already fully extended.

In current operational practice, CDA procedures – including SCDA – are carried out, following clearance by approach control, at the discretion of pilots. This results in great fluctuation of arrival times, so that landing intervals have to be extended by around two minutes. For this reason, CDA procedures have up to now only been employed with low traffic volume. Moreover, due to the difficulty of calculating the appropriate point of descent (POD), CDAs are generally not flown with idle thrust.

In order to be able to apply CDA procedures also with high traffic volume, enhanced approach planning systems are required on the ground and 4D flight management systems (FMS) on board the aircraft. Through ground-side specification of arrival times and more precise 4D flight path guidance, adverse effects on capacity could be reduced [Neise (2007)]. As a result, deviations of routes actually flown from intended routes could be reduced.

Since CDA procedures require upgrading, at least with dense air track, introduction of the optimized low drag low power (OLDLP) procedure is recommended, initially in dense air traffic, as an applicable intermediate and short-term measure without upgrading. Compared with the point of descent (POD) with LDLP procedures, the POD with OLDLP is shifted as far as possible in the direction of the airport. This way, the necessary intermediate thrust in the horizontal flight segment is dispensed with, and the horizontal flight segment can be shortened (see Figure 3). In addition, the landing gear can be extended on the 3°glide path at a lower height and, as a result, the aircraft stabilized at a later point, and engine thrust only has to be adjusted later. At the same time, prevailing safety regulations may not of course be infringed. The OLDLP procedure is technically relative easy to apply, yet achieves only a moderate noise level reduction. Thus, as a more effective second procedure, SCDA is selected, which, as shown in Figure 6, has the greatest effect beyond 10 kilometres around the airport.

Impact mechanisms

Table 15: Areas of direct impact of the measure 'Approach procedures'

Direct impact	**Sound emissions of aircraft (technical)**	**Sound-proofed windows and sound-insulated**	**building bans and resettlement**	**Approach and departure procedures**	**Fleet mix**	**Number of movements**
Day				x		
Night				x		

Note: x: main impact; (x): additional effects

Modelling assumptions

Through evaluation of radar tracks it was established that at the airports under investigation the LDLP procedure is predominantly used. LDLP is therefore applied as standard procedure in the base scenario. As noise-reducing measure, however, LDLP is replaced by OLDLP. In a further step, the SCDA procedure is introduced. Small propeller-driven aircraft are excluded.

4.4.2 Route optimisation

Objective and modality of the measure

With route optimization it is a matter of setting flight routes in such a way that they lie as far as possible over sparsely-populated areas. With landings, the measure can obviously have no effect in the immediate vicinity of the airport, since during the final kilometres of an approach the aircraft has to reach the runway on a straight path, and the noise level under approach routes in the direct vicinity of the airport is not reduced. The desired effect, particularly on noise exposure, is achieved, above all, in more distant residential areas as well as in areas within the impact range of departure routes at a distance of just a few kilometres from the runway.

Impact mechanisms

In route planning, care is already taken to ensure that sparsely-populated areas are overflown. Optimization is therefore in many cases possible only because indirect routes are accepted that increase both fuel consumption and flight time. Moreover, deviations from prescribed optimum routes could be reduced.

Route optimization can have the result that many persons suffer less noise exposure, while the few persons living below new flight paths will suffer considerably higher noise exposure. Through calculation of DALYs or the costs of adverse effects with the methods described in Section 3.3, the advantages and disadvantages can be weighed up and the superior alternative selected. Analysis of the effectivity of the measures for the airport under consideration would have involved considerable cost, and the conclusions would have been distinctly airport-specific; for these reasons the effectivity of the measure was not analysed within the framework of this study.

4.4.3 Legal framework

Approach procedures

The noise caused by operation of an aircraft may not be higher than proper airmanship inevitably demands (see Article 1 Air Traffic Act). This provision emphasizes the obligation arising from Article 29b (1) Air Traffic Act, according to which all airport operators, aircraft owners and pilots are obliged to prevent avoidable noise in the operation of aircraft in the air and on the ground, and to restrict the propagation of unavoidable noise to a minimum when this is necessary to protect the population against dangers, substantial detriments and considerable annoyance from noise. Infringement of Article 29b (1) Air Traffic Act on the part of pilots (and only by them) is punishable as an administrative offence (cf. Article 1 (2) in connection with Article 43 (1) No. 2 Air Traffic Act).

The Federal Administrative Court commented as follows on Article 1 (2) Air Traffic Act: "From this it already follows that with flight operations, also at airports, all possibilities of reducing engine noise must be exhausted. In accordance with Article 21 (1) of the Aircraft Traffic Act, appropriate regulations must be laid down by air traffic control for the conduct of airport traffic. Traffic on taxiways and manoeuvring areas is thus beyond the control of the planning approval authority."[31] Determination of flight procedures, including flight tracks, flight height / altitude and recording points is therefore not a matter for the planning approval authority, but takes place pursuant to Article 27a (2) Air Traffic Act by way of regulation through the

[31] See Decisions of the Federal Administrative Court: BVerwGE 87, p 332, margin no. 43.

Federal Supervisory Office for Air Traffic Control (*BAF*). The prescribing of approach procedures therefore becomes legally binding by way of statutory ordinance.

Air traffic control services and airspace control are assigned to German Air Traffic Control (*DFS*) within the scope of wide-ranging assignment of duties and obligations pursuant to Article 27c (2) Air Traffic Act. DFS assumes responsibility for obligations of the State in respect of air traffic control, for the fulfilment of which the DFS is obliged, pursuant to Article 29b (2) Air Traffic Act, to work towards protection of the population against unacceptable aircraft noise. There are different flight procedures for aircraft approach to an airport, such as continuous descent approach (CDA), which is regarded as a relatively low-noise procedure. At Cologne/Bonn Airport, for example, the CDA approach procedure has been obligatory since the beginning of 2009 for approaches between 10 p.m. and 6 a.m.,[32] following the coming into force of a similar regulation at Frankfurt Airport.

Ultimately, the pilot is responsible for the approach procedure, and he has to ensure within the scope of active noise protection that the noise caused by operation of an aircraft is not greater than that unavoidably necessitated by proper airmanship (cf. Article 1 (2) Air Traffic Act).

The ensuring of compliance with flight routes laid down by statutory ordinance is carried out following notification of the part of DFS by air traffic controllers via radar monitoring. Complaints or queries concerning supposed variations are checked by means of flight track recordings in the area surrounding an airport ("flight track and aircraft noise monitoring system" – FANOMOS).[33] The guaranteeing of safety and order in air traffic, pursuant to Article 1 (1) Air Traffic Act, can necessitate deviation from the regulatory specification.[34]

Low traffic volume favours application of the CDA procedure. Instructions issued under labour law can also give rise to application of noise-reducing flight procedures. For instance, air traffic controllers of approach and departure control at Munich Airport were required by an internal DFS regulation regarding individual clearance of approaching aircraft to assign the highest possible heights/altitudes in the extended vicinity of the airport between 10 p.m. and 6 a.m.[35]

Airlines can also contribute towards application of CDA by way of internal instruction. Application of low-noise approach procedures cannot be ensured merely through the issuance of a corresponding statutory regulation; it requires the awareness and the will of all involved with approach procedures.

Route optimisation

Flight routes are not laid down with the planning approval decision. Determination of flight routes takes places by way of statutory instrument issued by the Federal Supervisory Office for Air Traffic Control

[32] Cf. Airliners.de (2009) Press release of 11.02.2009: http://www.airliners.de/verkehr/netzwerkplanung/koeln-bonn-fuehrt-cda-anflugverfahren-ein/17372.

[33] Bremische Bürgerschaft (Bremen Parliament) (2008), Doc. No. 17/304 of 04.03.2008, p. 6, cf. http://www.gruene-fraktion-bremen.de/cms/default/dokbin/222/222827.antw_grosse_anfrage_laermentwicklung_und.pdf.

[34] Individual clearance may not be the rule, and it may not let routes and flight procedures laid down by statutory ordinance become meaningless; cf. Pache (2012), p. 7 ff. with further references.

[35] Cf. Doc. 16/8269 of the Bavarian State Parliament of 13.05.2011.

(BAF) (cf. Article 32 (4) No. 8 and (4c) Air Traffic Act in connection with Article 27a (2) of Air Traffic Regulations).[36] Technical planning for determination of flight routes is carried out by DFS, on whose preliminary work the BAF relies in issuing the statutory instrument. Here, the Aircraft Noise Commission plays an advisory role pursuant to Article 32b Air Traffic Act. The Federal Environment Agency is also involved in the process, since Article 32 (4c) Air Traffic Act requires that the statutory instrument be issued in consultation with the Federal Environment Agency. Following issuance, the statutory instrument has to be published in the Federal Gazette (*Bundesanzeige*) as well as in Notices to Airmen (*Nachrichten für Luftfahrer*).

As the law stands, determination of routes takes place independent of the planning approval decision, which is based, as far as routes are concerned, on a DSF forecast. "This forecast represents a source of knowledge for the process of planning and determination of flight procedures. It has, however, no binding force."[37]

Ideally, approach and departure routes are chosen in such a way that the aircraft's flight track lies for as long as possible over sparsely-populated or uninhabited areas. The determination of routes by way of ordinance is an expression of public planning. At the same time, air traffic safety is always of primary importance (Article 27c (1) Air Traffic Act. This does not mean, however, that the regulator may be guided solely by safety aspects. As the Federal Administrative Court pointed out: "The lawmaker gives expression to the fact that [...] in the determination of flight procedures a decision is to be made on the basis of a weighing-up process, in the course of which other concerns have also to be taken into account."[38] The aviation authorities and the air traffic control body, in particular, have to work towards protection of the population against unacceptable aircraft noise (Article 29b (2) Air Traffic Act). Issues of noise protection therefore necessarily influence the weighing-up process. Besides the criterion on noise avoidance, the criteria of ordered and fluid handling of air traffic as well as the avoidance of unnecessary CO_2 emissions are basically on an equal footing. The specific evaluation of interests has to be undertaken on an individual basis in the trade-off process.[39]

It could be considered whether better integration of noise protection issues and necessary analytic expertise is possible in the process for determination of flight routes. Conceivable, for example, is earlier and stronger[40] participation of the Federal Environment Agency and support of the Aircraft Noise Commission in the form of experts. Enhanced networking of municipal noise action planning (cf. Article 47d of the Federal Immission Control Act (BImSchG) that is based on the EU Environmental Noise Directive) with flight route planning is also conceivable.

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[36] The Act does not contain the term 'flight route', but instead 'flight procedures'. 'Flight route' is generally accepted, however, as a common term encompassing all determined flight procedures, flight height/altitude and recording points (cf. Pache (2012), p. 5 with further references.

[37] *Bundestag* Doc. 17/4781 of 15.02.2011, p. 3.

[38] Decisions of the Federal Administrative Court: BVerwGE, decision of 24.06.2004, NVwZ 2004, p. 1229, 1231.

[39] *Bundestag Doc.* 17/4781 of 15.02.2011, p. 4.

[40] Instead of mere consultation – as the Act requires – one could conceive of "agreement"; cf. Pache, p. 40ff.

4.4.4 Assessment

The measure 'Approach procedures' is assessed as follows:

Table 16: Assessment of the measure 'Approach procedures'

Measure	Depth of intervention	Administrative cost
Approach procedures	low (LP), mid-range (SCDA)	Low

Modified approach procedures are technical measures that do not intervene in the market mechanism. In order to implement the SCDA procedure, however, technical upgrading is necessary.

New approach procedures only entail administrative costs on their introduction. Subsequently, no such costs arise.

The measure 'Route optimization' is assessed as follows:

Table 17: Assessment of the measure 'Route optimization'

Measure	Depth of intervention	Administrative cost
Route optimization	Low	Low

Route optimisation is a technical measure that does not intervene in the market mechanism. It can, however, lead to distribution effects. This means that not only can noise reductions arise, but also higher noise exposure at other places. If built-up areas are more greatly affected by noise than previously, route optimization is difficult to enforce. Once introduced, however, no further administrative costs arise.

4.5 Noise charges

4.5.1 Description

Objectives and modality of the measure

Noise-related airport charges have the objective of influencing the fleet mix at an airport in such a way that quieter and less noisy aircraft take off and land. Depending on the design of noise-related airport charges, they can even wholly displace the loudest aircraft. In this case, noise charges have a similar effect to a ban on individual noise categories.

In Germany, all large airports have already introduced noise-related charges. Different approaches are applied. On the one hand, there are airports that levy charges on the basis of certificated noise levels of aircraft types. Most of the German airports that apply this variant refer to the "Bonus List" of the German Ministry of Transport. Other airports, such as Frankfurt/Main for example, differentiate their noise charges according to locally-measured noise exposure. Noise charges are levied in Germany on the basis of private law within the framework of airport charges. It could also be examined whether fiscal means such as taxes, special levies and fees are an option [Öko-Institut/DIW (2004)].

Impact mechanisms

Noise charges have basically two effects:

- Change of fleet mix towards quieter aircraft.
- Adjustment of demand through increased air fares.

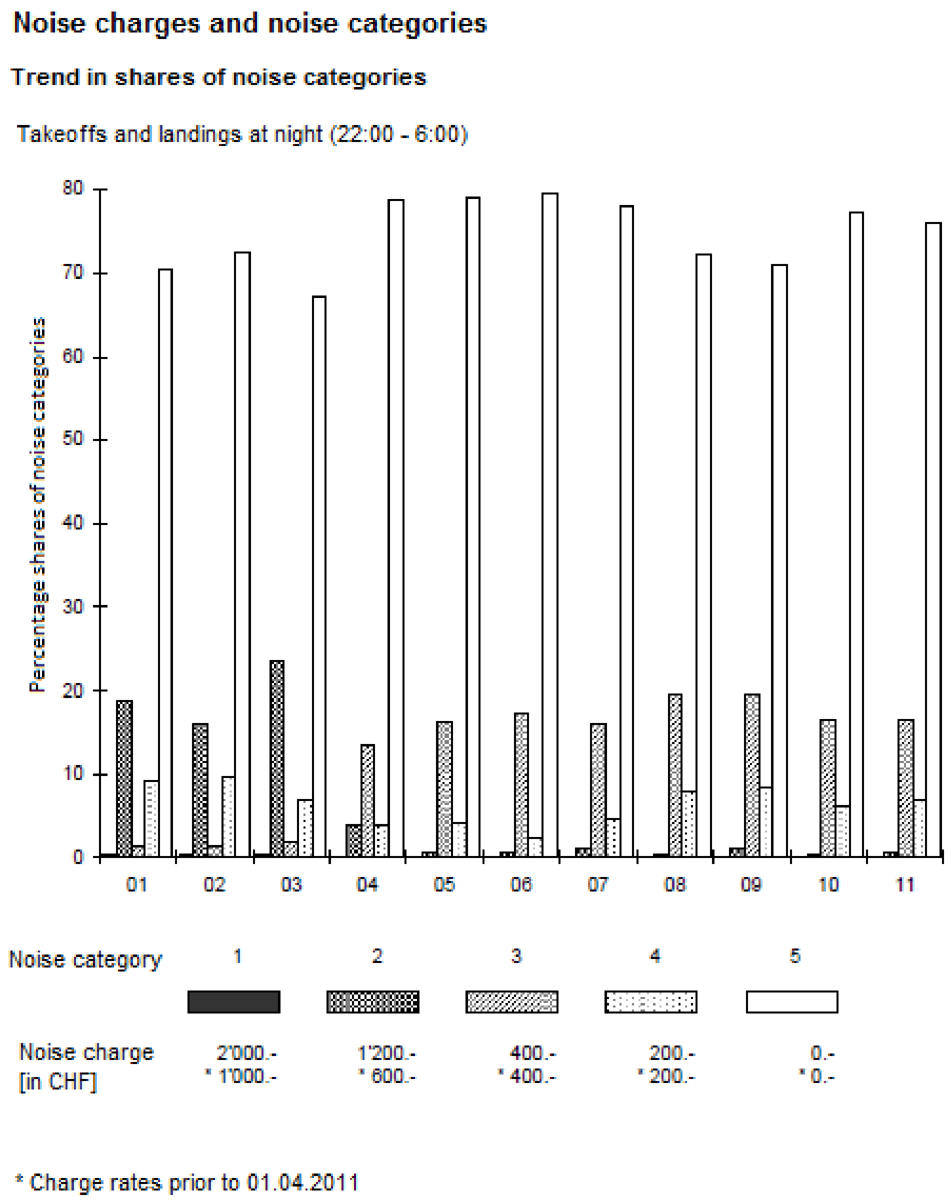
Table 18: Direct areas of impact of the measure 'Noise charges'

Direct impact	**Sound emissions of aircraft (technical)**	**Sound-proofed windows and sound-insulated**	**building bans and resettlement**	**Approach and departure procedures**	**Fleet mix**	**Number of movements**
Day					X	x
Night					X	x

Note: x: Main impact; (x): additional effects

Change in fleet mix

Zürich Airport has levied noise-related airport charges for some considerable time. Since it updated assignment of aircraft types to noise categories for the last time in 2000, it can be observed how the fleet mix has changed over a ten-year period (2001 to 2011) with given charges structure. Figure 7 shows the shares of noise categories from 2001 to 2011. In the year 2001, Noise Categories 1 and 2 accounted for about 20% of all flight movements. By the year 2011, aircraft of these categories were replaced almost completely by quieter aircraft. The share of Noise Category 3increased in the period up to 2009. This can be attributed to the fact that long-haul aircraft are not represented in higher noise categories and that long-haul aircraft of noise Category 2 were therefore replaced by Category 3 aircraft.



Source: Zürich Airport (2012)

Figure 7: Change in fleet mix at Zürich Airport in the period from 2000 to 2010

Note: Noise Category 1 is the loudest, Noise Category 5 the quietest noise category.

It remains to be said, that on the basis of empirical research at Zürich Airport it cannot be distinguished between the effect derived from noise charges and the effect of technological progress that would have taken place independent of noise charges. Öko-Institut points out that rapid adaptation tends to indicate technological progress, such as extensive restructuring by the most important airlines located at the airport, rather than the strong steering effect of noise charges [Öko-Institut (2004)]. It has to be considered, however, that nowadays airlines more and more frequently lease aircraft, which enables quicker reaction. Moreover, large airlines have the opportunity to react in the short term to varied charges systems at different airports by switching the operational base of the fleet. An increase in noise charges at one airport can have the effect that the quietest aircraft of the fleet are deployed at this airport. In order to achieve a strong steering effect, it is nevertheless of key importance that noise charges increase exponentially with noise level. Furthermore, charges for loud aircraft must be markedly raised, compared to the present level, and be at such a high level that the noise costs of loud aircraft account for a significant share of the costs of operators. The classification of aircraft types should relate to noise categories at Frankfurt Airport, since these more strongly differentiate the present fleet mix. The following table shows the present mix of fleets depending on noise categories at the three airports under consideration. The noise charge presently payable at Zürich Airport is also stated. This can be regarded as point of reference for the lower limit for effective noise charges.

Table 19: Noise charges payable in Zürich, and fleet mix by noise category at the three exemplary airports

Frankfurt noise category	**Noise charge in euros (adjusted) in Zürich**	**Share of flight movements for each noise category per airport**		
		Aircraft with a large volume of freight and night-flight operations	Medium-sized airport	Regional airport
8 and higher	833	2.9%	1.4%	0.0%
6 and 7	500	5.3%	0.9%	0.0%
4 and 5	333	9.0%	4.6%	4.5%
2 and 3	167	61.3%	52.8%	50.6%
1	0	21.9%	41.3%	35.3%

Example for reading the above table: The share of movements with aircraft of Frankfurt Noise Category 1, for which a noise charge of zero euros applies in Zürich, amounts at the airport with a large volume of freight and night-flight operations to 21.9%, at the medium-sized airport to 41.3% and at the regional airport to 35.3%.

Change in demand

Due to noise charges and associated higher costs for airlines, ticket prices could increase, and this could lead to a decline in demand. In order to be able to estimate the change in demand the following data is required: a) the price elasticity of demand, b) average ticket prices and c) the price increase.

In a market economy, airlines are willing to pay noise charges so long as exchange of aircraft is more expensive than noise charges. When an airline exchanges aircraft, it can be assumed that this is less expensive for the airline than noise charges. It must be considered, however, that fleet exchange also gives rise to costs.

When the costs for airlines are known, the question arises as to the share of costs that is passed on to passengers. Studies show that 90% of costs could be passed on [cf. INFRAS (2009)].

The price elasticity of demand differs according to customer segment. Private travellers have greater price elasticity than business travellers. Moreover, price elasticity with short-haul flights is greater than with long-haul flights. Table 20 shows price elasticity and average ticket prices according to purpose of journey and flight distance. This data is used subsequently to estimate the effect of noise charges and prohibitions.

Table 20: Price elasticity of demand and ticket prices according to purpose of journey and flight distance

Purpose of journey	**Flights within Europe (about 80% of flights)**		**Intercontinental flights (about 20% of flights)**	
	Elasticity	Ticket price		Elasticity
Leisure (about 70% of passengers)	-1.5	180 EUR	-1.0	500 EUR
Business (about 30% of passengers)	-0.9	450 EUR	-0.2	1200 EUR

Source: Umweltbundesamt (UBA) (2008b) und INFRAS (2009)

The studies under consideration contain no data on the price elasticity of air freight. It is assumed that air freight has about the same price elasticity as business travel. This could be a maximum value, however, since business travellers have more opportunities to avoid flights (e-mail, telephone conferences etc.).

In order to roughly estimate price increases, we apply the noise charges displayed in Table 19 under the assumption that the fleet mix remains unchanged. As a result, average price increases per average flight movement in the base scenario are as follows:

- 191 EUR per flight for the airport with a large volume of freight and night-flight operations,
- 123 EUR per flight for the medium-sized airport and
- 103 EUR per flight for the regional airport.

A flight within Europe carries an average of 150 passengers, while an intercontinental flight carries 300 passengers [UBA (2008b)]. Were the costs to be wholly passed on to flights in Europe, ticket prices would increase by 0.67 EUR to 1.27 EUR. Ticket prices for intercontinental flights would increase by 0.33 EUR to 0.63 EUR. On the maximum assumption that the price increase amounts to 190 EUR and 100% of the costs are passed on, demand for flights within Europe would fall by 0.8% and that for intercontinental flights by 0.04% (cf. Table 21). Were the minimum price increase of 100 EUR to be considered, demand for intercontinental flights would decline by a mere 0.4%, and that for intercontinental flights by 0.02%.

Table 21: Demand response under maximum assumptions

Purpose of journey	**Flights within Europe (about 80% of flights)**			**Intercontinental flights (about 20% of flights)**		
	Elasticity	Increase in ticket prices	Demand	Elasticity	Increase in ticket prices	Demand
Leisure (about 70% of passengers)	-1.5	1.27 /180 = 0.7%	-1.05%	-1.0	0.63 / 500 = 0.13%	-0.13%
Business (about 30% of passengers)	-0.9	1.27 / 450 = 0.3%	-0.27%	-0.2	0.63 / 1200 = 0.05%	-0.01%
Total			-0.79%			-0.04%

The calculation shows that demand response with noise charges at the level of noise charges of Zürich Airport is not an effective lever to reduce noise. This applies all the more, when it is considered that the decline is not necessarily accompanied by a corresponding reaction in flight movements. The effect of an increase in noise charges arises, above all, through a change in fleet mix.

Modelling assumptions

In the modelling of measures it is assumed, on the basis of noise emissions measured at aircraft noise measuring points, that airport operators assign aircraft to noise categories in line with the structure at Frankfurt Airport [FRAPORT (2011)]. The level of charges is set in such a way that the following reactions occur:

- 30 % of aircraft of noise category 3 are replaced by aircraft of noise category 2.
- Short- and medium-haul aircraft of noise categories higher than 3 are replaced with aircraft of noise categories 2 and 3 (each to the extent of 50%).
- 50% of long-haul aircraft that are louder than noise category 5 are replaced with category 5 aircraft. Airlines prefer to pay higher noise charges for the remaining 50% due to higher transportation capacity.

Since the expected demand response is comparatively low, this effect is ignored in modelling.

4.5.2 Legal framework

Air traffic charges are levied for the use of all airports by their operators. The umbrella term 'air traffic charges' covers, in particular, passenger, safety, parking as well as takeoff and landing charges. Whereas the calculation of passenger and safety charges is passenger-dependent, takeoff and landing charges are levied for each takeoff and landing. The fees applied vary from airport to airport,[41] and the respective airlines are liable for costs.

Noise-related landing charges have been levied for many years at German airports, without there having been a specific legal basis for this purpose. From the legal point of view, the principle of individual autonomy applies. It is left to the airport operator to decide whether and in what amount noise charges are levied. At some airports there are special noise charges for the financing of noise abatement measures and corresponding programmes[42]; and here, too, individual charging systems differ with regard to reference values and the level of charges. As far as the regulation of charges is concerned, lawmakers have made charging systems (including noise protection and control components[43]) subject to authorization, to which the amendment of the Air Traffic Act of May 2012 adheres.[44]

With implementation in German law of Directive 2009/12/EC of the European Parliament and of the Council on airport charges of 11.03.2009[45] through amendment of the Air Traffic Act – the legislative procedure was concluded with the amending act of 08.05.2012[46] – uniformity of charging systems should be achieved. The directive does not run counter to environment-policy orientation of charges; however, it does not itself contain binding specifications on noise components in charging systems. With the new Article 19b Air Traffic Act, commercial airports have to prepare a charging system in which charges are differentiated according to aspects of noise abatement. Further specifications are not contained, however, in the amended Air Traffic Act. Insofar as certain target values with respect to the level of fees should be achieved, the Air Traffic Act would have to be 'readjusted' and detailed differentiation criteria laid down. A common charges policy on the part of airport operators is also conceivable, which could be established on the basis of voluntary agreement.

Noise charges can be legally justified, but they have to be motivated by environment policy and may not merely serve the purpose of additional revenue. The fact that noise charges are levied according to the principles of private law[47] does not exempt airport operators from legal provisions that restrict individual

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[41] For example, Cologne / Bonn: www.koeln-bonn-airport.de/uploads/tx_download/GESAMTE_MAPPE_KOMPLET_03.pdf (as at: 01.08.2010); Leipzig / Halle: www.leipzig-halle-airport.de/media/files/lej/unternehmen/lej_eo_aviation_01-01-2010_rev09_de.pdf (as at 01.01.2012).

[42] For an overview of airports and current charges visit www.fluglaerm.de/koeln/LrmEntgltVglch.pdf (as at: 02/2011).

[43] For example: On the 08.05.2012, the Ministry of Economic, Transport and Regional Development of the State of Hessen granted Fraport AG authorization to levy noise abatement charges. The noise abatement charges serve the purpose of refinancing the costs of passive noise abatement measures, to which Fraport AG is obliged with the coming into force of the Ordinance on Designation of the Noise Protection Zone for Frankfurt/Main Airport of 13.10.2011; cf. http://www.business-services.fraport.de/content/fraport_ag_business-services/de/Flughafenentgelte.html.

[44] Cf. 14th Act on Amendment of the Air Traffic Act of 08.05.2012, BGBl. I 2012, p. 1032, Art. 1 No. 11. cc) and Article 2 No. 2.

[45] OJ EC 2009 No. L 70 of 14.03.2009, p 11 ff.

[46] Cf. 14th Act on Amendment of the Air Traffic Act of 08.05.2012, BGBl. I 2012, p. 1032 ff..

[47] The legal relationships between airport operators and airlines are indisputably subject to private law, and are to be assessed according to civil law; cf. Decision of the Federal Court of Justice (BGH) of 18.10.2007 - III ZR 277/06, p. 7.

autonomy. European law, and in particular Directive 2002/30/EC on operating restrictions,[48] requires transparent charging systems that are applied without discrimination, since noise charges, too, can be ascribed to 'operating restrictions' in terms of Article 2e of the directive. Environment-related charges, which are levied for the explicit purpose of financing measures for the reduction of environmental effects in the vicinity of airports – for example, sound insulation – are also compatible with existing ICAO policies on charges (cf. ICAO "Policies on Charges for Airports and Air Navigation Services" and "Airport Economics Manual").

Existing charging systems have to be distinguished from the levying of taxes by the state. Insofar as the exchequer practises control over levies (taxes, charges and contributions),[49] it is acting in full exercise of its powers and is subject to different principles (in particular, direct application of constitutional law) than private airport operators.

4.5.3 Assessment

The measure 'Noise charge' is assessed as follows:

Table 22: Assessment of the measure 'Noise charge'

Measure	Depth of intervention	Administrative cost
Noise charge	Low	Low

The depth of intervention of a noise charge is low. Airlines are still free in their choice of aircraft. A noise charge sets a financial incentive for operation of quieter aircraft.

The administrative cost is low. The noise charge has merely to be included in charging systems at large airports. Only in the case of airports that do not levy noise-related charges – in the case of the reference airports, for example, the regional airport – does the charging system have to be fundamentally changed.

4.6 Sound-proofed windows and sound-insulated ventilators

4.6.1 Description

Objective and modality of the measure

Through the installation of sound-proofed windows, noise exposure in indoor areas should be reduced with constant aircraft noise. Where sound-insulated ventilators are additionally installed, the necessary exchange of air is ensured also with closed windows. The opening of windows is no longer necessary to secure an

[48] Directive 2002/30/EC of the European Parliament and of the Council of 26.03.2002 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Community airports, OJ EC 2002 No. L 85 of 28.03.2002, p.40 ff.

[49] Approaches and reflections on state control of levies are to be found, for instance, at http://www.ald-laerm.de/downloads/veranstaltungen-des-ald/publikationen/Lindmaier_DAGA2011_Landeentgelte.pdf.

adequate air exchange rate. In insufficiently-insulated attics, however, this does not apply, since here improved insulation of the roof and / or installation of an air conditioning system are often required.

In the Aircraft Noise Protection Act (*FluLärmG*) and the Second Ordinance on Implementation of the Aircraft Noise Protection Act it is laid down that existing airports have to finance sound insulation of building shells of all buildings with an $L_{Aeq\ day}$ >65 dB(A). For all buildings with an $L_{Aeq\ night}$ >55 dB(A) airports have to pay the costs of constructional noise protection measures, including installation of ventilation systems for bedrooms. In the case of new airports and airports that have been fundamentally expanded, noise values are reduced by 5 dB(A) in each case.

In this study, long-term target values of $L_{Aeq\ day} \leq 55$ dB(A) and $L_{Aeq\ might} \leq 40$ dB(A) are aimed for. These are 10 and 15 dB(A), respectively, lower than the values stated in the Aircraft Noise Protection Act. In the measure 'Sound-proofed windows and sound-insulated ventilators' it is therefore assumed that airports are required to pay the cost of sound insulation also for buildings with an $L_{Aeq\ day}$ of between 55 dB(A) and 65 dB(A) as well as an $L_{Aeq\ night}$ of between 40 dB(A) and 55 dB(A). At the same time, the reduction of levels above which the costs of noise abatement measures are reimbursed could take place in two steps. In the medium term, these levels could be reduced to $L_{Aeq\ day}$ = 60 dB(A) and $L_{Aeq\ night}$ = 50 dB(A). In a further step, another reduction could takes place to $L_{Aeq\ day}$ = 55 dB(A) and $L_{Aeq\ night}$ = 40 dB(A).

Impact mechanisms

Through the installation of sound-proofed windows and sound-insulated ventilators the noise exposure of inhabitants decreases, provided they are in their homes.

Table 23: Direct areas of impact of the measure ' Sound-proofed windows and sound-insulated ventilators'

Direct impact	**Sound emissions of aircraft (technical)**	**Sound-proofed windows and sound-insulated**	**building bans and resettlement**	**Approach and departure procedures**	**Fleet mix**	**Number of movements**
Day		x				
Night		x				

Comment: x: Main impact

The costs of the noise protection measure are paid by the airport up to a prescribed maximum amount. It is conceivable that due to aesthetic or energy-related concerns, for example, grants are not applied for. Moreover, a certain impact delay has to be expected until all buildings are provided with sound insulation.

For characterization and assessment of noise protection of a part of a building, the so-called weighted sound reduction index R'w is used. This index states the proportion of sound power (airborne sound) falling onto part of a building that is radiated on the other side in a room, and is given in dB(A). The higher this value the better the building insulates airborne noise. Besides the sound-proofing of windows, the noise situation in a building is also determined by the sound insulating capabilities of other parts of a building (exterior masonry, roof etc.), as well as by the proportion of window space. The analysis of sound insulation values by RABAG (2009) shows, however, that with conventional buildings (at least with non-converted attics) the acoustic quality of windows (compared to walls, much worse sound insulation) is decisive for noise protection of a building shell, and that consequently sound-proofed windows are an important starting point.

According to Basner et al. (2004) and RABAG (2009), the average noise difference between outdoor and indoor noise levels with closed windows is 25 dB(A). In the investigation, a common situation for Germany with regard to noise protection of exterior parts of buildings is assumed. If windows are open, the level difference no longer depends on the sound insulation of windows. With tilted windows, a level difference (outdoor compared to indoor level) of 15 dB(A) is to be expected.

Modelling assumptions

In modelling constructional noise protection measures no changes in noise level are calculated; instead, the number or persons affected by the measure is established. At the same time, it is assumed that the airports additionally pay the costs of sound-proofed windows of all buildings with an $L_{Aeq\ day}$ of between 55 dB(A) and 65 dB(A), which enable a reduction in indoor noise level to 30 dB(A). For buildings with an $L_{Aeq\ night}$ of between 40 dB(A) and 55 dB(A) the airports finance the costs of sound-proofed windows and sound-insulated ventilators, so that with this measure, in accordance with the assumptions, in indoor areas an $L_{Aeq\ night}$ of 20 dB(A) is achieved. With values under 45 dB(A) it is assumed that the installation of sound-insulated ventilators (without sound-proofed windows) is sufficient, and that the residents then sleep with closed windows and no longer with tilted windows. As mentioned above, introduction of the measure takes place in two steps. The first step initially applies noise level values with $L_{(Aeq\ day)}$ from 60 dB(A) and $L_{Aeq\ night}$ from 50 dB(A).

4.6.2 Legal framework

The installation of sound-proofed windows is, according to current law, part of the existing instrument of passive aircraft noise protection. For residential buildings in areas subject to a high degree of aircraft noise exposure, entitlement to passive noise protection is laid down in the Aircraft Noise Protection Act as amended in 2007. The Act provides not only for constructional restrictions on use, but also for constructional noise protection, in order to ensure protection of the general public and the neighbourhood against dangers, substantial detriments and considerable annoyance from aircraft noise. The Act is orientated towards noise protection zones, as established by statutory instrument, which are divided, in turn, into daytime protection zones 1 and 2 and a night-time protection zone. The relevant degree of noise exposure for the respective protection zones distinguishes in the case of civil airports between new and fundamentally expanded airports on the one hand and existing airports on the other hand. The qualitative noise protection demands (including demands on ventilation devices) that have to be met in detail in noise protection zones are laid down in Articles 7 and 9 of the Aircraft Noise Protection Act in connection with the Second Ordinance on Implementation of the Aircraft Noise Protection Act concerning airport noise abatement measures.

Differentiated building bans and restrictions (Articles 5 and 6 Aircraft Noise Protection Act) in the area surrounding airports contrast with entitlement to constructional noise protection in respect of existing residential buildings (Article 9 Aircraft Noise Protection Act) in areas highly exposed to noise. Regulations on passive noise protection contain the obligation of the airport operator to reimburse the costs of constructional noise protection in existing residential buildings and in buildings requiring special protection in the vicinity of an airport. Entitlement is phased according to the degree of noise exposure and daytime/night-time noise, respectively. The costs of installation of ventilation devices in a property located in the night-time noise protection zone are, according to current law, reimbursable (cf. Article 9 (2) Aircraft Noise Protection Act).

The noise protection requirements laid down in the Second Ordinance on Implementation of the Aircraft Noise Protection Act of 2009 are understood to be a continuation and adaptation of requirements in the Ordinance on Noise Protection of 1974, and are based on relevant technical rules and regulations on constructional noise protection, in particular on DIN 4109 "Sound insulation in buildings".[50] Requirements for sound-insulated ventilation devices are laid down in Article 3 (6) of the Second Ordinance on Implementation of the Aircraft Noise Protection Act. At the outset, it is made clear that such ventilation devices have also to be considered in determination of required noise protection.

The costs of passive noise protection are capped. In accordance with Article 5 (4) of the Second Ordinance on Implementation of the Aircraft Noise Protection Act, the maximum amount for reimbursement of costs for constructional noise protection measures in residential buildings is 150 euros per square metre of living space. The maximum amount includes the costs for reimbursable ancillary services (and ventilation devices).

If this measure should be legally regulated, amendment of the Aircraft Noise Protection Act and the related administrative regulations would be appropriate. Should one want other values for protection zones, different demarcation of zones or greater protection within existing zones, or should another maximum amount apply for the reimbursement of costs, or phasing according to daytime and night-time noise be dispensed with, an initiative would be required on the part of lawmakers or regulators.[51] Tightening up of the law on protection of inhabitants can be justified by the protective function of constitutional rights, which, in Article 2 (2) of German Basic Law demands that public authorities take effective measures for protection of the physical integrity of the individual. Existing rules, which inadequately fulfil the order to protect have to be amended.[52] The additional costs that arise for airport operators remain manageable and represent a reasonable burden, which does not have a 'strangling or confiscatory' effect and which, with a glance at Article 14 and Article 12 of German Basic Law, appears to be acceptable.

Voluntary programmes for constructional noise protection are, by the way, not excluded by the Aircraft Noise Protection Act and the Second Ordinance on Implementation of the Aircraft Noise Protection Act, and have already been occasionally implemented alongside statutory measures.[53]

4.6.3 Assessment

The measure 'Sound-proofed windows and sound-insulated ventilators' is assessed as follows:

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[50] Thus the explanatory memorandum to the regulation. Cf. www.bmu.de/files/pdfs/allgemein/application/pdf/entwurf_2.fluglsv.pdf, p. 6; as at 08.09.2009.

[51] A legislative 'review' of the Aircraft Noise Protection Act should take place, pursuant to Article 2 (3) of the Act, by 2017 at the latest.

[52] Decisions of the Federal Constitutional Court: BVerfGE 56, p. 54, 78 f.

[53] See, for example: http://www.koeln-bonn-airport.de/unternehmen/umwelt-laermschutz/passiver-schallschutz.html.

Table 24: Assessment of the measure 'Sound-proofed windows and sound-insulated ventilators'

Measure	Depth of intervention	Administrative cost
Sound-proofed windows and sound-insulated ventilators	Low	mid-range

The depth of intervention of the measure 'Sound-proofed windows and sound-insulated ventilators' is comparatively low. It is a technical measure that does not directly intervene in the market mechanism.

The administrative cost is estimated to be mid-range. It comprises, in particular, the preparation and processing of reimbursement applications for passive noise protection measures.

4.7 Noise-related control of housing development through building bans and resettlement

4.7.1 Description

Objective and modality of the measure

The objective of building bans is to prevent further building of housing in areas in which continuous sound level is higher than target values. The measure can be structured with varied degrees of hardship.

In its moderate form, the measure is intended to preclude, through building bans, settlement of land now and in the foreseeable future that is exposed to aircraft noise in still undeveloped areas in the vicinity of airports. This is the present practice in Germany, which takes beyond certain trigger thresholds. Through reduction of these trigger noise limits, the zone in which the building ban applies should be extended. In this case, land might have to be appropriately designated elsewhere to replace planned residential development in areas exposed to noise. From the municipality's point of view, it would be desirable for substitute areas to be situated in its own territory. Provided this is practicable, suitable alternatives should be sought in the municipal territory. If, however, the whole municipal area is exposed to a critical level of noise, building land must be designated in another municipality, and this land then awarded to the municipality exposed to noise (in other words: displacement of building land between two municipalities). Furthermore, in existing built-up areas a ban on expansion is issued (as a rule, with more or less far-reaching exemptions).

Whereas population projections of the Federal Statistics Office for Germany as a whole and for all Federal States excluding the three City-States (Berlin, Bremen and Hamburg) show for the post-2007 period a steadily decreasing number of inhabitants with at the same time increasing living space per capita, further growth is expected in the vicinity of airports and, in particular, with new airport construction and airport expansion [cf. Bayerisches Staatsministerium für Wirtschaft, Verkehr und Technologie, 2002; LBV, 2010]. This can be frequently attributed to existing favourable locations on the outskirts of cities, to good transport connections as well as to jobs created directly and indirectly through such airports. Building bans in areas around airports that are exposed to noise are therefore necessary, despite the decreasing number of inhabitants in Germany as a whole.

The Aircraft Noise Protection Act lays down that in the case of existing airports housing may not be built in areas with an $L_{Aeq\ day}$ >65 dB(A) and an $L_{Aeq\ night}$ >55 dB(A). The long-term target values aimed for in this study lie 10 dB(A) and 15 dB(A), respectively, below the values stated in the Aircraft Noise Protection Act. In order to achieve a building ban also in expanded protection zones, the values stated in the Aircraft Noise Protection Act for determination of daytime Protection Zone 1 and the night-time Protection Zone should be correspondingly reduced. The same values should then also be applied for new or fundamentally-expanded airports. Daytime Protection Zone 2 would then be obsolete.

In a stringent form of the measure, resettlement of the existing resident population is undertaken in respect of areas that are particularly exposed to noise, where no reasonable measures can reduce noise exposure to a level below short-term target values. Resettlement can be carried out in accordance with the practice in Switzerland, where property owners are invited to sell their property at 'market value' to the competent public authority, which then converts such residential areas to industrial zones, or can ban any constructional use whatsoever. This 'market value' is assumed to be the price that the respective house and land would have fetched had there been no aircraft noise.

Impact mechanisms

Since this measure has the objective of reducing or limiting the number of residents in areas exposed to aircraft noise, it reduces the number of residents subject to high noise exposure both during the day and at night. The noise exposure of newcomers to these areas can thus be avoided, the exposure to aircraft noise of the existing population remains unchanged, provided it is not resettled. That proportion of the population, which is resettled, benefits from reduced aircraft noise, but the private lives of the persons affected are nevertheless greatly affected by factors such as the loss of neighbourly relations and familiar surroundings.

Table 25: Direct areas of impact of the measure 'Building bans'

Direct impact	Sound emissions of aircraft (technical)	Sound-proofed windows and sound-insulated	building bans and resettlement	Approach and departure procedures	Fleet mix	Number of movements
Day			x			
Night			x			

Comment: x: Main impact

Modelling assumptions

The measure is analysed in two stages:

a) Through amendment of the Aircraft Noise Protection Act, no new housing may be built in areas in which, in accordance with long-term noise forecasts, long-term target values of $L_{Aeq\ day}$ = 55 dB(A) or $L_{Aeq\ night}$ = 40 dB(A) are exceeded. This is achieved through reduction of the values stated in the Aircraft Noise protection Act for establishment of daytime Protection Zone 1 and the night-time Protection Zone. Since estimation of the number of persons that would move into the noise-polluted areas without implementation of the measure would involve great uncertainties, in this study the number of persons that with implementation of the measure would no longer live in the corresponding noise protection zones is not quantified.

b) Additional to stage A, the proportion of the population that lives in areas in which $L_{Aeq\ day}$ is above 65 dB(A) and $L_{Aeq\ night}$ above 55 dB(A) are invited to sell their property (house and land). There, decibel categories are higher than those with building bans, in order to take adequate account of the degree of hardship. The maximum number of persons affected by resettlement is computed for quantification of the consequences of the measure.

4.7.2 Legal framework

Building bans and building restrictions are part of the regulatory core of the Aircraft Noise Protection Act. Article 5 of the Act specifies "graded" building bans, which differ as to type and need for protection of use as well as to the level of noise exposure during the day and at night, respectively. Pursuant to Article 5 (1) Aircraft Noise Protection Act, hospitals, old people's homes, convalescent homes and other facilities requiring a similar degree of protection may accordingly not be built in a noise protection zone. In daytime noise protection zones, the same applies for schools, kindergartens and other facilities requiring a similar degree of protection; whereby exceptions are possible. Pursuant to Article 5 (2) Aircraft Noise Protection Act, housing may not be built in daytime Noise Protection Zone 1 and in the night-time Protection Zone. Here, too, exceptions are possible, pursuant to Article 5 (3) Aircraft Noise Protection Act.

The establishment of noise protection zones is the responsibility of the federal states, and is enacted by ordinance of the respective state government (cf. Article 4 (2) Aircraft Noise Protection Act. The federal states administrate the Aircraft Noise Protection Act and related regulations under their own responsibility. In accordance with Article 70 ff. of German Basic Law, the federal government can here perform no functional supervision: "With regard to earliest possible and uniform nationwide execution, the Federal Ministry for the Environment and the Federal Environment Agency support, however, work on the establishment of noise protection zones *inter alia* through provision of extensive information and intensive advice."[54]

Building bans that derive from establishment of noise protection zones always have the above-mentioned effects; namely, on the establishment of land-use plans on the one hand and land development plans on the other (cf. Article 1 (2) Federal Building Code (*BauGB*)). Urban land-use planning is orientated towards requirements of state and regional planning; it regulates the urban development of municipalities. Municipalities are required, pursuant to Article (3) Federal Building Code, to prepare urban land-use plans, as soon and as far as required for urban development and regulation. In the process, environmental and health aspects that are necessary for protection of the population have always to be incorporated into planning. In the vicinity of an airport, urban land-use planning has therefore to ensure, in particular, that the population is protected against aircraft noise; whereby screening measures – such as applied in the case of road or railway noise – hardly come into question for the areas affected.

[54] Answer of the Federal Government to a parliamentary question on the status of implementation of ordinances in accordance with the Aircraft Noise Protection Act, *Bundestag* Doc. 17/3566 of 28.10.2010.

As a measure of control of housing development, it is recommended that municipalities create a sufficiently large protective distance to the noise source. This can cause problems when alternative land is not available within a municipality's territory. Yet, where alternatives exist, the idea of an 'exchange' of building land between two municipalities does not appear to be unreasonable. From the legal point of view there is nothing to be said against such a procedure, provided that voluntariness exists on all sides.[55]

The strategic objective of imposing building bans already from a value of 55 dB(A) requires amendment of the Aircraft Noise Protection Act. It has to be borne in mind, however, that legally binding building bans are routinely touch on issues of constitutional law (in particular, Article 2 (1) and Article 14 of German Basic Law. They encroach, moreover, on the local planning autonomy of municipal authorities, and must therefore be judged in terms of the guarantee of municipal self-administration pursuant to Article 28 (2) of German Basic Law. An extension of building bans has consequences for municipal infrastructure and urban development. Even now it is sometimes no longer possible for municipalities to build new schools or kindergartens. The legal limit is then reached when the guarantee of municipal self-administration pursuant to Article 28 (2) of German Basic Law is at issue. The same applies, should one intend to consider exchange of land against the will of the respective municipalities.

For owners of land, Article 14 of German Basic Law, which guarantees property and its use, lays down the constitutional standard. Encroachment upon ownership rights is not *per se* impermissible, as Article 5 Aircraft Noise Protection Act shows. Owners have to accept to a certain extent restrictions on the possible use of their land. However, German Basic Law sets limits on encroachment upon ownership; in particular, when encroachment assumes the intensity of expropriation. Article 14 of German Basic Law is ultimately also touched upon when owners of land exposed to noise have an interest in acquisition of their land by public authorities, whether by way of exchange or payment of compensation. If use of land is not possible because aircraft noise exposure has reached such a level that the constitutional threshold of reasonableness is overstepped, Basic Law grants the right to compensation.

4.7.3 Assessment

Table 26: Assessment of the measure 'Building bans and resettlement'

Measure	Depth of intervention	Administrative cost
Buildings bans	mid-range	mid-range
Resettlement	high	High

Assessment of the depth of intervention in the market mechanism of building bans and resettlement is not a trivial matter. These measures generally change the income and financial circumstances not only of property owners but also of the municipalities concerned, which as a result are restricted to a greater or lesser extent in their urban development. The depth of intervention in the case of building bans is estimated to be mid-range, that of resettlement high.

Building bans and resettlement give rise in their implementation to a relatively high administrative cost, since negotiations have to be conducted with many owners and residents (for example, concerning the

[55] Voluntary exchange of land is known, for example, from land consolidation law (cf. Articles103a-i of the Land Consolidation Act (*Flurbereinigungsgesetz - FlurbG*)) as a quick and simple procedure for improvement of agricultural structures.

treatment of a fall in value that arises as a result of restricted rights to use. Once the measure has been implemented, however, administrative costs hardly arise. The administrative cost in the case of building bans is estimated to be mid-range, that of resettlement high.

4.8 Effectivity and comparison of measures under investigation

The effects of implementation of different measures on noise levels, health impairment and noise annoyance are calculated for the reference airports with the models described in Chapter 3. In the following tables and figures the results are shown, initially for the airport with a large volume of freight and night-flight operations.

4.8.1 Airport with a large volume of freight and night-flight operations

Figure 8 reveals the number of persons in the base scenario and in the measure scenarios that are exposed to certain noise level categories of L_{den}, when in each case one of the measures under investigation is implemented. In order to retain an overview, the effects are apportioned to the two Figures 8 and 9.

Besides the base scenario, Figure 8 displays the following measures: Movement quota A' designates the flight movement quota by which flight movements of all types of aircraft are equally reduced by 20% Section 4.2). In the case of 'Movement quota B', smaller aircraft are partially replaced by large aircraft. With 'Noise quota', loud aircraft are replaced by quieter aircraft and, additionally, flight movements reduced by 40% (Section 4.2). With the 'Noise charge' measure, noise-related takeoff and landing charges are increased (Section 4.5).

Figure 9 displays the remaining measures. With 'Night-flight ban' there are no flight movements at night; with 'Night-flight restriction' quieter aircraft are operated at night and the number of flight movements is reduced (Section 4.3). In the case of 'OLDLP procedure', optimized low drag low power is applied; with 'SCDA procedure', segmented continuous descent approach is applied (Section 4.4).

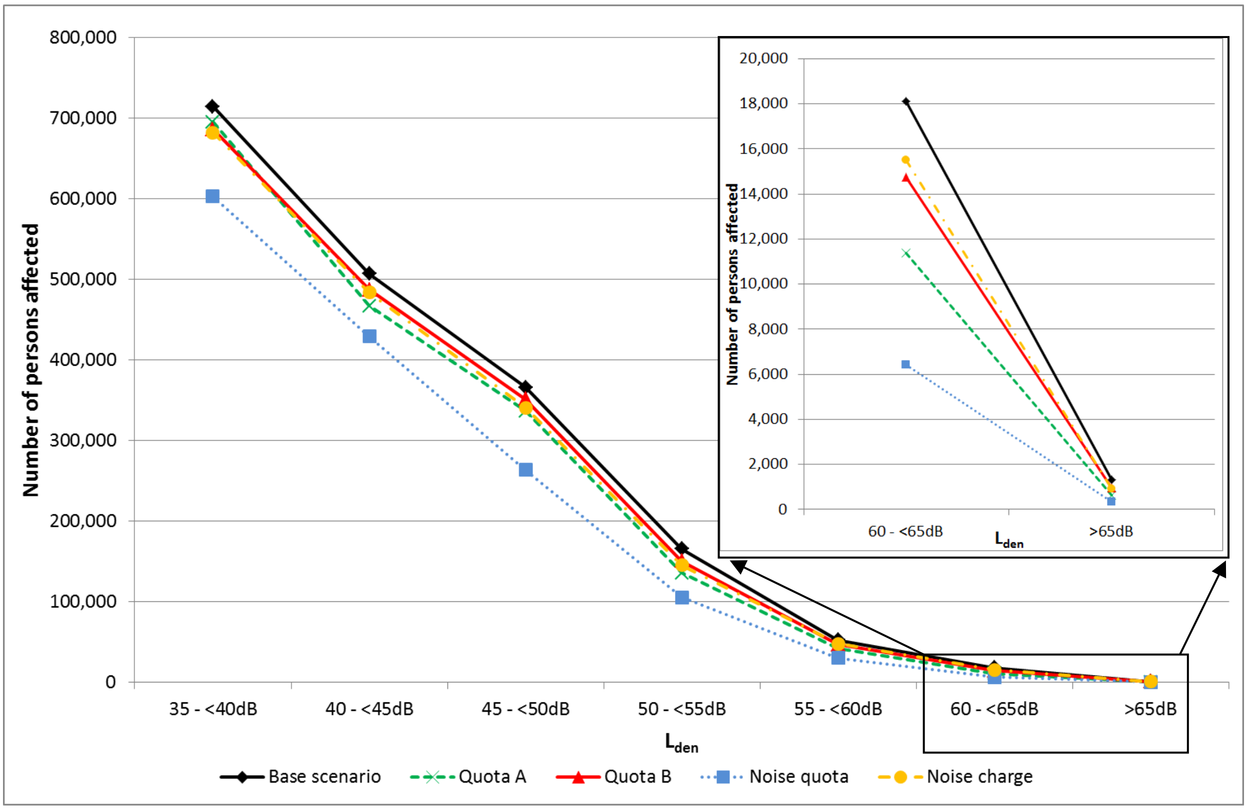

Figure 8: Persons affected depending on exposure categories (L_{den}) for the base scenario, and measures under investigation for the airport with a large volume of freight and night flight operations (2017)

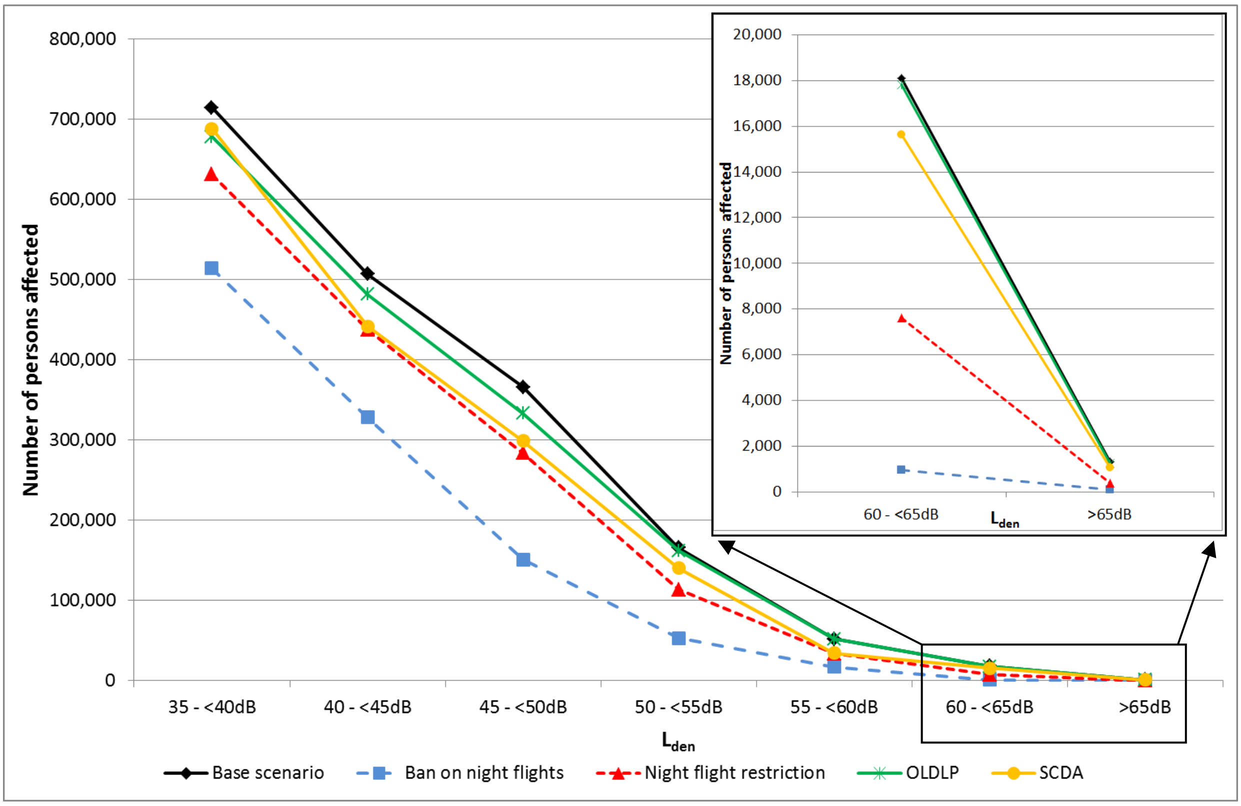

Figure 9: Persons affected depending on exposure categories (L_{den}) for the base scenario, and measures under investigation for the airport with a large volume of freight and night flight operations (2017)

In Table 27, health and annoyance effects for the base scenario and measure scenarios are displayed. Table 28 displays the consolidated effects expressed in DALYs (disability-adjusted life years) as well as the total costs of damage per year through noise. The applied methods and parameters are explained in Section 3.3.

Table 27: Maximum equivalent continuous sound level in residential areas, and noise effects for the base scenario and measure scenarios for the airport with a large volume of freight and night-flight operations

Airport with a large volume of freight and night-flight operations										
		Base Scenario	**Movement quota A**	**Movement quota B**	**Noise quotas**	**Noise charges**	**Night-flight ban**	**Night-flight restriction**	**OLDLP**	**SCDA**
Maximum value in residential areas	L_{den} [dB(A)]	72	71	71	70	72	67	70	72	72
	$L_{Aeq\ day}$ [dB (A)]	63	62	62	61	63	66	64	63	63
	$L_{Aeq\ night}$ [dB(A)]	66	65	65	64	65	0	64	66	66
Number of persons suffering annoyance	1000 HA	30.9	254.	28.2	18.7	28.6	9.7	20.5	29.9	24.7
	1000 A	116.5	102.5	109.5	84.0	109.8	51.9	88.8	110.8	97.4
	1000 LA	214.7	196.4	204.5	168.4	203.5	120.1	176.0	202.5	188.5
Number of persons suffering disturbed sleep	1000 HSD	11.0	8.8	9.9	6.1	9.7	0	5.8	11.0	7.9
	1000 SD	18.4	14.7	16.5	10.2	16.2	0	9.8	18.4	13.2
Persons suffering from high blood pressure		4,490	3,474	3,982	2,288	4,228	1,048	3,647	4,454	3,402

Note: HA = highly annoyed, A= annoyed, LA = little-annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed; see Section 3.3.

Table 28: DALYs and total cost of damage for the base scenario and measure scenarios for the airport with a large volume of freight and night-flight operations

Airport with a large volume of freight and night-flight operations									
	Base scenario	**Movement quota A**	**Movement quota B**	**Noise quotas**	**Noise charges**	**Night-flight ban**	**Night-flight restriction**	**OLDLP**	**SCDA**
Total damage in DALYs	2,439	1,934	2,186	1,333	2,236	440	1,669	2,409	1,844
Total costs of noise damage in mill. $€_{2010}$/a	188	162	176	128	173	66	134	181	113

With the measure 'Installation of sound-proofed windows' (Section 4.6), the trigger thresholds for establishment of zones, in which constructional noise protection measures are financed, are reduced in two stages, initially to $L_{Aeq\ day}$ = 60 dB(A) and $L_{Aeq\ night}$ = 50 dB(A) and then, in the long term, to $L_{Aeq\ day}$ = 55 dB(A) and $L_{Aeq\ night}$ = 40 (A). Table 29 shows the number of persons in the base scenario and following implementation of the measures under investigation that live in housing located in extended noise zones, for which new claims arise for reimbursement of the costs of constructional noise protection. When a measure of active noise protection is implemented noise exposure decreases in accordance with the effectiveness of the measure. Correspondingly smaller is then the number of persons whose noise protection costs are reimbursed.

Table 29: Number of persons additionally entitled to reimbursement of the cost of installation of sound-proofed windows and sound-insulated ventilators, for the airport with a large volume of freight and night-flight operations.

Installation of sound-proofed windows and sound-insulating ventilators		**Number of persons**
Stage 1	$L_{Aeq\ day}$ 60 to <65dB(A)	247
	$L_{Aeq\ night}$ 50 to <55dB(A)	36,028
Stage 2	$L_{Aeq\ day}$ 55 to <60 dB(A)	6,546
	$L_{Aeq\ night}$ 45 to <50dB(A)	121,092
	$L_{Aeq\ night}$ 40 to <45dB(A)	307,328

A further measure involves resettlement of all persons living in areas in which in the long term an $L_{Aeq\ day}$ above 65 dB(A) as well as an $L_{Aeq\ night}$ above 55 dB(A) are to be expected (Section 4.7). In the base scenario, the given $L_{Aeq\ day}$ is not exceeded, and 8,500 persons are exposed to a night-time continuous level >55 dB(A).

The assessment and comparison of the results for all three airports under investigation are to be found in Section 4.7.3.

4.8.2 Medium-sized airport

Figures 10 and 11 as well as Tables 27 to 30 display the results of noise level and impact calculations for the medium-sized airport.

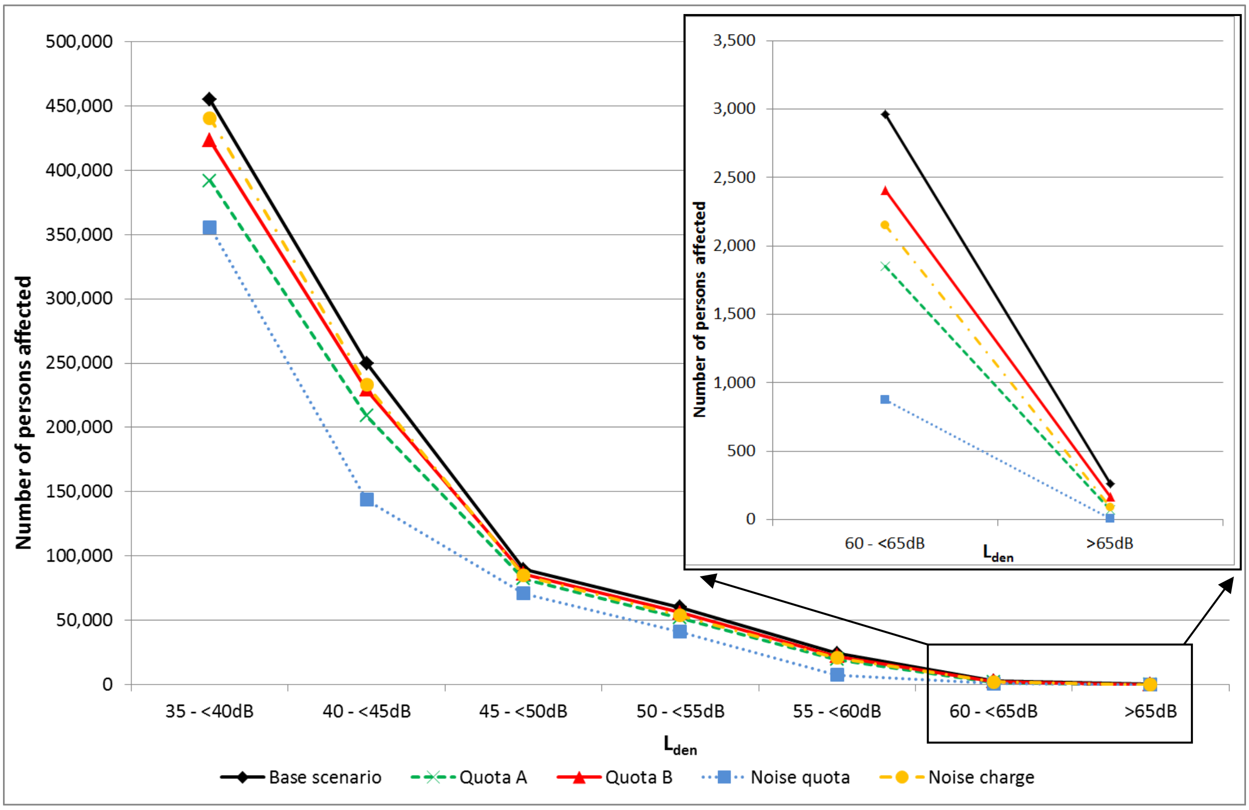

Figure 10: Persons affected by exposure categories (L_{den}) for the base scenario and the measures under investigation for the medium-sized airport (2020)

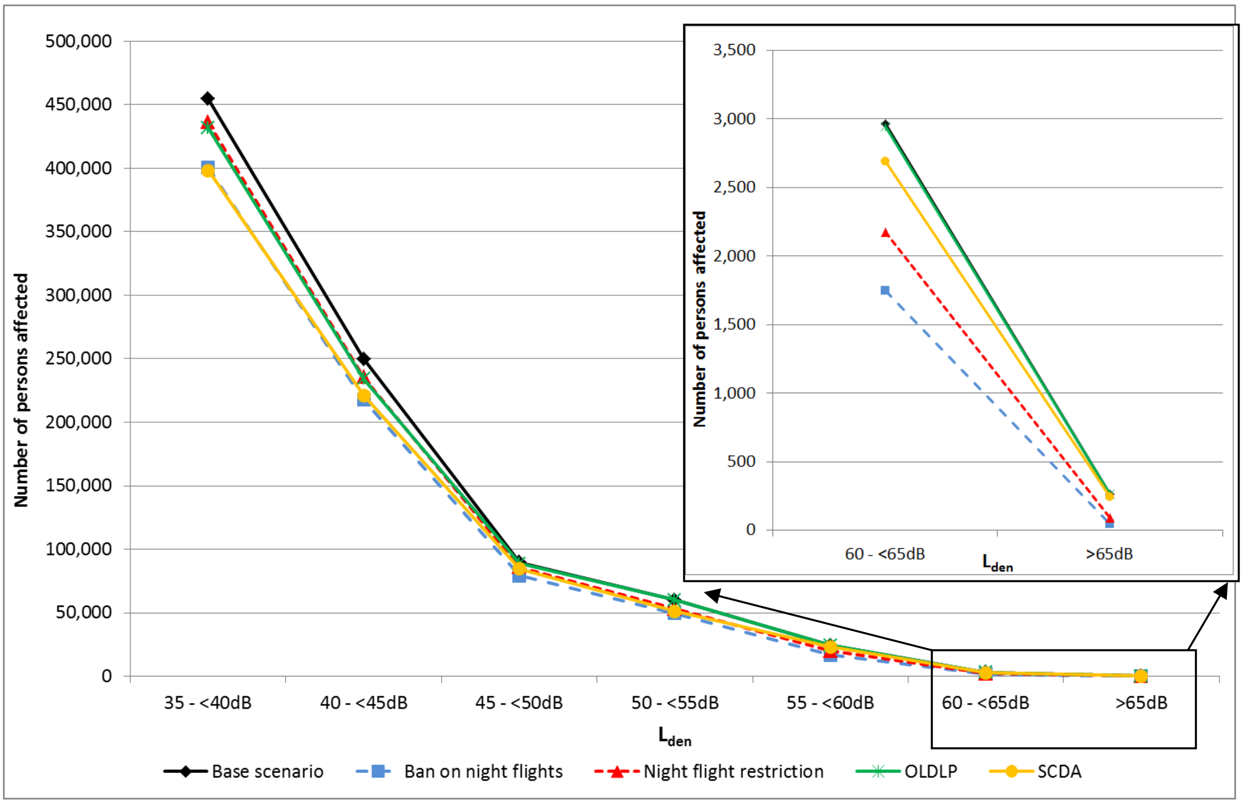

Figure 11: Persons affected by exposure categories (L_{den}) for the base scenario and the measures under investigation for the medium-sized airport (2020)

Table 30: Maximum equivalent continuous sound level in residential areas as well as noise effects for the base scenario and measure scenarios for the medium-sized airport

Medium-sized airport										
		Base scenario	**Movement quota A**	**Movement quota B**	**Noise quota**	**Noise charge**	**Night-flight ban**	**Night-flight restriction**	**OLDLP**	**SCDA**
Maximum Value in residential areas	L_{den} [dB(A)]	67	66	66	64	66	66	66	67	67
	$L_{Aeq\ day}$ [dB(A)]	65	64	64	62	64	65	65	65	65
	$L_{Aeq\ night}$ [dB(A)]	56	56	56	53	56	0	53	56	56
Number of persons suffering annoyance	1000 HA	10.2	8.4	9.3	5.6	8.9	7.9	8.7	10.1	9.1
	1000 A	42.5	36.1	39.3	26.3	38.8	35.4	38.7	41.4	38.3
	1000 LA	97.0	83.4	90.2	66.2	91.3	84.0	91.0	92.6	86.2
Number of persons suffering sleep disturbance	1000 HSD	1.4	1.0	1.2	0.3	1.0	0	0.3	1.3	1.2
	1000 SD	2.3	1.7	2.0	0.5	1.7	0	0.5	2.3	2.1
Persons suffering from high blood pressure		1,554	1,183	1,369	636	1,272	1,060	1,228	1,541	1,367

Note: HA = highly-annoyed, A= annoyed, LA = little-annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed; see Section 3.3.

Table 31: DALYs and costs of noise damage for the base scenario and measure scenarios for the medium-sized airport

Medium-sized airport									
	Base scenario	**Movement quota A**	**Movement quota B**	**Noise quota**	**Noise charge**	**Night-flight ban**	**Night-flight restriction**	**OLDLP**	**SCDA**
Total of damage in DALYs	663	514	589	284	546	406	482	657	59
Total costs of noise damage in mill. $€_{2010}$/a	62	52	55	37	56	47	52	60	55

Table 32 shows the number of persons who, with extension of protection zones intended for the medium-sized airport, are additionally entitled under the measure 'Sound-proofed windows and sound-insulated ventilators' to reimbursement of the costs of constructional noise protection measures.

Table 32: Number of persons additionally entitled to reimbursement of the cost of installation of sound-proofed windows and sound-insulated ventilators, for the medium-sized airport

Installation of sound-proofed windows and sound-insulated ventilators		**Number of persons**
Stage 1	$L_{Aeq\ day}$ 60 to <65 dB (A)	1,230
	$L_{Aeq\ night}$ 50 to <55 dB(A)	1,888
Stage 2	$L_{Aeq\ day}$ 55 to <60 dB(A)	9,477
	$L_{Aeq\ night}$ 45 to <50 dB (A)	21,147
	$L_{Aeq\ night}$ 40 to <45dB (A)	53,577

The number of persons affected by resettlement due to exceedance of the trigger threshold of $L_{Aeq\ night}$ of 55 dB(A) amounts to 20 in the base scenario.

4.8.3 Regional airport

Figures 12 and 13 as well as Tables 33 and 35 show the results of noise-level and impact calculations for the regional airport.

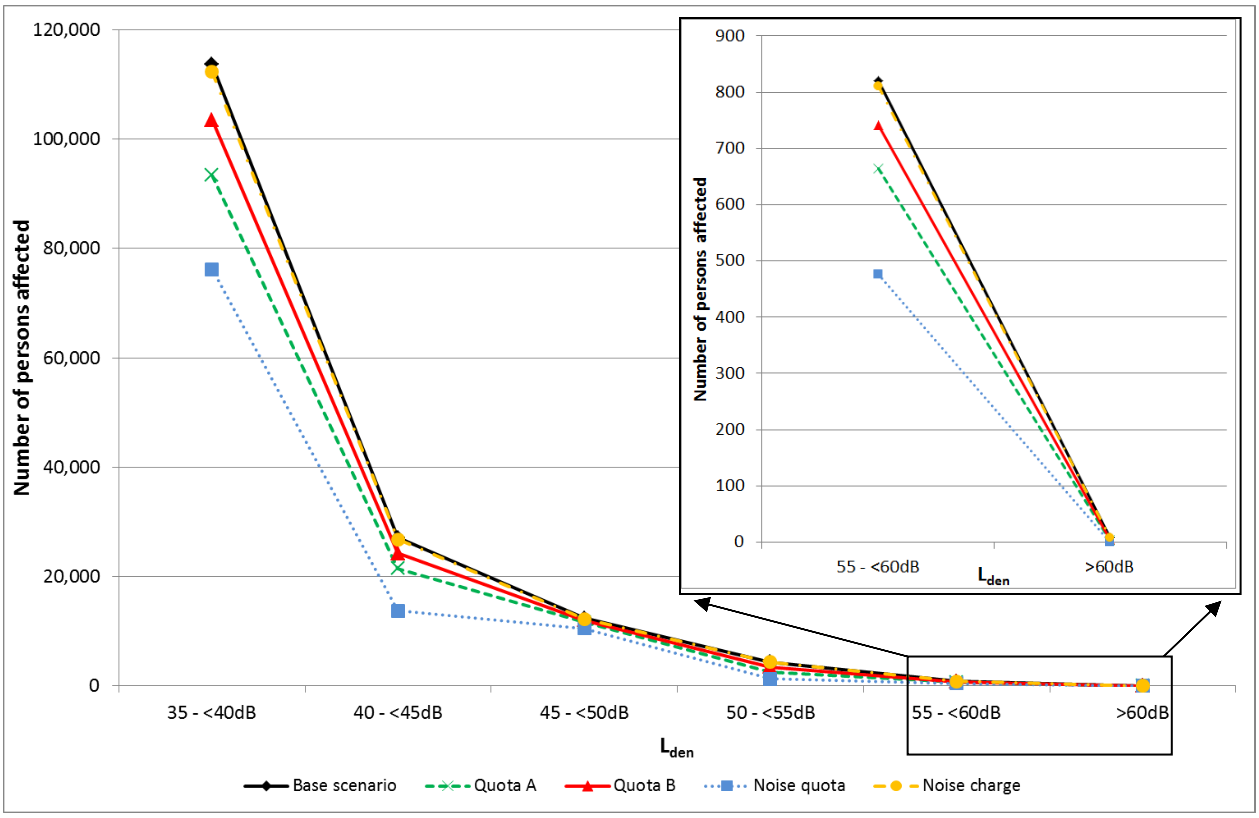

Figure 12: Persons affected depending on exposure categories (L_{den}) for the base scenario and measure scenarios for the regional airport (2017)

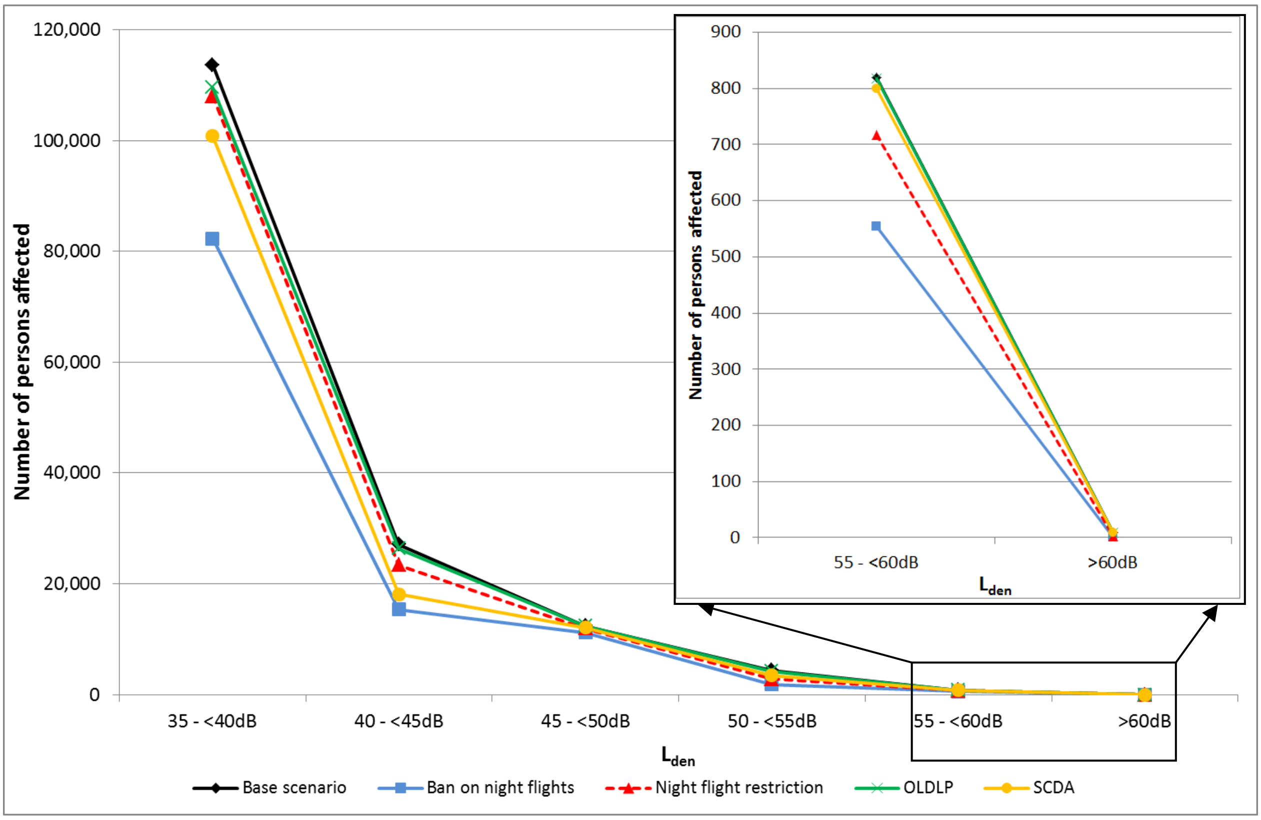

Figure 13: Persons affected depending on exposure categories (L_{den}) for the base scenario and measure scenarios for the regional airport (2017)

Table 33: Maximum equivalent continuous sound level in residential areas and noise impacts for the base scenario and measure scenarios for the regional airport

Regional airport		Base scenario	Movement quota A	Movement quota B	Noise quota	Noise charges	Night-flight ban	Night-flight restriction	OLDLP	SCDA
maximum value in residential areas	L_{den} [dB(A)]	61	61	60	58	61	59	60	61	60
	$L_{Aeq\ day}$ [dB(A)]	58	57	58	56	58	58	58	58	58
	$L_{Aeq\ night}$ [dB(A)]	51	50	51	49	51	0	48	51	50
Number of persons suffering annoyance	1000 HA	0.7	0.6	0.6	0.4	0.7	0.5	0.6	0.7	0.6
	1000 A	4.4	3.5	3.9	2.5	4.3	3.0	3.7	4.1	3.5
	1000 LA	15.6	12.6	14.1	9.6	15.4	10.7	14.2	14.9	12.9
Number of persons suffering sleep disturbance	1000 HSD	0.05	0.04	0.04	0.03	0.05	0	0.03	0.05	0.05
	1000 SD	0.09	0.07	0.08	0.05	0.08	0	0.05	0.08	0.08
Persons suffering from high blood pressure		84	56	70	32	79	41	62	83	72

Note: HA = highly-annoyed, A= annoyed, LA = little-annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed; see Section 3.3

Table 34: DALYs and cost of noise damage for the base scenario and measure scenarios for the regional airport

Regional airport	Base scenario	Movement quota A	Movement quota B	Noise quota	Noise charges	Night-flight ban	Night-flight restriction	OLDLP	SCDA
Total of damage in DALYs	37	27	32	17	36	19	28	37	33
Total costs of noise damage in million €$_{2010}$/a	7.0	5.6	6.3	4.1	6.9	4.6	6.0	6.6	5.7

Table 34 gives the number of persons additionally entitled to reimbursement of costs for sound-proofed windows and sound-insulated ventilators with extension of intended protection zones for the regional airport

Table 35: Number of persons additionally entitled to reimbursement of the cost of installation of sound-proofed windows and sound-insulated ventilators, for the regional airport

Installation of sound-proofed windows and sound-insulated ventilators		Number of persons
Stage 1	$L_{Aeq\ day}$ 60 to <65 dB(A)	0
	$L_{Aeq\ night}$ 50 to <55 dB(A)	7
Stage 2	$L_{Aeq\ day}$ 55 to <60 dB(A)	362
	$L_{Aeq\ night}$ 45 to <50 dB(A)	840
	$L_{Aeq\ night}$ 40 to <45 dB(A)	4,728

Due to the low noise level at the regional airport, no-one is affected by the measure 'Resettlement'.

4.8.4 Assessment of the measures for all reference airports

In the analysis of results, one first notices that none of the active noise protection measures achieves a decrease of more than 1 to 2 dB(A) in the daytime level $L_{Aeq\ day}$ in residential areas in the vicinity of the reference airports with the highest exposure to noise. Modified approach procedures have more or less no effect on the maximum continuous sound level in the residential areas under investigation, since the approaches over the last few kilometres before the runway no longer differ and the residential areas exposed to the greatest noise lie below final approach zones. In residential areas further away from the airport the approach procedures can in fact reduce continuous sound level. A decrease in maximum continuous sound level can therefore be achieved only through a reduction in flight movements and the replacement of loud aircraft with quieter aircraft. At night, $L_{Aeq\ night}$ can be reduced to any extent through night flight restrictions including night-flight bans.

The abatement of annoyance effects through the measures is much greater than the reduction of maximum continuous sound level. In Table 36, the four most effective measures are rated according to their effectivity.

Table 36: Rating of the four most effective measures with regard to effects

Rating	Airport with a large volume of freight and night-flight operations	Medium-sized airport	Regional airport
1	Night-flight ban	Noise quotas	Noise quotas
2	SCDA Procedure	Night-flight ban	Night-flight ban
3	Noise quotas	Night-flight restriction	Linear movement quotas
4	Night-flight restriction	Linear movement quotas	SCDA Procedure

It should be noted that effectivity depends on the design of the measure. The smaller the movement quota, or the higher the noise charge, the greater the noise-reducing effect. Ranking according to effectivity has always to be seen in connection with the design of measures as described in Sections 4.2 to 4.7. The high effectivity of noise quotas and linear movement quotas, in particular, arises due to the substantial reduction in target values selected for simulation. High effectivity is therefore shown for measures that affect night flights, particularly at airports where unrestricted night-flight operations have previously been possible, followed by the introduction of the SCDA approach procedure. The following table provides an overview of the assessment of measures:

Table 37: Assessment of measures on the basis of varied criteria

Measure	Effectivity	Depth of intervention	Administrative cost	Legal implementation by:
Allocated movement quotas	low to high depending on design	High	mid-range	Modifications of planning approval
Noise quotas (cap and trade)	low to high depending on design	mid-range	high	Modifications of planning approval
Noise charges	mid-range	Low	low to mid-range	Modification of charging systems by airport operators
Night-flight restrictions	mid-range to high depending on design	mid-range	mid-range	Modification of planning approval (or modification of charging systems)
Night-flight ban	high	High	low	Modification of planning approval
Approach procedures	mid-range	Low	low	statutory instrument of the Federal Supervisory Office for Air Traffic Control
Sound-proofed windows and sound-insulated ventilators	high	Low	mid-range	Modification of the Aircraft Noise Protection Act
Building bans	low	mid-range	mid-range	Modification of the Aircraft Noise Protection Act
Resettlement	high	High	high	Negotiations, Offers

Flight movement quotas are poorly targeted. Through the replacement of quiet aircraft with loud aircraft the effect is largely frustrated. Moreover, high effectivity only occurs when flight movements are substantially reduced, but this is hardly enforceable. In the case of noise quotas with cap and trade the administrative cost is very high, and implementation is also here a problem, since for this a noticeable reduction in flight movements is required.

An increase in noise-related takeoff and landing charges is easy to implement and has, at least, mid-range effectivity. This would decline in the short term, however, were all or nearly all European airports to increase charges accordingly, since then loud aircraft in service could not be operated elsewhere. In the medium term, however, an additional incentive would arise for airlines to purchase quieter aircraft. Night-flight restrictions and night-flight bans have mid-range to high effectivity since, with the same noise level at night, considerably greater health and annoyance effects are caused than during the day. The depth of intervention is mid-range, and in the case of a night-flight ban it is high. Restrictions on flight operations, however, have to be assessed more moderately than movement quotas, since a proportion of night flights does not disappear altogether but can be switched to daytime operation.

Noise-reducing approach procedures are easy to implement, and for the reduction of noise exposure at a distance of more than 10 kilometres from the runway there is a mid-range effect. Even if with active noise reduction measures the set target values are not achieved, through installation of sound-proofed windows and sound-insulated ventilators a lower noise level can be achieved at least in indoor areas. Through a reduction in the legal trigger threshold for entitlement to reimbursement of the costs of these passive measures to the target value set in this study, considerable costs can arise for airport operators when a ban on night flights is not imposed. Building bans prevent, with mid-range depth of intervention, an increase in the number of persons highly exposed to noise. Through resettlement, the exposure of persons otherwise subject to the highest level of aircraft noise exposure can, of course, be effectively avoided, but the administrative cost and the social effects are very high.

5 Deduction of strategies

5.1 Overview

Having investigated the benefits of individual measures in Chapter 4, in this chapter noise abatement strategies are developed, which are defined as packages of measures aimed at achievement of noise abatement targets. These targets were deduced in Chapter 2, and are shown once more in Table 38.

Table 38: Recommended indicator and target values

	$L_{Aeq\ night}$	$L_{Aeq\ day}$	Number of highly-annoyed persons
Long-term target values	40 dB(A)	55 dB(A)	Reduction insofar as is possible efficiently
Short-term target values	55 dB(A)	65 dB(A)	

On the basis of results of the base scenario, the gap between actual noise exposure – stated as maximum equivalent continuous sound level in residential areas – and target values is initially determined together with the reduction in noise level that has to be achieved in order to meet these targets.

Table 39: Maximum equivalent continuous sound level during the day ($L_{Aeq\ day}$) and at night ($L_{Aeq\ night}$) in residential areas in the vicinity of the airports, and the gap to the target values for the three airports under investigation

Airport	Noise level	Max. equivalent continuous sound level in residential areas	Gap to the target of 65/55 dB(A)	Gap to the target of 55/40 dB(A)
Airport with a large volume of freight and night-flight operations	$L_{Aeq\ day}$ dB(A)	63	-2	8
	$L_{Aeq\ night}$ dB(A)	66	11	26
Medium-sized airport	$L_{Aeq\ day}$ dB(A)	65	0	10
	$L_{Aeq\ night}$ dB(A)	56	1	16
Regional airport	$L_{Aeq\ day}$ dB(A)	58	-3	3
	$L_{Aeq\ night}$ dB(A)	51	-4	11

The two columns to the right show the gap to achievement of the targets stated in the header line. Negative values indicate that the target values have already been met or bettered. It can be seen that there are large differences between the airports. The greatest noise problem is caused by night flights at the airport with a large volume of freight and night-flight operations. The short-term target for $L_{Aeq\ day}$ has been met or bettered at all airports; in the case of the regional airport this also applies for $L_{Aeq\ night}$. This does not mean, however, that measures are not necessary to reduce daytime noise, since the target of efficient reduction of annoyance effects has also to be met. Long-term targets are met at none of the reference airports.

The difficulty of achievement of long-term target values is highlighted by the fact that for a reduction of 3 dB(A) in noise level a reduction in flight movements of about 50% would be required, were sound emissions of aircraft and flight procedures to remain unchanged. For a reduction 6 dB(A) flight movements would have to be reduced by 75%.

Two strategies are deduced below, which can be implemented in the short term (that is, in the course of a few years). Each of the strategies is comprised of a package of measures selected from the measures analysed in Chapter 4. The impact of these strategies is then simulated for the years 2020 and 2017.

The available measures can be categorized according to their mode of impact, as described below. In addition, the mechanisms are mentioned with which these measures can be realized.

- Reduction of flight movements, differentiated according to daytime and night-time hours.
  Mechanisms: higher takeoff and landing charges, fuel taxes, movement quotas, noise quotas and night-flight bans.

- Operation of quieter aircraft, differentiated according to daytime and night-time; in the short term through displacement of aircraft, and in the long term through replacement of loud aircraft with new quieter aircraft.
  Mechanisms: higher charges graded according to noise categories, noise quotas, ban on aircraft of high noise categories and, in the long term, tightening-up of noise limits for certification of aircraft.

- Noise-reducing approach procedures (for example, continuous descent approach (CDA), optimized low drag low power (OLDLP), segmented continuous descent approach (SCDA)), noise-reducing departure procedures (for example, steep departure procedures such as ICAOA-FLEX and ICAOA-TOGA) and optimized flight routes over sparsely-populated areas.
  Mechanisms: Specifications for approach and departure procedures and flight routes.

- Sound-proofed windows and noise-insulated ventilators. Reimbursement by airport operators of the cost of installation of sound-proofed windows, in bedrooms with noise-insulated ventilators, also with lower trigger thresholds than those laid down in the Aircraft Noise Protection Act.
  Mechanism: Reduction of trigger thresholds for establishment of noise protection zones provided for in the Aircraft Noise Protection Act.

- Control of housing development. Building bans in areas where noise levels lie above the long-term target values applied in this study, and renaturation of residential areas with excessive noise exposure.
  Mechanisms: Modification of land-use plans and legally-binding land-use plans, reduction of trigger thresholds provided for establishment of noise protection zones in the Aircraft Noise Protection Act, offers of compensation for departure from noise-polluted areas as well as expropriation.

5.2 Efficiency strategy

For an initial strategy, measures are selected that are effective and at the same time legally implementable at a moderate cost without amendment of existing law or the necessity of a new planning approval procedure, and furthermore require only a low to mid-range depth of intervention in the market mechanism. This strategy is termed an efficiency strategy, since the relationship between impact (noise reduction) and cost is particularly high. The efficiency strategy is comprised of the following measures:

- Increase of noise-related takeoff and landing charges.

  Noise-related takeoff and landing charges for aircraft of high noise categories (from Frankfurt Noise Category 3) are increased to such a level that the number of flight movements of loud aircraft markedly decreases. Determination of noise charges is at the discretion of airport operators; if they support the measure, its implementation is unproblematic. Should this not be the case, the supervisory authorities have to work towards implementation through negotiations with the airport operator. Charges must be noticeably increased compared to the present level. The required level must be initially estimated on the basis of observed price elasticity of demand, and its impact should then be reviewed after a few years and, if necessary, adjusted.

  For estimation of the impact of the measure aircraft are assigned to noise categories, as carried out at Frankfurt Airport. It is assumed that short- or medium-haul aircraft of noise category 4 or higher are no longer in service, and that they are replaced with aircraft of noise categories 2 and 3. Furthermore, 50% of long-haul aircraft of noise category 6 and higher are replaced with aircraft of noise category 5.

- Introduction of noise-optimized approach procedures

  Low-noise approach procedures are applied instead of previously-envisaged standard approach procedures. Two procedures come into question: continuous descent approach (CDA) and optimized low drag low power (OLDLP) (see Section 4.4). The CDA procedure is primarily applied at times of light traffic, whereas the OLDLP procedure is employed at times of dense traffic. This way, upgrading of aircraft and airports can initially be largely avoided.

  The introduction of specific approach and departure procedures takes place by way of ordinance issued by the Federal Supervisory Office for Air Traffic Control (*BAF*), and it is implemented by German Air Traffic Control (*DFS*) together with the airport operator.

  In simulation, it is assumed for the purpose of simplification that all approaches in the base scenario are flown with the LDLP procedure, and that they are now switched to the OLDLP procedure. This assumption leads on the one hand to slight underestimation of actually achievable noise reduction, since the CDA procedure – as displayed in Figure 6, Section 4.4 – comes off somewhat better than the OLDLP procedure in lower noise level categories. On the other hand, this assumption also leads to overestimation of the impact on comparable real airports, at which the CDA procedure has already been partially employed.

The effects of efficiency strategy measures are shown in Table 40. Maximum equivalent continuous sound levels in built-up areas are shown as well as health risks and the number of persons suffering sleep disturbance and annoyance for the base scenario and the efficiency strategy for the reference airports. In Table 41, the effects are converted into DALYs and monetary values. The methods and parameters applied are explained in Section 3.3.

Table 40: Maximum equivalent continuous sound levels in residential areas as well as noise effects in the base scenario and with implementation of the efficiency strategy

Health and annoyance effects		**Airport with a large volume of freight and night-flight operations**		**Medium-sized airport**		**Regional airport**	
		Base	Efficiency strategy	Base	Efficiency strategy	Base	Efficiency strategy
maximum value in residential areas	L_{den} [dB(A)]	72	72	67	66	61	61
	$L_{Aeq\ day}$ [dB(A)]	63	63	65	64	58	58
	$L_{Aeq\ night}$ [dB(A)]	66	66	56	56	51	51
Number of persons suffering annoyance	1000 HA	30,9	26.2	10.2	8.8	0.7	0.7
	1000 A	116.5	100.9	42.5	37.7	4.4	4.0
	1000 LA	214.7	188.3	97.0	86.6	15.6	15.3
Number of persons suffering sleep disturbance	1000 HSD	11.0	9.3	1.4	1.0	0.05	0.05
	1000 SD	18.4	15.6	2.3	1.7	0.09	0.08
Persons suffering from high blood pressure		4,490	3,645	1,554	1,262	84	78

Note: HA = highly-annoyed, A= annoyed, LA = little-annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed; see Section 3.3

Table 41: DALYs and costs of noise damage in the base scenario and with implementation of the efficiency strategy

Health and annoyance effects	**Airport with a large volume of freight and night-flight operations**		**Medium-sized airport**		**Regional airport**	
	Base	Efficiency strategy	Base	Efficiency strategy	Base	Efficiency strategy
Total damage in DALYs	2.439	2.026	663	542	37	35
Total costs of noise damage in mill. €$_{2010}$/a	188	162	62	54	7.0	6.7

The impact of the strategy on maximum continuous sound levels in built-up areas is rather low. At relatively large airports maximum continuous sound levels are reduced by around 0.5 to 1 dB(A). The reason for this moderate reduction is that the increase in noise-related charges, and thus increased operation of quieter aircraft, leads to a limited, even reduction of noise level in the area around airports. The introduction of noise-optimized approach procedures has no impact whatsoever in the direct vicinity of the airport, since approach routes in the final kilometres before the runway with all approach procedures under investigation are roughly the same. Only at a greater distance from the airport do noise-optimized approaches lead to considerable reductions – in the simulation, about 15% compared to the base scenario – in the number of persons highly-annoyed by noise, due primarily to the greater distance to the ground. This substantial reduction in annoyance effects justifies implementation of the efficiency strategy.

With the exception of the target value $L_{Aeq\ night}$ = 55 dB(A), which is greatly exceeded at the airport with a large volume of freight and night-time operations as well as at the medium-sized airport (here to the extent of 1 dB(A), short-term target values are complied with in the base scenario and in the efficiency strategy.

Due to the high night-noise level at the airport with a large volume of freight and night-time operations, it is proposed, as an additional measure at this airport, that takeoff and landing charges be raised to such a level that – apart from emergencies and other exceptional cases – only quiet aircraft or, in particular, long-haul aircraft of Frankfurt Noise Category 5 or lower, take off and land at night. As a result, $L_{Aeq\ night}$ could be reduced by up to 2.5 dB(A). The short-term target for night noise is nevertheless noticeably exceeded.

According to the Aircraft Noise Protection Act, all persons who are exposed at night to an equivalent continuous sound level in excess of 55dB(A) are entitled to reimbursement by the airport operator of the costs of sound-proofed windows and sound-insulated ventilators. Such persons suffer annoyance and loss of comfort, since they cannot open windows at night; the health risk, compared to that of persons whose bedrooms are not protected against aircraft noise, are reduced [Greiser, 2010].

In order to take the first step towards meeting long-term targets, a further element of the efficiency strategy is implemented, namely Stage 1 of the measure 'Sound-proofed windows and sound-insulated ventilators'. The Aircraft Noise Protection Act is amended insofar as the threshold level for financing of passive noise protection measures at existing airports is reduced to $L_{(Aeq\ day)}$ = 60 dB(A) and $L_{(Aeq\ night)}$ = 50 dB(A). This adjustment could be made, for instance, during the prescribed review of noise limits laid down in the Aircraft Noise Protection Act, which is due every 10 years, and the next by 2017 at the latest. The number of persons that as a result of such an amendment are entitled for the first time to financing of noise protection measures is shown in Table 42.

Table 42: Number of persons additionally entitled to reimbursement of the costs of installation of sound-proofed windows and sound-insulated ventilators within the framework of the efficiency strategy

Installation of sound-proofed windows and sound-insulated ventilators		**Airport with a large volume of freight and night-flight operations**		**Medium-sized airport**		**Regional airport**	
		Base scenario	Efficiency strategy	Base scenario	Efficiency strategy	Base scenario	Efficiency strategy
Stage 1	$L_{Aeq\ day}$ 60 to <65 dB(A)	247	185	1.230	917	0	0
	$L_{Aeq\ night}$ 50 to <55 dB(A)	36.028	28.379	1.888	1.226	7	8

Particularly because of night-flight operations this measure involves high costs especially at the airport with a large volume of freight.

5.3 Effectivity strategy

In a further strategy, measures that are particularly effective in the medium term should be employed, despite the difficulty and cost of implementation. This strategy is termed an effectivity strategy. Additional to efficiency strategy measures, the following measures are applied in the effectivity strategy:

- Night-flight bans

  From the point of view of health protection, protection against night noise has the highest priority. With a ban on night flights all night-time target values can be met. In order to implement such a ban, however, modification of permission under air traffic law is necessary. At the same time, the concerns of the airport operator and protection of the general public against adverse environmental effects have to be weighed-up. A night-flight ban is therefore difficult to enforce, yet highly effective.

  In simulation of measures it is assumed that all short- and medium-haul flights and 80% of intercontinental flights are shifted to daytime operation; the remaining intercontinental flights and cargo flights at night are displaced to other airports where a night-flight ban is not in place.

- Introduction of enhanced, noise-reducing approach procedures

  Besides the noise-reducing approach procedures applied under the efficiency strategy, namely CDA and OLDLP, further approach procedures are described in Section 4.4 that considerably reduce noise levels on the ground. Here, too, the impact is hardly registered in the direct vicinity of the airport, but rather at a distance of some kilometres from the airport. Noise-reducing approach procedures are, above all, an effective mechanism for reduction of the annoyance effects of aircraft noise. Particularly effective is the segmented continuous descent approach (SCDA), which is applied under the efficiency strategy. For this purpose, 4D Flight Management Systems have to be further developed and employed in aircraft. Approach planning systems have likewise to be installed at airports [Boguhn et al. (2007), Neise (2007)].

The results of simulation for the effectivity strategy are shown in the following tables. In these tables, maximum equivalent continuous sound levels in built-up areas as well as health risks and the number of persons suffering sleep disturbance and annoyance are displayed for the base scenario and the effectivity strategy for the reference airports. In addition, the effects are converted into DALYs and monetary values. The applied methods and parameters are described in Section 3.3.

Table 43: Maximum equivalent continuous sound levels in residential areas and noise effects in the base scenario and with implementation of the effectivity strategy

Annoyance and health effects		**Airport with a large volume of freight[1)]**		**Medium-sized airport**		**Regional airport**	
		Base	Effectivity strategy	Base	Effectivity strategy	Base	Effectivity strategy
Maximum values in residential areas	L_{den} [dB(A)]	72	66	67	65	61	59
	$L_{Aeq\ day}$ [dB(A)]	63	65	65	64	58	58
	$L_{Aeq\ night}$ [dB(A)]	66	0	56	0	51	0
Number of persons suffering annoyance	1000 HA	30.9	6.7	10.2	6.2	0.7	0.4
	1000 A	116.5	38.7	42.5	29.4	4.4	2.5
	1000 LA	214.7	94.8	97.0	72.9	15.6	8.5
Number of persons suffering sleep disturbance	1000 HSD	11.0	0	1.4	0	0.05	0
	1000 SD	18.4	0	2.3	0	0.09	0
Sufferers from high blood pressure		4,490	717	1,554	777	84	38

[1)] and intense night-flight operations in the base scenario

Note: HA = highly-annoyed, A= annoyed, LA = little-annoyed; HSD = highly sleep-disturbed, SD = sleep-disturbed; see Section 3.3

Table 44: DALYs and costs of noise damage in the base scenario and with implementation of the effectivity strategy

Annoyance and health effects	**Airport with a large volume of freight and night-flight operations [1)]**		**Medium-sized airport**		**Regional airport**	
	Base	Effectivity strategy	Base	Effectivity strategy	Base	Effectivity strategy
Total damage in DALYs	2.439	302	663	306	37	17
Total costs of noise damage in mill. $€_{2010}$/a	188	50	62	39	7.0	3.7

[1)] and intense night-flight operations in the base scenario

As a result of the night-flight ban, aircraft-noise-related continuous sound levels and the number of persons suffering sleep disturbance at night are practically zero. Through both effectivity strategy measures there is a drastic reduction in annoyance and health effects. The maximum $L_{Aeq\ day}$ in built up areas increases though at the freight airport with its previously-high volume of night flights, since night flights are now partially shifted to daytime operation, and the optimized approach procedure has no noise-reducing effect in the vicinity of the airport.

As with the efficiency strategy, the long-term target value $L_{Aeq\ day}$ is considerably exceeded at both large airports under the effectivity strategy. In Stage 1 of the effectivity strategy measure 'Installation of sound-proofed windows and sound-insulated ventilators' only the reduction of the daytime trigger threshold is of relevance, since the night-time target value is not exceeded due to the night-flight ban. However, installation of sound-proof windows for protection against aircraft noise is not to be regarded as equivalent to the reduction of noise levels outdoors. Residents also want to spend time outdoors, and noise protection with opened windows is also severely limited.

Through the lowering of noise limits for establishment of noise protection zones the limit value for the ban on housing development is correspondingly reduced.

The following table shows, for the base scenario and the effectivity strategy, the number of persons in the vicinity of the airport that with an increase in the threshold level $L_{Aeq\ day}$ to 60 dB(A) would be entitled to reimbursement of the costs of noise protection measures. On account of the shifting of night flights to daytime operation, the number of persons exposed to noise at the airport with a large volume of freight and night-flight operations also increases. As a whole, due to the omission of night-flight operations, the number of noise protection measures that have to be financed is markedly lower than with implementation of the efficiency strategy.

Table 45: Number of persons additionally entitled to reimbursement of the costs of installation of sound-proofed windows and sound-insulated ventilators within the scope of the effectivity strategy

Installation of sound-proofed windows		**Airport with a large volume of freight and night-flight operations** [1)]		**Medium-sized airport**		**Regional airport**	
		Base	Effectivity strategy	Base	Effectivity strategy	Base	Effectivity strategy
Stage 1	$L_{Aeq\ day}$ 60 to <65 dB(A)	247	359	1,230	996	0	0

[1)] and intense night-flight operations in the base scenario

5.4 Solution approaches for achievement of long-term targets

As we have shown, even with application of the effectivity strategy there remains for the two large airports in 2020 and 2017 a substantial gap between daytime continuous sound levels and long-term target values. The long-term targets for the night-time period will be met with implementation of the proposed measures – especially as a result of the ban on night flights – at the reference airports. The question arises as to whether and how one can advance towards meeting long-term daytime targets in the decades after 2020.

Table 46: Maximum equivalent continuous sound level in built-up areas and the gap to target values under the effectivity strategy 2017/2020

Airport	**Level**	**Max. noise exposure**	**Gap to the target $L_{Aeq\ day}$ = 55 dB(A)**
Airport with a large volume of freight and night-flight operations	$L_{Aeq\ day}$[dB(A)]	65	10
Medium-sized airport	$L_{Aeq\ day}$ [dB(A)]	64	9
Regional airport	$L_{Aeq\ day}$ [dB(A)]	58	3

It has initially to be resolved how the number of flight movements at German airports will develop in the long term, namely after 2020. This will be influenced by a great number of factors and trends that partially cannot yet be forecast, including the declining population, the decrease in the economically-active population and the rise in the proportion of elderly persons, the raising of the official retirement age, changed leisure-time behaviour, increasing fuel prices, incorporation of air traffic in CO_2 emissions trading and economic growth, which is increasingly achieved through improvement in the quality rather than the quantity of goods. A forecast of future flight movements is therefore not possible; at best a projection.

Scenarios of the trend in air traffic in Europe and worldwide up to 2050 were prepared in CONSAVE 2050, a project of the European Commission [Berghof et al. (2006)]. The four scenarios are based on varied assumptions concerning economic growth, the reduction of regional disparities, environmental awareness and many other parameters. For the EU, the "Down to Earth" Scenario shows a decline of 3% in the number of passengers and of 28% in the number of flight movements between 2000 and 2050. In the other three scenarios there is growth, which is at its highest in the "Unlimited Skies" Scenario, in which the number of passengers increases by a factor of 3.29 and that of flight movements by a factor of 2.26. In the case of flight movements this corresponds to an annual growth rate of 1.65%. Such growth necessitates airport expansion; for example, through construction of additional runways.

In all scenarios it is assumed that the average size of aircraft increases. Changes in fleet mix and the effects of such changes on continuous sound levels in the area surrounding airports were modelled. With a constant number of flight movements, changes in fleet composition in the "Down to Earth" Scenario increase continuous sound levels by 2.7 dB(A). In the "Unlimited Skies" Scenario the figure is 4.1 dB(A).

No scenarios are available in CONSAVE for Germany. Due to the stronger decline in the population, compared to other EU countries, low rates of growth have to be expected. Energy scenarios for Germany, in particular, also contain scenarios of the development in air traffic. As an example, the results of a study on the trend in energy scenarios by Prognos/EWI/GWS (2010) can be mentioned, which, under the assumptions applied in the development of the above-mentioned factors, estimate *inter alia* the development of air traffic up to 2050. According to this, the number of air transport passengers in Germany stagnates after 2020, while air cargo (in tonnes transported) doubles between 2020 and 2050. With increasing aircraft size, this would correspond to stagnation in the number of flight movements after 2020. For the purpose of comparison, it can be mentioned that the number of takeoffs and landings according to Instrument Flight Rules in Germany increased in the last ten years (from 2001 to 2011) by 0.8% [ADV (2012)]. Kritzinger et al. (2009) estimate that the number of flight movements at 12 airports in and around the Federal State of Baden-Württemberg (including Stuttgart and Frankfurt) will increase between 2005 and 2025 by 0.8 % per annum.

It should also be noted that the capacity of existing airports is restricted. As the selected reference airports in this study have more or less large capacity reserves, they can extend the number of flight movements to a limited extent. Capacity would be further restricted by measures under the above-mention strategies, and in particular by night-flight restrictions and bans. Further expansion of airports encounters increasing resistance among the affected population, and is therefore hardly realizable. Expansion of Munich Airport, for instance, was recently rejected in a referendum.

The following estimations are therefore based on growth in the number of flight movements of 0% to 0.8% per annum in the period from 2020 to 2050. Such an increase in flight movements of 0% to 27% between 2020 and 2050 would – were the aircraft fleet mix and approach procedures not to change – give rise to an increase in equivalent continuous sound levels on the ground of 0 to 1 dB(A). There would also be the effects of a change in fleet composition in favour of larger and thus louder aircraft; an effect that has a greater influence on noise exposure than an increase in flight movements. Application of the above-stated estimates from the CONSAVE Project results in a further increase in noise exposure of about 2.7 to 4.1 dB(A); that is, a total of about 2.7 to 5.1 dB(A). The continuous sound levels in residential areas with high noise exposure, as shown in Table 46, could therefore increase in the period to 2050 by an amount of this order, and the gap to long-term target values widen accordingly, if one assumes that the aircraft fleet is no longer significantly improved. The further reduction of aircraft noise emissions is discussed below in terms of a measure.

Noise emissions of new aircraft tend to decline, since they are mostly quieter than older aircraft. At an international level, certification of aircraft is regulated by the International Civil Aviation Authority (ICAO). In ICAO Annex 16, noise limits are laid down in individual Chapters for every type of aircraft. The values laid down in Chapter 3 have been applicable since 1990 for all commercial aircraft certificated in the EU. Since 1 June 2006, the noise limits of Chapter 4 have to be applied for certification of all new aircraft. Cumulated over three defined measuring points on the ground, these noise limits are 10 EPNdB(A) below those in Chapter 3.

The question is raised as to how one can reduce the gap between expected continuous sound levels on implementation of the effectivity strategy and the long-term target, which at the airports under investigation will then amount to a maximum of about 15 dB(A). For this purpose, three long-term measures are outlined below:

A) Development and operation of noticeably quieter aircraft

The best solution for the problem of aircraft noise is obviously the development and operation of new aircraft with lower noise emission, with which target values can be achieved. Since such new aircraft concepts have first to be developed, one has to rely on rough estimations with regard to achievable noise reduction.

In its research programme "Environmentally Responsible Aviation (ERA)", NASA challenged the aviation industry to develop revolutionary new aircraft concepts, with which considerable progress concerning sound emission reduction, fuel consumption and NOx emission reduction could be expected. With its 'blended wing-body' concept, Boeing has designed an aircraft whose turbojet engines are screened towards the ground. NASA had one of its concepts simulated and evaluated with models in Guynn et al. (2004), and achieved a reduction at each measuring point of between 12 and 21 dB EPNL[56].

In the "National Aeronautics Research and Development Plan" of the US Government, the target is set of developing aircraft within 25 years that fall below ICAO Chapter Four noise limits by a cumulated 62 dB EPNL; that is, by an average of 20.7 dB EPNL at each of three measuring points [National Science and Technology Council (2010)].

MTU/Öko-Institut (2006) estimate the cumulative noise reduction potential for new types of aircraft at 18 to 22 EPNdB, or an average per measuring point of 6 to 7 EPNdB. The Advisory Council for Aeronautical Research in Europe (ACARE) sets in its Vision for 2020 the objective of a reduction of noise level on the ground of about 10 EPNL dB with new aircraft in the period from 2000 to 2020.

The research network '*leiser Verkehr*' (Quiet Traffic) estimates that the noise level on the ground with new aircraft will decrease by 2025, compared to 2006, by about 10 dB(A) [DLR, 2006)]. In the CONSAVE study (see above) it is assumed that in the long term newly-developed aircraft of a particular type will reduce noise level on the ground by 18 dB [Berghof et al. (2006)].

The aviation industry will only develop new revolutionary concepts when it is set corresponding standards at the international level; that is, when the ICAO further reduces noise certification limits. NASA has set in its research programme the development target that new aircraft concepts (see above) should be operational before 2030. If one does not reduce service life of aircraft manufactured earlier, it will take about another 30 years – that is, up to 2060 – before only aircraft of this new type take off and land. On the other hand, improvements will occur from around 2030, since older aircraft that are gradually replaced will tend to be noisier aircraft.

We therefore propose that the noise limits laid down in ICAO Annex 16, Chapter 4 be drastically reduced for aircraft that should be certificated from 2030 on. Decisions on noise certification limits are made by the ICAO Council with its 36 Member States, including Germany. Such a reduction in noise limits should be carried out as soon as possible, in order to provide aircraft manufacturers with sufficient time for necessary development work.

With complete renewal of the aircraft fleet – that is, after 2060 – a reduction of noise levels on the ground of more than 15 dB(A) would appear to be possible. On this premise, the long-term, daytime target value of 55 dB(A) could be met at least in the case of the airports under investigation. .

The long-term target $L_{Aeq\ night}$ is already achieved in the efficiency strategy by means of a ban on night flights. Should this be unenforceable, however, the introduction of new aircraft concepts at the airport with a large volume of freight and night flight operations is insufficient to decrease $L_{Aeq\ night}$ to or below the long-term target value. This emphasizes the importance of a night-flight ban – or at least a drastic restriction of night flights that permits only a few exemptions from a night-flight ban – as an element of an aircraft noise protection strategy.

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[56] The term EPNL (effective perceived noise level) was created for the purpose of adequate assessment of aircraft noise exposure, and it is used almost exclusively in ICAO certification. It comprises time and tone correction factors, but cannot be compared with other A-weighted levels. A reduction by 1 EPNL dB approximately leads to a reduction of 1 dB(A).

B) Reduction of trigger thresholds in the Aircraft Noise Protection Act

Where areas remain in which long-term target values are exceeded despite the above-mentioned measures, noise levels for determination of trigger thresholds – above which financing of constructional noise protection measures as well as bans on housing development pursuant to the Aircraft Noise Protection Act occur – should be further reduced to the long-term target values of $L_{Aeq\ day}$ = 55 dB(A) and $L_{Aeq\ night}$ = 40 dB(A), not only for existing airports, but also for new and fundamentally expanded airports. As a result, in all areas that have higher noise exposure also after 2050, the costs of constructional noise protection measures have to be reimbursed by airport operators. Besides the Aircraft Noise Protection Act, the Second Ordinance on implementation of the Aircraft Noise Protection Act has also to be amended. Furthermore, in such areas no new housing development is permitted, in order not to further increase the number of persons exposed to aircraft noise.

C) Reduction in the number of flight movements through displacement to other airports or, in the case of short distances, to rail and road

If the intention is to achieve further reductions in aircraft noise more quickly in the period after 2020, this can be achieved, additional to the further development of measures discussed in Chapter 4, by reduction of flight movements at airports with high noise exposure, remaining traffic being displaced to airports with lower noise exposure, or even to rail and road. With displacement to rail and road it has to be examined, however, whether additional exposure at the new airport does not outweigh the decrease in noise damage at the airport where flight movements are reduced. How this can be realized in practice is the subject of a separate study. In simplified assessment, the effectivity of the measure is lower than that of more stringent ICAO Chapter 4 noise certification limits. If one reduces air traffic by 40% with unchanged fleet composition and the same flight routes, one achieves a reduction in continuous sound level of about 2.2 dB. There is also noise reduction that is not quantified here, which results from a change in fleet composition, due primarily to displacement of intercontinental and cargo flights, and alternative flight operation regimes that are made possible by a reduced number of flight movements.

The sites of existing airports have been mostly chosen on account of their proximity to cities and agglomerations, and therefore found in areas with high population density. This makes it difficult to find airports in areas with lower population density and lower noise effect that could still absorb a largish number of additional flights. A solution is the planning of new airports (hubs) at sites that are optimized in terms of noise effects; that is, specifically located in sparsely-populated areas. Since the destinations to which both passengers and freight are transported are still in urban centres, passengers and freight must therefore be transported quickly and efficiently from these hubs into such urban centres. For relatively short distances (up to around 200 kilometres) the railway network should be used, and in the case of freight also heavy-duty vehicles. For this purpose, the airports should have very good connections to the ICE rail network and to the motorway network. Greater distances to travel destinations could be handled with connecting flights within Germany. The new airports would be used, in particular, by cargo flights (also at night), intercontinental flights and medium-haul flights to destinations that are less in demand and at a greater distance from Germany.

The number and location of the hubs would be determined by optimization of feeder traffic systems. A central hub would have the advantage of optimum combination of flights; the remoteness from urban centres in northern and southern Germany would also necessitate, however, a great deal of connecting transportation within Germany. Two hubs in northern and southern Germany could be planned in such a way that no urban centre is at a linear distance of more than about 250 kilometres from a hub. As a result, air traffic and thus aircraft noise in the vicinity of airports in agglomeration areas could be markedly reduced and, moreover, air traffic switched to quieter aircraft.

A long planning and construction phase has to be taken into account for the building of new airports outside large urban areas. The new Berlin-Brandenburg Airport will probably come into operation 21 years after commencement of the planning phase. One can therefore expect that even with an expeditious planning process a new hub would commence operations in 2035 at the earliest. A further aspect is the considerable cost of new infrastructure and, if necessary, complete revision of the existing legal framework for responsibilities and planning co-ordination.

For construction of such hubs, traffic planning for Germany (perhaps even involving neighbouring countries) would be an optimal approach.

Germany already has a high settlement density. With construction of new airports, even in sparsely-populated areas, it can hardly be avoided that persons will be exposed to noise levels above the ambitious long-term target values. Should in such a case technical measures not provide a remedy, resettlement of the affected population in less-noisy areas would be an option for compliance with noise limits. Experience is available, in particular, with resettlement in connection with opencast lignite mining. In the case of the Garzweiler ll opencast lignite mine in North Rhine-Westphalia, for example, 7.600 persons were affected by resettlement. In order to preserve the social cohesion of the population involved, the attempt was made to offer a single new building site for all residents of a specific municipality affected by resettlement. With the construction of the new Berlin-Brandenburg Airport, 370 persons who lived directly on the planned airport site were resettled. In this case, the residents were compensated on the basis of "new for old", which meant that houseowners could build or buy a comparable new house.

5.5 Legal implementations

The legal issues that have to be considered with implementation of the three proposed strategies, or solution approaches, are discussed below. So far as the legal framework of individual measures is concerned, reference is made to the detailed comments in Chapter Four and in the Annex (separate document, in German only). The remarks below are to be regarded as supplementary.

Efficiency strategy

The efficiency strategy is comprised of the measures 'noise charges', 'flight procedures (CDA/OLDLP)' and 'sound-proofed windows and sound-insulated ventilators'. With implementation of the efficiency strategy the following applies:

The efficiency strategy makes use of existing noise charges to influence behaviour. Noise charges are accordingly not only a means of financing the costs of reduction or avoidance of noise problems; they equally serve the promotion of operation of quieter aircraft. Since May 2012, Article 19b of the Air Traffic Act requires, in the case of large commercial airports, differentiation of charging systems according to noise emissions. As a result, no airport operator can avoid – also with reference to individual autonomy – the levying of noise charges. The Act does not regulate how such differentiation should be practised. EU Directive 2009/12/EC on airport charges, whose implementation in German law is the purpose of the amendment to the Air Traffic Act, contains no further specifications. Insofar as certain target values should be achieved, however, the Air Traffic Act would have to provide for specifications as well as detailed differentiation criteria. A common charges policy on the part of all airport operators is also conceivable, which could be established by way of voluntary commitment; provided, of course, that airport operators were willing to commit themselves to a voluntary agreement.

Determination of flight procedures, such as continuous descent approach (CDA) in the efficiency strategy, and including flight tracks, flight height/altitude and recording points, is carried out by decree pursuant to Article 27a (2) of Air Traffic Regulations (*LuftVO*). Not only the spatial distribution of air traffic but also approach and departure procedures are the subject of these regulations, which are issued by the Federal Supervisory Office for Air Traffic Control (*BAF*) on the basis of preliminary planning by German Air Traffic Control (*DFS*). The aircraft pilot receives "three-dimensional specifications that have to be complied with on his ground track"[57]. Safety aspects are also reflected in the specifications for pilots in flight procedures of the Federal Supervisory Office for Air Traffic Control pursuant to Article 1 (1) of Air Traffic Regulations, but are not decisive for the content of such specifications. Determination of flight procedures is based on a weighing-up process, in the course of which other interests have also to be taken into account.[58] Aircraft noise abatement, in particular, must have an influence on the decision. German Air Traffic Control (*DFS*) is supported in its planning activities by the Aircraft Noise Commission and the Federal Environment Agency, bodies that, according to Air Traffic Regulations, have to be involved in the process and provide their specific expertise. The role and influence of these two bodies are, however, restricted. For greater consideration of noise abatement issues, earlier and stronger participation of the Federal Environment Agency or support of the Aircraft Noise Commission in the form of expert advisors is conceivable. Greater emphasis on aircraft noise abatement in legal provisions on flight procedures would also be useful.

In determination of flight procedures it has to be borne in mind that assignment of the CDA procedure – and, in principle, all flight procedures laid down in the AIP (Aeronautical Information Publication) of German Air Traffic Control (*DFS*) – by statutory instrument is not necessarily decisive for their application.[59] According to Article 27a (1) of Air Traffic Regulations, individual clearance has, in principle, priority over flight procedures laid down by statutory instrument. The sense and importance of this regulation are not in question; it is absolutely essential, in order to be able to guarantee the safety and efficiency of air traffic in every situation. Individual clearance may not, however, become the rule, and thereby more or less 'annul' determination of flight procedures by way of ordinance.[60] The proposed arrangement of the CDA as standard instrumental approach procedure will not affect this regulation. Therefore, a deviating approach procedure can be applied in a particular case as it is already common practice. It would, however, be possible to supplement Air Traffic Regulations with an appropriate 'recommendation' on maximum use of a particular procedure, and to create a rule governing how exceptions would have to be requested and justified as well as approved and documented. Adoption in the corresponding official instructions of the DFS[61] might also be a

[57] Pache (2012), p. 5.

[58] Decisions of the Federal Administrative Court: BVerwGE, decision of 24.06.2004, NVwZ 2004, p. 1229, 1231.

[59] On legal misgivings concerning a too-generous administrative practice and the emergence of '*de facto* flight routes' through individual clearance, cf. in particular Pache (2012), p. 8 f.

[60] In practice, such conflicts can be observed time and again; cf. for instance, the decision of the Constitutional Court of the State of Hessen of 11.02.2003, http://www.lareda.hessenrecht.hessen.de/jportal/portal/t/s15/page/bslaredaprod.psml?&doc.id=MWRE108640300%3Ajuris-r01&showdoccase=1&doc.part=L.

[61] Cf. Regulations on approach and departure control in Munich, Doc. 16/8269 of the Bavarian State Parliament (*Landtag*) of 13.05.2011.

way to achieve consistent application of CDA. Ultimately, awareness of noise-reducing conduct has also to be created and promoted on the part of airlines and pilots, and this could be achieved by means of training and airline instructions to pilots.

Constructional noise protection measures – as a further element of the strategy – are legally anchored in the Aircraft Noise Protection Act (*FluglärmG*). The law currently in force recognizes not only building bans but also the obligation to invest in constructional noise protection. Article 5 of the Act provides for "graduated" building bans that differ according to the type of use and the need for protection of use as well as to the level of noise exposure during the day and at night. With reference to guidelines for protection zones, it is possible that building bans first take effect from LAeq day = 60 or 65 dB(A). The strategic objective of imposing building bans already from a level of 55 dB(A) therefore requires amendment of the Aircraft Noise Protection Act. It has also to be considered that building restrictions also encroach on the freedom of ownership of the respective land owners as well as on the planning autonomy of municipal authorities. Expansion of building bans has consequences for municipal infrastructure and urban development. Even now, it is occasionally not possible for municipalities to build new schools or kindergartens. The legal barrier is reached when municipal self-government, which is guaranteed under Article 28 (2) of German Basic Law, is called into question. For land owners Article 14 of German Basic Law provides the constitutional standard, according to which restrictions on the possible use of land are to a certain extent to be accepted (possibly on payment of compensation).

In the case of investment in noise protection, Article 9 of the Aircraft Noise Protection Act, in connection with the Second Aircraft Noise Protection Ordinance, grants owners of existing residential buildings entitlement to reimbursement of the costs of certain constructional noise protection measures. The cost of installation of ventilation appliances is reimbursable under current law in the case of owners of land situated in the night-time protection zone. In both cases, the respective airport operator is liable for such costs pursuant to Article 12 of the Aircraft Noise Protection Act; in the case of newly-constructed buildings the building owner has himself to bear the cost. The proposed strategy initially has no effect on the basic concept. The proposal does, however, extend the circle of those entitled to reimbursement of costs. The present 'capping' of costs and timing of eligibility for reimbursement are not necessarily conducive to implementation of the outlined idea. Here, a change in the law would therefore be necessary and desirable, provided that additional investment is concerned that gives rise to noticeable improvement in the protection of persons exposed to noise and does not 'over-compensate' the cost.

Considering efficiency strategy measures as a whole, no legal obstacles can be perceived in the interaction of individual measures. Noise charges, approach procedures and constructional noise protection interact, and can exist side by side without legal distortion.

Effectivity strategy

The strategy of "strong noise protection" is founded on the basic strategy and adds a further element to the 'instrument mix', namely a strict ban on night flights. For the measures 'noise charges', approach procedures' as well as 'sound-proofed windows and sound-insulating ventilators' and 'building bans' the same comments apply as in connection with the respective measures in the efficiency strategy. Flight procedures are proposed that require upgrading in aircraft and at airports (SCDA); without such upgrading they cannot be implemented. It has to be added, however, that with aircraft that satisfy ICAO rules and are certificated according to the rules but cannot perform the flight procedure in question the flight procedure may not be *conditio sine qua non*; that is, it may not result in an operating ban. If, from the safety point of view, the procedure cannot be classified as 'safe', the noise protection aspect has to give way to the greater priority of protection of the lives and health of passengers.

The strict, generally-valid ban on night flights that is part of the effectivity strategy would be an innovation compared to current law. Night-flight bans and restrictions are at present always the result of an airport-specific decision in a particular case. Within the framework of planning approval or authorization to operate an airport, protection against unacceptable noise and particular consideration of peace at night for the population are a legislative precept (cf. Article 29b Air Traffic Act). How concerns of noise protection are taken into account, whether night-flight restrictions are prescribed and, if so, which restrictions, is decided by the planning approval authority following proper weighing-up of the issues involved. The protection of the public against the adverse effects of aircraft noise is particularly important, yet it is not determinative for the decision of the authority. A general night-flight ban – that is, a ban that is not dependent on a particular case – has to be anchored in law, whereby exemptions have to be permitted should the protection of the public not necessitate the ban. One decision based on a weighing-up process could not be avoided by lawmakers. In the case of prohibition, fundamental rights stand face to face: economic freedom as enshrined in Articles 12 and 14 of German Basic Law on one side, and the right of the individual to be protected against noise-related effects of air traffic on body, health and property on the other side. The rights of aircraft manufacturers and air traffic users and the rights of residents enjoy equal constitutional protection. The protection of life and health pursuant to Article 2(2) of German Basic Law can and must carry particular weight; it may not, however, thwart other constitutional rights. A night-flight ban must be in accordance with the noise situation at the respective airport site, and take account of the constitutional prohibition of excessiveness. Whether a general night-flight ban is politically enforceable appears to be questionable.[62]

In the interaction of measures combined in the effectivity strategy, no legal obstacles can be identified that, would set one measure against another.

Long-term strategy for infrastructure efficiency

In this strategy, the reduction of noise certification limits for new aircraft, the displacement of flight movements to other airports or other means of transport as well as the renaturation of residential areas greatly exposed to noise are brought together. To put the strategy into perspective one must first state that the proposals go, in part, beyond the measures discussed in Chapter 4 and should be regarded as approaches rather than outlined measures.

The development of quieter aircraft can be most easily realized from a legal point of view at the international level. Tightening-up of noise limits through the ICAO would commit all member States, including Germany, and as a binding regulation under international law would have the broadest impact. Should stimuli through promotional measures be regarded as promising, the necessary agreements would have to be laid down in international conventions. The legal possibilities of achieving a reduction in noise limits solely at a national or European level are the subject of dispute, and within the scope of the strategy they are not regarded as expedient.

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[62] According to a newspaper report of 05.04.2012, the Federal Minister of Transport rejects a general night-flight ban at German airports: "Since in the vicinity of airports not only densely-populated but also sparsely-populated areas are to be found, it is proper that the Federal States continue to lay down the permitted hours of operation." http://www.maerkischeallgemeine.de/cms/beitrag/12306108/62249/.

The displacement of air traffic is treated within the strategy as a complementary element of control. At the same time, this strategy also relies on operating restrictions in the form of noise quotas and noise charges. As far as the idea of new location concepts for airports is concerned, it can be said that the location of an airport is the result of land-use and technical planning. In the authorization of large projects, co-ordinated use of space pursuant to planning law and planning approval pursuant to air traffic law are interconnected. Through regional planning, the bases for construction and expansion of an airport are laid down. Within the framework of sovereign functions, it is the duty of the federal states to create the legal bases for planning the airport, for instance through a regional development plan.[63] According to the Federal Administrative Court, "the regional planning authorities are [therefore] empowered to designate sites for infrastructure projects that are significant for a particular area."[64] When authorization is requested for an airport project at the site designated by the regional planning authority, the Federal Administrative Court went on, "it is neither the duty of the planning approval authority nor is it empowered to replace, confirm or amend preceding spatial planning considerations with its own open and unbiased consideration of, in its view, significant site requirements. The planning approval authority has to accept the result of comparison of sites in the regional planning process. That is justifiable, since the choice of a site for an international commercial airport is primarily a spatial planning decision."[65] The strategy of national planning emphasizes the important of spatial planning; it requires on the one hand, however, a rearrangement of responsibilities between federal and federal state authorities, and possibly also a change in relations between spatial planning and site-related technical planning on the other hand.

Renaturation of residential areas subject to noise exposure should be achieved through resettlement of the persons affected and exchange of land either within the particular municipality or between municipalities. This strategic approach serves the purpose of spatial separation of divergent interests in a conflict over aircraft noise. Resettlements have already been demanded and, in part, also practised.[66]

Resettlement based on agreement of all parties (property owners, airport operators and municipalities) are always possible and raise no particular legal issues.[67]

Legal concerns do not arise concerning interaction of proposed measures within and among long-term approaches. They are to be regarded in each individual case as complementary.

6 Monitoring and management concept

The monitoring and management concept serves the purpose of recording the development of the noise situation at German airports. It enables recognition of whether in individual cases, or for airports as whole, improvements have been made towards attainment of target values. It shows whether changes in noise

[63] For Frankfurt Airport, for example, see Doc. 16/6057 of the Hessen State Parliament of 26.09.2006.

[64] Decision of the Federal Administrative Court (BVerwG) of 16.03.2006, 4 A 1075/04, margin no. 65.

[65] Ibid. margin no. 72.

[66] "Lärm-Opfer umsiedeln" [resettle noise victims], interview with Thomas Jühe, Head of the Aircraft Noise Commission, *Frankfurter Neue Presse*, 25.05.2012, cf. http://www.fnp.de/fnp/region/lokales/frankfurt/l-rmopfer-umsiedeln_rmn01.c.9869191.de.html.

[67] For instance, within the framework of construction of the new Berlin-Brandenburg Airport, where according to the Berlin State Ministry for Urban Development, the Diepensee community as well as parts of the Selchow community have been resettled with the consent of the respective residents; cf. http://www.stadtentwicklung.berlin.de/verkehr/politik_planung/luft/schoenefeld/index.shtml.

strategy measures are necessary, identifies whether they are effective and offers stakeholders planning security insofar as it defines the trigger thresholds that apply. At this point, no detailed concept for direct implementation of a noise strategy can be presented. Data in this report on the effectiveness of different measures regarding the noise exposure of the affected population is merely of an indicative nature. The monitoring and management concept can also be more precisely defined within the scope of specification and clarification of an aircraft noise strategy. Important factors for the success of reliable monitoring and management are:

- defined, manageable objectives,
- clear responsibilities regarding data recording and processing,
- dependable recording and reliable indicators,
- interpretation by the responsible, independent monitoring and management unit,
- clear responsibilities for compliance with targets and eventual implementation of measures,
- control of the impact of changes in measures,
- clear definition of threshold values and trigger thresholds and
- the setting of intermediate targets as motivator.

The target values of the aircraft noise strategy in this study should be gradually attained. An appropriate data monitoring system will be required that records the development of the noise exposure situation in terms of the initial status and identifies the degree and rate of progress of strategy implementation. This monitoring data is assessed within the scope of controlling (measurement of results) and compared with target values (target-performance comparison). Closely associated with monitoring and controlling is a management system focused on achievement of targets set in the strategy. If the target-performance comparison shows deviations (such as, for example, persons still exposed to daytime aircraft noise above 55 dB(A)), measures or mechanisms applied for implementation of the strategy have, where appropriate, to be adjusted or modified. How the legal implications of different aspects should be dealt with is explained in respect of individual measures in the corresponding sections of Chapter 4, and for the strategies themselves in Section 5.5.

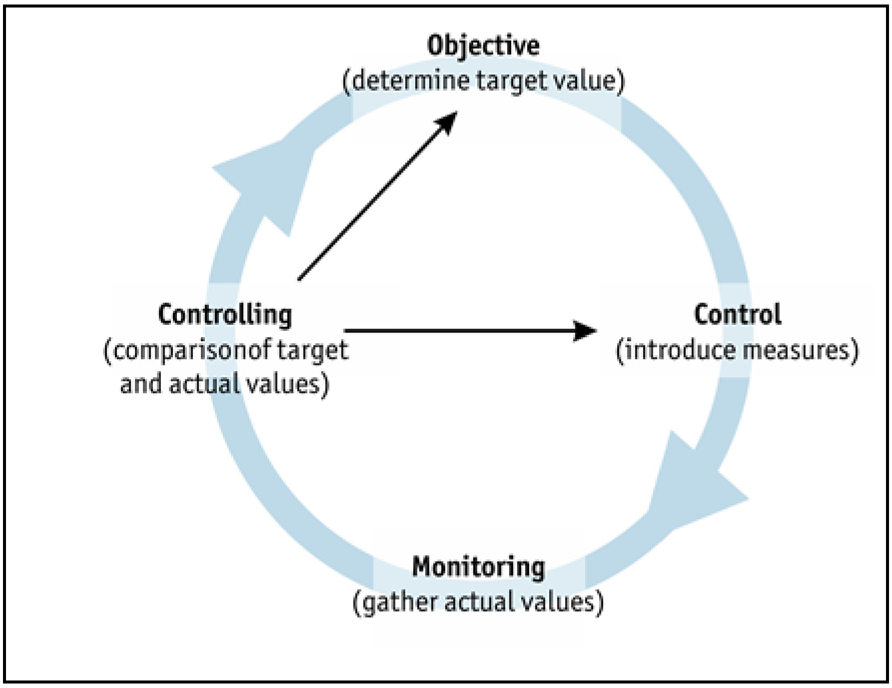

Figure 14: Process cycle of monitoring, controlling and management

6.1 Indicators

It is pointed out in Section 2.5 of this report that a noise strategy should have the primary objective of protection against the adverse effects of night noise and daytime noise on human health, and the secondary objective of protection against annoyance. In Section 2.3 measureable and calculable indicators are stated for these targets, as well as their long-term target values at which the objectives are regarded as attained.

Table 47: Long-term target values of an aircraft noise strategy

	$L_{Aeq\ night}$	$L_{Aeq\ day}$	**Annoyance Index AI = number of highly-annoyed persons (HA)**
Long-term target	40 dB(A)	55 dB(A)	Reduction insofar as is possible efficiently

With concrete implementation of the respective aircraft noise strategy, measuring and calculation techniques must also be specified for these target values, in order that the strategy is implemented on a comparable basis at all airports concerned.

At the beginning of the monitoring and controlling process the initial status of these indicators must be recorded, so that the progress of all future measurements can be presented in terms of initial status and target value. On this basis, the degree of target attainment can be given for the time of each observation.

6.2 Monitoring

The target indicators are comprised, on the one hand, of two hard indicators for noise exposure, which can be explicitly recorded by way of exposure measurements or calculations ($L_{Aeq\ night}$ and $L_{Aeq\ day}$). On the other hand, target indicators also comprise a soft indicator for noise annoyance, which is based on a standardized annoyance-response relationship. Within the scope of monitoring, further indicators must be applied that in subsequent controlling enable recognition of the causes of observed developments in target indicators. This, in turn, enables the carrying out of appropriate adjustment of measures in the subsequent management process.

In monitoring every airport in Germany, the following indicators have to be ascertained for the initial status and at yearly intervals, and then reported to the responsible enforcement authority (monitoring and management unit).

Table 48: Necessary information required from airports for monitoring and management of target attainment

Information required to be submitted annually by every airport
• Noise contours $L_{Aeq\ day}$ with effect from 55dB(A) in 1dB steps
• Noise contours $L_{Aeq\ night}$ with effect from 40dB(A) in 1dB steps
• Noise contours L_{den} with effect from 42dB(A) in 1dB steps
• Number of flight movements at the respective airport in the year under investigation
• Fleet mix at the respective airport
• System of noise-related takeoff and landing charges
• Applied approach and departure procedures in the year under review, and frequency of application
• Net migration of the population in areas within noise contours with L_{den} of 40dB and higher
• Possible measure-specific additional information: When, compared to the initial status, measures have to be supplemented or adjusted at an airport, additional specific information has to be submitted, in order that the enforcement authority can recognize whether the measure has the desired effect (for example, trend in the number of night flights in the case of night-flight restrictions).
• Should indicators dramatically deviate at an airport (for example, following infrastructure development), a detailed analysis of such development is required together with identification of individual influencing factors, in order that in subsequent years monitoring and controlling can be appropriately conducted.

In order to be able to interpret information submitted annually by airports, the authority responsible for enforcing the noise strategy also requires the updated basic data mentioned below. Normally, it will suffice to update such basic data every three to five years, since changes are mostly not dramatic. On the basis of noise contours of airports the number of persons affected can be determined.

- Population maps for the initial state, for overlapping with noise contours to determine the number of persons initially exposed to noise at each airport.

- Periodic new population maps (for example, every 3 years) for overlapping with annually-transmitted noise contours for determination of the number of persons exposed to noise at each airport. Comparison with the initial population map shows the number of persons exposed to noise in the previous residential area, and how many now live in a newly-built residential area.

It is important for subsequent controlling and management that every time monitoring is carried out the number of persons exposed to noise above a target value is available and classified according to a) persons that were exposed to noise within the residential area at the time of the initial status, and b) persons that have since moved into the noise-polluted area (either into the previous or the new residential area). Persons are regarded as newly-exposed to noise who live in areas that in the initial status – that is, in the year of introduction of monitoring – were not yet developed. On the basis of this distinction, the proportion of persons exposed to noise above a target value can be identified that results from housing developments in the vicinity of an airport. This information is on the one hand pivotal for recognition over a period of time of measures whose effect has been too weak. On the other hand, it indicates new or further measures (for instance, dealing with in-fill development within existing residential areas or stipulation of no additional residents following redevelopment), which have to be implemented within the framework of the aircraft noise strategy.

The precise timing of measurements, recording standards and standards for transmitting monitoring data to the enforcement authority have then to be clarified.

It is important in analysis of monitoring data to consider central exogenous factors of influence (such as, for example, the volcano eruption in 2010 or the "Arabian Spring" in 2011). This is important, in order that temporary exogenous factors that dampen air traffic growth are not interpreted as the success of applied noise protection measures.

6.3 Controlling

Evaluation and interpretation of monitoring results is undertaken within the framework of controlling. It has to be examined to what extent the observed situation is developing towards the target values. The degree of target attainment in respect of the three target values for night noise, daytime noise and annoyance should be compared with the long-term target for each individual airport and for airports throughout Germany.

An early indication of whether expansion or adjustment of measures is required at an airport can be obtained from initial screening of data submitted by airports and processed by the enforcement authority. Basically, for every airport, it has to be assessed whether the targets have been achieved and whether a trend can be identified. From these fundamental assessments four possible combinations emerge (for targets relating to night noise on the one hand, and for targets relating to daytime noise on the other). The 'softer' target relating to annoyance can be called upon as indicator for expected future development (for example, an increasing proportion of the highly-annoyed (HA) can point to a growing trend in future exposure).

If the target has not been met, and the trend points to a worsening in the situation, then, in principle, adjustment or modification of measures is indicated. If the target has not been met, and the trend points to an improvement in the situation, it has to be more closely examined whether previous measures can give rise to further improvement quickly enough (that is, examination of a possible dynamic effect). If not, then adjustment or modification of measures is likewise indicated. If the targets have been achieved, but the trend shows a worsening in the situation, it has then to be more closely examined whether additional measures are required, in order not once more to fall short of target values. At best (target attainment and a trend towards further improvement), no modification of measures is required, and a relaxation of existing standards might even be conceivable.

Table 49: Rough appraisal of the need for action

		Trend of development	
		Improvement	***Improvement***
Target attainment	***Yes***	+	+/-
	No	-/+	-

In a rough examination of the need for action a distinction has to be made for target attainment between day and night. The indicator for annoyance is additionally used as indicator for a possible trend in future developments. A stronger increase in the number of annoyed persons can suggest that in future an increase in annoyance values is to be expected without further measures.

An assessment overview can be prepared for long-term targets on the basis of the above rough appraisal, from which the need for action, classified according to stakeholder or area of action (airlines, airports, noise abatement measures, regional planning etc.), can be deduced for modification of measures. In order to recognize the areas in which there is a need for action, the enforcement authority requires the additional information listed in Table 48. Table 50 provides illustrative examples.

Table 50: Deduction of need for action following a rough appraisal

Objective	Target value indicator	Target attainment / trend, further indicators	Need for action
No sleep disturbance	Zero persons > $L_{Aeq\ night}$ 40dB existing residential area	• -/+ • *Overall reduction in the number of flight movements at night,* • *Improved fleet mix at night*	*No*
	Zero persons > $L_{Aeq\ night}$ 40dB new residential area	• -/- • *Increased number of persons subject to noise exposure at night due to new departure routes*	*Yes, concerning passive noise protection: passive noise protection programme for residential areas exposed to night noise for the first time.* *Yes, regarding spatial planning: new measures are required for building restrictions or bans in future for areas exposed to aircraft noise at night.*
No damaging daytime noise	Zero persons > $L_{Aeq\ day}$ 55dB existing residential area	• -/+ • *Decreasing number of flight movements* • *Improved fleet mix*	*Probably no.*
	Zero persons > $L_{Aeq\ day}$ 55dB new residential area	• -/- • *Increase in the number of persons exposed to aircraft noise due to expansion of the residential area*	*Yes, regarding spatial planning: new measures are required to prevent expansion of the residential area as well as of future exposure to daytime aircraft noise.*
Low annoyance	Lowest possible number of annoyed persons > 47dB existing residential area	• -/+ • *Slight decrease in the number of annoyed persons*	*No*
	Lowest possible number of annoyed persons > 47dB new residential area	• -/- • *Slight increase in the number of annoyed persons*	*Yes, soft measures (information, involvement etc.)*

Note: *Cursive text*: illustrative examples

A national table or map can be prepared that shows the degree of target attainment depending on airport location. This provides, in a regional overview, a good overall impression of the structure of implementation of noise reduction measures with regard to the targets of the aircraft noise strategy. It also shows target deviations at different types of airport, and whether there are greater target deviations in individual regions of Germany or at certain airports than in other regions or at other airports. This provides the basis for the subsequent review of measures.

In order that target-performance comparison can be appropriately assessed and a need for action identified within the scope of controlling, threshold values and trigger thresholds have to be established. These define target-deviation threshold values above which measures have to be supplemented or tightened-up, and the depths of intervention that are differentiated in the process. These threshold values represent the preferences of society (for example, until when the targets should be met), which have to be determined in a political process and are not scientifically deducible. So that aviation stakeholders have planning security, however, and are then able to take efficient decisions concerning aircraft noise, it is important to define and communicate such thresholds at the beginning of implementation of the aircraft noise strategy.

Table 51: Exemplary threshold value with depth of intervention

		Depth of intervention ***with quantitative measures***		
		Greatly exceeded (x% target attainment, or y persons)	**Averagely exceeded** (x% target attainment, or y persons)	**Slightly exceeded** (x% target attainment, or y persons)
Indicator	***Threshold value***			
Target: daytime noise	from x% target attainment	*Renovation of residential buildings* *Target:* zero persons > $L_{Aeq\ day}$ 55dB, *initial status 13,000 persons, today 11,000 persons; that is 15% target attainment*	*Building ban*	*Influence fleet mix*
Target: night noise	from x% target attainment			
Target: annoyance	from x% target attainment			

Note: *Cursive text*: illustrative examples

Graduated noise limits are helpful in defining and implementing threshold values and trigger thresholds. When the trigger threshold value is exceeded initial measures take place. When further trigger threshold values are exceeded, the package of measures and the severity of possible measures become more stringent. With regard to spatial planning measures, it would be very useful for controlling by the enforcement authority for supplementary information to be available concerning where noise is to be expected in future, and at what level, in order to be able to act preventively and prevent housing development in future noise-polluted areas.[68]

Responsibilities / allocation of functions / obligations

At the very beginning it should be established where responsibility for effective controlling lies. The legal basis for controlling exists when corresponding limit values are established and an enabling provision is laid down by law. If this is the case, controlling should be prescribed by public authorities and its conduct delegated to airports. These airports have to compile the required data at the intervals stipulated in accordance with the methodical specifications of the enforcement authority. Airports then regularly report the results of controlling to this authority, together with a proposal concerning how the measures should be adjusted or modified in future at the respective airport, in order to meet the long-term targets of the noise strategy. The enforcement authority examines such information and approves or modifies the proposed measures.

This results in allocation of functions in the monitoring of successful implementation of the noise strategy, which concern the definition of indicator methods and data compilation as well as creation of the legal bases of the legislature at a federal level (*Bundestag*, see Section 5.7) for execution of the required measures. Enforcement is effected by the competent executive authority. Shortcomings in target attainment determined in the course of controlling can be remedied by the tightening-up or modification of measures already applied, or by application of new measures.

The following table shows the measures that appear to be most appropriate for attainment of targets concerning night-noise exposure, daytime noise exposure and annoyance.[69]

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[68] At Zürich Airport, for example, there is a "demarcation line" that indicates the maximum future extension of noise exposure. This is combined with building restrictions – binding in planning terms – within the border, even when there is no noise exposure at present.

[69] Based on the results of model calculations for broadly-examined measures in Chapter 4.

Table 52: Appropriateness of varied measures by target deviation

	Deviations from night-noise target	***Deviations from daytime noise target***	***Deviations from annoyance target***
Measures with an impact on fleet mix (charges)	x	X	X
Noise or movement quotas	x	X	X
Night-flight restriction	x		X
Night-flight ban	x		X
Approach and departure procedures, route optimization			X
Noise protection measures in buildings	x	X	X

Depending on whether deviations are determined in connection with protection against exposure to night noise, daytime noise or noise annoyance, various measures, or modifications of measures, come into question. With deviation from the night-noise target value, modification of measures should be chosen that directly affect fleet mix during night-time hours, the number of flight movements at night or night-flight bans (see Table 52).

6.4 Measures management, feedback

On the basis of target-performance comparison and insights gained from impact analysis, it can be advisable to adjust previous measures or instruments at an individual airport or generally. The objective of modification of measures is optimum orientation of future developments towards set targets.

The process of controlling and measures management is outlined exemplarily below. We consider a notional airport that attempts to direct development towards long-term target values on the basis of the "effectivity strategy". We assume in this case that the noise abatement measures of this strategy have been applied for one year. The success of the measures should now be reviewed and, where necessary, modification of measures considered. In actual implementation this would have to be carried out in respect of every individual airport. When noise-exposure controlling is available in this exemplary case, the question of management is then raised. It has to be decided whether one has to adjust the mix and / or severity of measures or is on the desired path.

The following table suggests how controlling might result for an exemplary airport. It initially provides an overall impression of the present state of measure implementation as well as target values and degree of target attainment. The focus is then shifted to individual measures. From the results of controlling, proposals are finally deduced for necessary modifications.

Table 53: Illustration of the controlling process for the aircraft noise strategy on the basis of measures at an exemplary airport.

Example for Airport xy	**Status** **Degree of strategy implementation**	**Target** **Expected impact up to 2020**	**Controlling** **Target-performance comparison in the current year**	**Measures management** **Required adjustments to measures**
Target attainment, trend of developments ***Measures***		*Attainment of medium-term target values for $L_{Aeq\ night}$ and $L_{Aeq\ day}$, HA*	*Degree of target attainment: 40% $L_{Aeq\ night}$ and 55% $L_{Aeq\ day}$, Noticeably below expectations, no visible trend towards improvement*	*Examination of more stringent measures or modification of measures*
Noise charges	*Implemented*	*Shift to quieter aircraft*	*Below expectations, since fee level is low*	*Increase in charges for loud aircraft*
Night-flight restriction	*Largely implemented, but with exceptions*	*Aircraft of loudest noise category banned after 10 p.m.*	*Only modest decrease in night noise*	*Abolish exemptions and extend restriction to other noise categories*
Approach procedures	*Implemented*	*Noise reduction on approach*	*Expected impact*	*No adjustment*
Sound-proofed windows and sound-insulated ventilators	*insufficient degree of implementation*	*No additional measure, since legally required before the strategy*	*20% of buildings affected are not upgraded*	*Strengthen enforcement control; improve implementation of the measure through financial incentives for renovation*
Night-flight ban	*not applied*	-	-	*examine a year later, if target attainment has not noticeably improved*
Noise authorization limits	*not applied*	-	-	*Still not to be applied*
Movement quota	*Not applied*	-	-	*Still not to be applied*
Noise quota (cap and trade)	*Not applied*	-	-	*Still not to be applied*
Building bans /	*Not applied*	-	-	*Supplement noise strategy with this instrument, since*

Example for Airport xy	**Status** Degree of strategy implementation	**Target** Expected impact up to 2020	**Controlling** Target-performance comparison in the current year	**Measures management** Required adjustments to measures
rezoning				*it is shown that there are many additional persons exposed to noise*
Resettlement	*Not applied*	-	-	*Still not to be applied*
Route optimization	*Not applied*	-	-	*Still not to be applied*

Note: *cursive text*: illustrative examples

Insofar as the noise quota measure is employed, in the case of deviation from target values the airport operator is required to submit and implement a plan that guarantees compliance with indicator limit values in the following year.

It is important for aviation stakeholders, persons exposed to noise and the communities in the area surrounding airports to have the greatest possible planning security and legal certainty. Otherwise the danger increases that decisions on capital investment plans and corporate strategies are not economically efficient. At the time of concrete implementation of an aircraft noise strategy, stakeholders should therefore be able to foresee – ideally from the outset – the adjustments of measures or the new instruments that will come into question should target attainment remain below expectations. This means that the maximum applicable package of measures should be known from the very beginning. High spatial and operational security arises from specification of noise emission limits with or without continual tightening. Stakeholders (airlines and airport operators) can adapt to these conditions and take the measures that in a given situation are in their best interests. Graduation of such noise emission limits on the basis of varied trigger thresholds further facilitates controlling and management and provides stakeholders with planning security.

The enforcement authority publishes an annual monitoring and management report on the aircraft noise strategy, which serves the dual purpose of sensitization of broad sections of the population for the topic of aircraft noise and of motivating stakeholders. The report allows comparison of airports in terms of the noise situation and efforts towards target attainment.

7 Summary and recommendations

Annoyance and damage to human health resulting from aircraft noise has reached such a high level that further reduction of aircraft noise is urgently needed. For this purpose, noise protection targets must be initially defined. Based on insights into the effects of aircraft noise as well as own socio-economic considerations, the following noise protection targets are recommended:

Tab. 54: Recommended indicator and target values

	$L_{Aeq\ night}$	$L_{Aeq\ day}$	Number of highly-annoyed (HA) sufferers from aircraft noise
Short-term targets	55	65	Reduction insofar as is possible efficiently
Long-term targets	40	55	

$L_{Aeq\ night}$ describes the maximum energy-equivalent continuous sound level at night that occurs in a built-up area in the vicinity of an airport. $L_{Aeq\ day}$ describes, correspondingly, the maximum energy-equivalent continuous sound level during the day. An 'efficient' reduction in the number of highly-annoyed persons implies that all measures should be applied for the reduction of annoyance by which the benefit outweighs the cost.

In order to be able to assess noise exposure in the vicinity of existing German airports and the reduction of noise exposure to be expected from implementation of noise abatement measures, noise contours for different levels were calculated and evaluated with regard to their effects on human health for three types of airport (a medium-sized airport, an airport with a large volume of freight and night-flight operations and a regional airport). The results show that in the base scenario in 2017/2020 (without noise abatement measures) short-term targets are only just met, with the exception of the target value for the night-time level, which is exceeded at the medium-sized airport and the airport with a large volume of freight and night-flight operations. Exceedance is particularly high at the airport with night-flight operations.

Assessment of the effects of aircraft noise, with subsequent conversion into a common unit of measurement – disability-adjusted life years (so-called DALYs) – and a monetary value, shows that annoyance effects and sleep disturbance account for a much greater proportion of total damage than health effects such as high blood pressure and health attacks. Total costs of noise damage amount to 7 million euros per year in the case of the regional airport, 62 million euros per year for the medium-sized airport and 188 million euros per year for the airport with a large volume of freight and night-flight operations. This indicates that night-flight operations are the main cause of annoyance and health effects.

In order to achieve further noise reductions, the following measures are recommended within the framework of a short-term and easily-implementable efficiency strategy:

- Operation of loud aircraft is reduced in favour of quieter aircraft. This occurs by way of a further increase in the noise-related component of landing charges for aircraft assigned to high noise categories. The determination of noise charges is the responsibility of airport operators.
- In the case of the medium-sized airport measures are taken, which ensure that aircraft assigned to high noise categories only take off and land at night in exceptional cases such as emergencies. This can be achieved, for example, through a drastic increase in landing charges for aircraft of high noise categories.

- As far as possible, low-noise approach procedures are employed; for example, continuous descent approach (CDA) and optimized low drag low power (OLDLP). The introduction of particular approach and departure procedures is enacted by ordinance issued by the Federal Supervisory Office for Air Traffic Control (*BAF*), and is implemented by German Air Traffic Control (*DFS*) and airport operators.

As a result of the above-mentioned measures, the number of highly-annoyed sufferers from aircraft noise decreases by about 15% at the medium-sized airport and the airport with a large volume of freight and night-flight operations, and by 4% at the regional airport; on the other hand, the maximum continuous sound level in residential areas declines by a mere 0.5 to 1 dB(A). In the case of the medium-sized airport and the airport with a large volume of freight and night-flight operations the short-term target for night noise will continue to be exceeded. In accordance with the Aircraft Noise Protection Act, persons living in areas where trigger values are exceeded, which nearly refer to the short-term target values, are entitled to reimbursement of the costs of constructional noise protection measures.

- The long-term target values are greatly exceeded at all three reference airports. The following measure is recommended as an initial step towards compliance with long-term target values. The Aircraft Noise Protection Act requires that in areas around existing airports, in which short-term target values are exceeded, the costs of constructional noise protection measures be reimbursed by airport operators up to a prescribed level. Furthermore, in such areas no new housing development is permitted, in order that the number of persons exposed to noise does not increase further. The so-called trigger thresholds for reimbursement of costs and building bans stipulated in the Aircraft Noise Protection Act should be reduced by 5 dB(A), namely from $L_{Aeq\ day}$ = 65 dB(A) to 60 dB(A) and from $L_{Aeq\ night}$ = 55 dB(A) to 50 dB(A). This could be executed within the scope of the review of noise levels in the Aircraft Noise Protection Act, which has to be carried out by 2017 at the latest.

A further strategy, the effectivity strategy, is comprised of additional, medium-term measures that have a substantial noise reduction effect but whose legal implementation could be more difficult:

- Night-flight ban. The greatest annoyance and health effects are the result of noise at night. For this reason the reduction of night noise has the highest priority with aircraft noise reduction. A ban on night flights reduces the continuous sound level at night, depending on the regulation of exceptions, almost to zero. Introduction of a night-flight ban requires, however, modification of authorization under Air traffic law. At the same time, the interests of the airport operator and protection of the general public against adverse effects on the environment have to be weighed up. The result is dependent on each individual case. A night-flight ban is therefore difficult to enforce but, as already mentioned, highly effective. As an alternative, noise quotas can be introduced. If in course of a noise contingent, the continuous sound level for $L_{Aeq\ night}$ is set at a low level (for example, 45 dB(A)), this is only to be achieved with a far-reaching ban on night flights, bearing in mind that the airport operator can permit a limited number of exceptions.
- Employment of optimized, noise-reducing approach and departure procedures. Further approach and departure procedures are presently being investigated, which compared to the above-mentioned low-noise procedures achieve further reductions in noise levels. All procedures develop their impact at some distance from the airport; closer to the runway approach and departure routes are more or less the same with the different procedures. One example is the segmented continuous descent approach (SCDA) procedure, with which further noticeable reductions in annoyance effects can be achieved.

For the introduction of SCDA, however, further development and upgrading – for example, 4D flight management systems – are required.

If these measures are introduced, the long-term target value for continuous sound level at night can be met. The number of highly-annoyed sufferers from aircraft noise decreases at the airport with night-flight operations by 78%. At the airports that in the base scenario already have restricted night-flight operations the decline is about 40 %.

Even with introduction of the effectivity strategy the long-term target value for continuous sound level during the day (55 dB(A)) is markedly exceeded. If the night-flight ban is not introduced, the target value for continuous sound level at night (40 dB(A)) is also greatly exceeded. How then can long-term targets be achieved? Concepts are outlined below that together could contribute towards target attainment.

- The most promising measure in the long term is the development and operation of much quieter aircraft. Concepts with engine configurations that enable effective acoustic shadowing or sound encapsulation could achieve reductions in continuous sound levels on the ground in excess of 15 dB(A), compared to present-day aircraft. It will take about 40 to 50 years, however, before corresponding aircraft are developed and have largely replaced present aircraft, which have a service life of about 30 years. For implementation of the measure, noise authorization limits stated in ICAO Chapter 4 should be tightened up in further Chapters until such time as noise abatement targets have been met. Decisions on noise authorization limits are taken by the Council of the ICAO, on which representatives of the 36 Member States, including Germany, sit.

  Following complete renewal of the fleet with newly-designed aircraft – that is, after 2060 – a reduction of noise levels on the ground appears to be possible, with which the daytime long-term target level of 55 dB(A) can at least be met at the airports under investigation. The long-term target value $L_{Aeq\ night}$ has already been met in the efficiency strategy through a ban on night flights. Should this not be enforceable, however, introduction of new aircraft concepts will be insufficient at the medium-sized airport and the airport with a large volume of freight and night-flight operations to reduce the $L_{Aeq\ night}$ to or below the long-tern target value. This underlines the importance of a night-flight ban, or at least of drastic restriction of night flights that permits only few exceptions to the night-flight ban, as a component of a strategy for aircraft noise abatement.

- Insofar as areas remain in which long-term target values are exceeded, despite the above-mentioned measures, a further reduction should be made in noise levels for determination of trigger thresholds – above which the costs of constructional noise protection measures are reimbursed and building bans ensue pursuant to the Aircraft Noise Protection Act – to the long-term target values of $L_{Aeq\ day}$ = 55 dB(A) and $L_{Aeq\ night}$ = 40 dB(A), and not only for existing, but also for new and fundamentally expanded airports. As a result, in all areas with higher noise exposure the costs of constructional noise protection measures are reimbursed by the airport operator. Moreover, in such areas no new housing developments are permitted, in order not to increase the number of persons exposed to noise.

- A further strategy could be concerned with the development, examination and implementation of a nationwide mobility concept, in which a large proportion of air traffic, namely intercontinental traffic, freight traffic and parts of medium-haul air traffic is switched to two new airports located in sparsely-populated areas. Further transport of passengers and freight to urban conurbations could then be carried out, with corresponding connections to the railway network, by rail. Thereby, air traffic and thus air traffic noise could be considerably reduced in the vicinity of airports in urban conurbations and, moreover, smaller, quieter aircraft operated. Realization of this strategy requires very long periods of several decades. A new airport would not come into operation before 2035, and would involve considerable costs for new infrastructure and, if necessary, complete legal revision of responsibilities and planning procedures.

The discussion on legal implementability of the above measures and strategies is summarized below. The outlined strategies are based in the main on instruments of behavioural control that are already practised. They strengthen, however, regulatory intensity and combine them with each other. The packaging of measures is basically unproblematic from the legal point of view. The measures are components of a unified structure for protection against aircraft noise; they should supplement each other and interact.

For implementation of individual measures the help of legislators is needed. For instance, when the tightening-up of constructional noise protection is involved, or binding parameters for noise charges. The reduction of noise authorization limits for individual aircraft also requires a legally binding procedure. In this respect, an international agreement under the aegis of the ICAO proves to be a promising legal approach. In the case of low-noise flight procedures the legal instrumentarium already exists, and is also made use of. It could, however, be employed and applied more consistently. Proposed night-flight bans are already a legal reality, but are currently based on decisions in specific cases. Were a general ban to be striven for, it would have to be anchored in law. The weighing of interests, which is required under constitutional law, can on no account be dispensed with. With the obligation of the airport operator to acquire land, too, which as an infrastructure measure can contribute towards the long-term target, the principle of proportionality provides the standard. Acquisitions below the proportionality threshold can therefore hardly be justified. In this case, a procedure based on the principle of co-operation is suggested, in which all participants are involved. Voluntary measures, by the way, can also offer with other strategy components a solution for noise protection conflicts.

Controlling of implementation of measures can be based on the selected target indicators; namely, energy-equivalent continuous sound levels $L_{Aeq\ day}$ and $L_{Aeq\ night}$ as well as the number of highly-annoyed (HA) persons, for whose calculation noise contours of L_{den} are required. In order to ascertain progress in implementation of strategies, $L_{Aeq\ day}$ and $L_{Aeq\ night}$ must be measured every year at points in built-up areas in which the highest noise level occurs, as well as L_{den} in the overall area around the respective airport. The points at which the highest value for $L_{Aeq\ day}$ and $L_{Aeq\ night}$ occurs can be initially determined by model calculations. Noise measurements are then carried out at the identified points, on the basis of which noise level is then calculated at the end of every year and compared with target values.

The L_{den} contour has to be generated by model calculations (area-wide measurement is not possible), for which recorded radar tracks of approaches and departures at the airport are utilized. On the basis of the noise contour, the Annoyance Index (AI) is calculated with application of population distribution.

Should actually-achieved indicator values lie above target values, the employed noise protection measures have to be modified, extended or supplemented.

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