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AIRPORT NOISE:
FROM MONTHLY VARIABILITY TO THE
IMPACT OF TECHNOLOGY UPTAKE ON
LONG-TERM PROJECTIONS

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Abstract

The surrounding communities of Dublin Airport are experiencing increasing noise due to increasing air traffic. Aircraft noise is a significant environmental issue, with substantial implications for public health and quality of life, contributing to annoyance and increasing the risk of health problems, including cardiovascular diseases. Consequently, it is essential to analyze current and future noise exposure in terms of population and area exposure, and to lay focus on noise mitigation measures to reduce negative health effects.

This thesis examines the short-term and long-term airport noise at Dublin Airport, exploring monthly fluctuations and the integration of future aircraft concepts.

Currently, environmental noise, including airport noise, is mapped every five years under Environmental Noise Directive (END), which mandates the production of annual noise contours. However, this thesis demonstrates that conventional annual noise maps fail to capture substantial monthly fluctuations in noise exposure. In some cases, the maximum monthly change in area exposure reaches up to 100% a level of variation that annual averages are incapable of representing. To address this gap, the thesis introduces maximum monthly change in area exposure as a novel metric to quantify and visualize these significant temporal dynamics.

To address a critical aspect of airport noise communication related to long-term forecasting for improved planning, including land use management and the protection of communities near airports, this thesis presents noise level projections through to the year 2050. The forecasts for 2030, 2040, and 2050 combine expected increases in air traffic with technology uptake, including the introduction of quieter generation 2 and 3 aircraft.

From 2023 to 2030, the area exposed to noise levels of $L_{den} = 45$ dB(A) is projected to increase from 171.48 km² to 217.32 km². In the 2040 scenario, despite an increase in air traffic, it is possible to reduce the exposed area to 199.30 km², representing a decrease of 8.29 % compared to 2030.

The 2050 noise predictions are based on simulated noise data for future aircraft concepts, specifically the Blended Wing Body aircraft, as a proxy for emerging technologies. Therefore, Noise-Power-Distance (NPD) data was generated for integration into the noise model. The study further evaluates Dublin Airport's communication strategy regarding noise exposure and offers recommendations for improving public engagement and policymaker responses to evolving noise trends.

However, even with the introduction of future aircraft concepts, the exposed area increases to 214.10 km², which corresponds to an increase of 24.87 % compared to 2023, while the total number of flights increases by 47 %.

The findings highlight significant gaps in current noise forecasting and communication, stressing the need for more detailed, and dynamic models that account for seasonal and monthly noise variations. This thesis concludes with policy recommendations for better noise mitigation, land-use planning, and the adoption of quieter aircraft technologies to reduce long-term airport noise exposure.

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Nomenclature

Greek Letters

β	Elevation Angle	$^{\circ}$
Δ_F	Finite Segment Correction	dB
Δ_I	Engine Installation Correction	dB
Δ_i	Time-Dependent Decibel Weighting	dB
Δ_V	Duration (Speed) Correction	dB
ℓ	Perpendicular Distance from an Observation Point to the Ground Track	m
γ	Geometric Aircraft Flight Path Angle	$^{\circ}$
Λ	Lateral Attenuation	dB
λ	Length of a Flight Path Segment	ft
ϕ	Lateral Radiation Angle	$^{\circ}$
ε	Bank Angle	$^{\circ}$
φ	Depression Angle	$^{\circ}$

Roman Letters

A_{ex}	Area Exposure	km^2
$C(k)$	Tone Correction Factor	dB
D	Duration Correction	dB
d	Propagation (Slant) Distance	m

d_λ	Scaled Distance	ft
g	Time-Period Weighting Factor	
i	Noise Event	
j	Flight Track	
k	Flight Track Segment	
$L(t)$	Sound Level at Time t	dB
L_T	Threshold Noise Level	dB
$L_{A,max}$	A-Weighted Maximum Sound Pressure Level	$dB(A)$
L_{Aeq}	A-Weighted, Equivalent Continuous Sound Level	$dB(A)$
L_{AE}	Sound Exposure Level	dB
$L_{approach}$	Noise Level at the Approach Certification Point	dB
$L_A(t)$	A-Weighted Sound Level at time t	$dB(A)$
L_{day}	Daytime Noise Level	$dB(A)$
L_{den}	Day-Evening-Night Noise Level	$dB(A)$
$L_{eq,W}$	Cumulative Noise Level	dB
$L_{evening}$	Evening time Noise Level	$dB(A)$
$L_{flyover}$	Noise Level at the Flyover Certification Point	dB
$L_{lateral}$	Noise Level at the Lateral Certification Point	dB
L_{max}	Maximum Sound Pressure Level	dB
L_{night}	Nighttime Noise Level	$dB(A)$
$L_{eq,W}$	Time-Weighted equivalent Sound Level	dB
M_{ij}	Weighted Number of Operations	
N	Sum of all Noise Events	

$n(i, k)$	Perceived Noisiness	<i>noy</i>
$N(k)$	Total Perceived Noisiness	<i>noy</i>
P	Engine Power Parameter in NPD Variable	
$PNL(k)$	Instantaneous Perceived Noise Level	<i>PNdB</i>
$PNLT$	Tone Corrected Perceived Noise Level	<i>TPNdB</i>
$PNLTM$	Maximum Tone Corrected Perceived Noise Level	<i>TPNdB</i>
$SPL(k, i)$	Instantaneous one-third Octave Band Sound Pressure Level	<i>dB</i>
t, T	Time	<i>s</i>
T_0	Time Period	<i>s</i>
V	Velocity	<i>kt</i>
x	Ground Distance or Longitudinal Distance	<i>ft</i>
y	Lateral Distance perpendicular to Aircraft's Ground Flight Track	<i>ft</i>
z	Height	<i>ft</i>

Acronyms

AAGR Average Annual Growth Rate.

ANCA Aircraft Noise Competent Authority.

ANP Aircraft Noise and Performance.

APU Auxiliary Power Unit.

AR Absolute Risk.

ARTEM Aircraft Noise Reduction Technologies and related Environmental iMpact.

AzB Anleitung zur Berechnung von Lärmschutzbereichen / Instructions on the Calculation of Noise Protection Areas.

BA Base Air Traffic Increase.

BEMUSE Boundary Element Method Code by Onera.

BOLT Blended wing body with Optimised Low-noise Technologies.

BPR Bypass Ratio.

BTU Base Technology Uptake.

BWB Blended Wing Body.

CARMEN Codes Acoustiques par Rayons pour la Modélisation et l'Estimation de Nuisances / Ray-Based Acoustic Codes for Modeling and Estimation of Nuisances.

CNOSSOS-EU Common Noise Assessment Methods in Europe.

CSO Central Statistics Office.

CSV Comma-Separated Values.

DA Dublin Airport.

DAA Dublin Airport Authority.

DALY Disability-Adjusted-Life-Year.

DART Dublin Area Rapid Transit.

DCC Dublin City Council.

EASA European Union Aviation Safety Agency.

ECAC European Civil Aviation Conference.

END Environmental Noise Directive.

EPA Environmental Protection Agency.

EPNdB Effective Perceived Noise in Decibels.

EPNL Effective Perceived Noise Level.

EPSG Geodetic Parameter Dataset.

EU European Union.

FRIDA Framework for Innovative Design in Aeronautics.

GDP Gross Domestic Product.

GIS Geographic Information System.

HA High Air Traffic Increase.

HSD Highly Sleep Disturbed.

HSIP Home Sound Insulation Programme.

HTU High Technology Uptake.

ICAO International Civil Aviation Organization.

IHD Ischemic Heart Disease.

IR Intermittency Ratio.

LA Low Air Traffic Increase.

LTU Low Technology Uptake.

MTOW Maximum Take-Off Weight.

NAT Number Above Threshold.

NMT Noise Monitoring Terminal.

NPD Noise-Power-Distance.

NPR Noise Preferential Route.

ONERA Office National d'Études et de Recherches Aérospatiales / National office for aerospace studies and research.

PNL Perceived Noise Level.

PNLT Tone Corrected Perceived Noise Level.

PNLTM Tone Corrected Perceived Noise Level at its Maximum Value.

QC Quota Count.

RNIS Residential Noise Insulation Scheme.

RR Relative Risk.

SEL Sound Exposure Level.

SOR Start of Roll.

SPL Sound Pressure Level.

UK United Kingdom.

US United States.

UTM Universal Transverse Mercator.

WHO World Health Organization.

YLD Years Lived with Disability.

YLL Years of Life Lost.

Chapter 1

Introduction

1.1 Scope and Research Objectives

Aircraft noise is a persistent environmental concern around major airports, with significant implications for the health, well-being, and quality of life of surrounding communities [1]. Dublin Airport, as Ireland's busiest international gateway, is no exception to this challenge [2]. With increasing air traffic and the anticipated growth of aviation over the coming decades [3], the noise impact on local populations is projected to increase, making it imperative to explore effective strategies for mitigating this environmental nuisance.

This thesis aims to advance the understanding of airport noise by introducing a new approach to noise mapping and prediction, demonstrated on a case study of Dublin Airport. Specifically, monthly fluctuations in noise exposure are addressed, which are not displayed by the current standard of annual noise maps. To quantify these fluctuations a new metric, the maximum change in area exposure, is introduced. The metric visualizes the extent of monthly variation in noise exposure depending on the area over a full year, providing a more detailed view of how airport surrounding communities are affected by airport noise throughout different times of the year.

In addition to these short-term variations, this research explores long-term noise prediction for Dublin Airport, extending forecasts to 2030, 2040, and 2050. This includes a combination of air traffic increase and technology uptake, which consists of fleet share trends and generation shifts. These forecast scenarios integrate both short-term and long-term projections, offering a detailed look at the evolving noise landscape.

The 2050 airport noise forecast includes future aircraft concepts (generation 3), for which there is currently no real-world data. To address this gap, Noise-Power-Distance (NPD) data is generated and incorporated into the noise prediction model. In this study, all future aircraft concepts are assumed to be Blended Wing Body (BWB) aircraft. This aircraft type is anticipated to be among the first next-generation models to enter the market and is expected to have the most significant impact on noise reduction. Even with a small fleet share by 2050, generation 3 aircraft are projected to demonstrate noticeable differences, illustrating the potential influence of future aircraft concepts on the airport's noise footprint [3, 4].

Furthermore, this thesis reports on the communication strategy surrounding aircraft noise at Dublin Airport and compares it to best practices. It examines the communication of noise information to the public and local stakeholders, assessing its accessibility and clarity while providing recommendations to enhance transparency, public engagement, and awareness of noise exposure and mitigation efforts. This includes suggesting more dynamic and accessible platforms for residents to track noise forecasts, as well as advising policymakers on how to integrate these predictions into land-use planning and noise management decisions.

The key areas of this research are:

- **Monthly Fluctuations in Noise Exposure:** The development of a metric to display the maximum change in area exposure, highlighting the significance of modeling monthly fluctuations and extreme noise events.
- **Long-Term Noise Prediction:** Forecasting future noise levels for 2030, 2040, and 2050, incorporating detailed air traffic increase and technology uptake.
- **Future Aircraft Concepts:** Modeling the noise impact of generation 3 aircraft, using simulated NPD data for the BWB concept to represent future aircraft technologies in the 2050 scenario.
- **Communication Strategy and Policy Recommendations:** Evaluation of Dublin Airport's noise communication strategies and recommend improvements, including how policymakers should respond to evolving noise trends and how the public should be informed about current and future noise exposure.

By addressing these objectives, this research aims to contribute to more effective noise mitigation strategies, improve long-term planning for airport operations, and foster a clearer understanding of the future trajectory of airport noise in Dublin. The findings of this thesis provide actionable insights for airport authorities, policymakers, and local communities, helping them navigate the challenges posed by increasing air traffic and advancing aircraft technologies.

1.2 Thesis Outline

The structure of the thesis is as follows: The literature review outlines the principles of environmental noise mapping, discusses sources of aircraft noise, and examines strategies for noise reduction. It also highlights the negative health impacts of noise and the relevant EU regulations governing airport noise.

Subsequently, the thesis provides a comprehensive overview of Dublin Airport as the major airport of the Republic of Ireland, serving as the case study. It covers the airport's historical context, current operations, operational restrictions, and communication strategies.

The methodology chapter outlines the detailed process of noise mapping, encompassing the generation of future aircraft concept data and the operational mechanics of the overall noise model. The publication *Predicting Airport Noise Impact to 2040: Traffic Growth and Technology Uptake* [5] significantly contributes to the methodology. During post-processing, the generated noise contours are thoroughly analyzed to evaluate key metrics, including area affected, population exposure levels, and variations in monthly noise exposure trends.

The analysis chapter presents the monthly noise maps for Dublin Airport in 2023, comparing these to mandatory annual results collected every five years under the END directive. Monthly fluctuations are displayed in the form of noise contour lines and the maximum noise exposure change. The chapter draws on insights from the papers *Benefits of Monthly Noise Maps in Comparison to Annual Assessments* [6], *Noise Impact of changing Flight Routes: from Planning to Reality* [7] and *Re-surfing Airport Noise: Understanding Aircraft Noise Dynamics During and After the COVID-19 Pandemic at Dublin Airport* [8].

In the noise prediction chapter, forecasts for airport noise at Dublin Airport extend to 2050. Scenarios of air traffic growth and advancements in aircraft technology are combined to predict low, base, and high noise levels for 2030, 2040, and 2050. In the noise prediction models for 2050, future aircraft concepts (generation 3 aircraft) are incorporated as part of the anticipated technology uptake. All Generation 3 aircraft concepts are assumed to be represented by the Blended Wing Body (BWB) aircraft for this study, for which Noise-Power-Distance (NPD) data is generated and subsequently integrated into the airport noise

prediction model. This chapter has been informed by the findings and methodologies presented in the papers *The Future of Airport Noise: A Comprehensive Analysis of Population Exposure at Dublin Airport 2023 to 2030* [9], *Predicting Airport Noise Impact to 2040: Traffic Growth and Technology Uptake* [5], and *Airport Noise Forecasting to 2050: Integrating the Blended Wing Body Concept* [10].

The discussion section evaluates the noise contours for 2023 to 2050, while the conclusion summarizes findings and recommendations, and suggests potential avenues for future research.

1.3 Published Work

Multiple papers have been written as part of this research to disseminate key findings and contribute to the broader scientific community.

1.3.1 Journal Papers

- [10] Karina Einicke, and John Kennedy. Airport Noise Forecasting to 2050: Integrating the Blended Wing Body Concept. Accepted: Applied Acoustics, 2025.
- [6] Karina Einicke, and John Kennedy. Benefits of Monthly Noise Maps in Comparison to Annual Assessments- an Analysis of Dublin Airport. Applied Acoustics, 235:110650, 2025. ISSN 0003-682X. doi: <https://doi.org/10.1016/j.apacoust.2025.110650>
- [5] Karina Einicke and John Kennedy. Predicting Airport Noise Impact to 2040: Traffic Growth and Technology Uptake. Applied Acoustics, 227:110229, 2025. ISSN 0003-682X. doi: <https://doi.org/10.1016/j.apacoust.2024.110229>. URL <https://www.sciencedirect.com/science/article/pii/S0003682X24003803>.

1.3.2 Conference Papers

- [7] Karina Einicke and John Kennedy. Noise Impact of changing Flight Routes: from Planning to Reality. INTER-NOISE and NOISE-CON Congress and Conference, 08 2023 doi: 10.3397/IN_2023_0424.
- [11] Karina Einicke and John Kennedy. The Impact of Changing Fleet Makeup on Airline Noise emission. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 265: 846–853, 02 2023. doi: 10.3397/IN_2022_0119.
- [8] Karina Einicke and John Kennedy. Re-surgin Airport Noise: Understanding Aircraft Noise Dynamics during and after the Covid-19 Pandemic at Dublin Airport. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 2024, doi: 10.3397/IN_2024_2654.
- [9] Karina Einicke and John Kennedy. The Future of Airport Noise: A comprehensive Analysis of Population Exposure at Dublin Airport 2023 to 2030. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 2024, doi: 10.3397/IN_2024_2656.
- [12] Harun Siljak, Karina Einicke, John Kennedy, and Stephen Byrne. Noise Mitigation of UAV Operations through a Complex Networks Approach. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 2022, doi: 10.3397/IN_2022_0316.

Chapter 2

Literature Review

2.1 Background

Environmental noise is defined as unwanted or harmful sound that constitutes a form of environmental pollution and cannot be overlooked. It arises from a wide range of open-air sources, including road, rail, and air traffic, industrial activities, and recreational events. It affects not only the environment but also human health and well-being. Over time, the study of noise pollution has progressed from simply recognizing it as a general annoyance to developing a deeper understanding of its broader effects on public health and overall quality of life [1, 13].

This literature review addresses the multifaceted nature of noise pollution, emphasizing its significance and relevance in contemporary society. The review covers environmental and aircraft noise, exploring their sources, characteristics, and specific impacts. It also gives an overview of the health effects of noise exposure, including cardiovascular diseases, cognitive impairment, and sleep disturbances [13]. Furthermore, the review examines regulatory measures and noise management strategies, in particular the Balanced Approach proposed by the International Civil Aviation Organization (ICAO) [14].

Relevant noise mapping regulations are introduced, providing a foundation for a detailed analysis of current research and practices in noise management. This background section highlights the importance of understanding noise pollution and the need for effective management strategies, addressing the advancements and the gaps in the existing literature.

2.2 Aircraft Noise as Part of Environmental Noise

Noise tends to spread widely in the environment, particularly in highly urbanized areas [1, 13, 15]. It is closely associated with industrial development, transport infrastructure, and ongoing urbanization. Undesired noise represents a significant source of pollution not only affecting human physiology but also impacting the environment as a whole.

2.2.1 Aircraft Noise

Aircraft noise is a significant component of environmental noise, especially in areas close to airports and flight paths [1]. As air travel continues to grow globally [16], the impact of aircraft noise on surrounding communities and environments has become increasingly prominent [1].

This work concentrates on aircraft and airport noise, which is one of the most harmful and disturbing noise sources for people in airport surrounding areas. Aircraft noise is a major localized noise pollution source. At the same time, road traffic and railway noise affect more people, as the aircraft noise is limited to below flight paths and airport surrounding areas.

Aircraft noise is generated from various sources during different phases of flight, including approach, departure, and taxiing [17]. In terms of noise sources, composite noise (airframe noise) is the major noise component of overall noise in all stages of the flight. Fan noise is following closely, while jet noise is the quietest noise component. Overall these two noise sources can be categorized as engine noise.

Engine Noise

During take-off procedures, engine noise is the predominant noise source of the aircraft. Aircraft engines have multiple noise sources, which include fan, compressor, combustion, turbine, and exhaust (jet) noise [18].

Noise emitted during the approach is mainly high-frequency originating from the engine's intake and exhaust [18]. The main noise source is described as the fan-compressor [17, 19]. Combustion noise contributes at very low frequencies and its contribution increases downstream the high-pressure turbine [20]. The dominant noise source for subsonic jets is believed to be small-scale turbulence. Large-scale structures are not seen as effective regarding acoustic sources [18].

Airframe Noise

Airframe noise is aerodynamic noise, mainly generated by landing gear and high-lift devices of the aircraft [21, 22]. Ever since the bypass ratio of aircraft engines was increased significantly, thus reducing engine noise (a larger proportion of air bypasses the engine core, the jet velocity decreases, leading to a reduction in jet noise, which is one of the dominant noise sources in aircraft engines), airframe noise has become more dominant. It can even dominate the overall aircraft noise, and thus engine noise [23–25]. During the approach phase, airframe noise has become the most prominent aircraft noise source, when engines are throttled down [24, 26]. It is also significant during take-off after thrust reduction is applied. Airframe noise is mainly caused by the wing systems, airbrakes, spoilers, landing gear, and high lift devices (consisting of flaps and claps), as well as cavities on the airframe. Acoustics waves are formed as flow structures around the body get distorted and cause local pressure variation. High-lift devices

in landing configuration cause 10 dB higher noise in comparison to the cruise configuration at the same speed.

The interaction between various noise sources on an aircraft is referred to as the installation effect [27]. For example, turbulence generated by high-lift devices can interact with the vortices produced by the rear landing gear, increasing the overall turbulence in the flow field. Reducing this interaction and the associated turbulent flow can help mitigate noise. Similarly, when engine-generated turbulence interacts with airframe flow fields, altering the engine placement can be an effective measure to reduce noise.

Overall Aircraft Noise

The analysis of noise spectra for wide body fan jets, a pattern observed across all aircraft types, demonstrates that sound pressure levels are significantly higher during takeoff than during the landing approach [28]. Figure 2.1 illustrates a typical departure spectral class for commonly used narrow body aircraft, such as variants of the A320 and Boeing 737max8. This spectrum is employed in the noise modeling process and is defined in ECAC Doc. 29, Volume 3, Part 1 [29]. It has been included here as a standardized acoustic reference for departure scenarios. This particular spectral class has been selected as an example because these aircraft types are the most commonly operated narrow-body jets at Dublin Airport, accounting for over 50 % of all aircraft movements (see Table A.1).

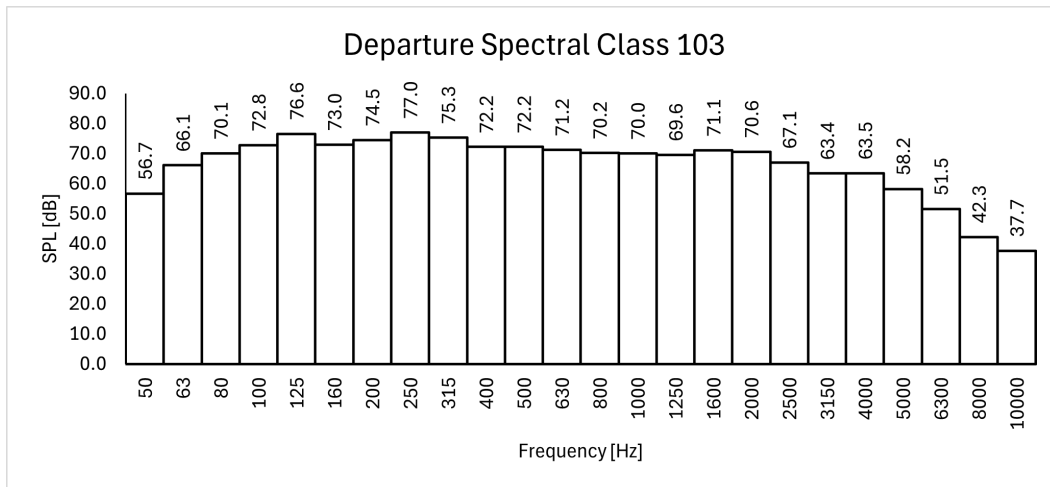


Figure 2.1: Departure spectral class 103 for aircraft types such as A320 and 737max8 [30]

Noise Source Modeling and Prediction

Predicting the noise generated by the entire aircraft differs from analyzing noise produced by isolated sources [27]. Local flow fields affect installed noise sources, making it essential to account for interactions between them. This installation effect, plays a significant role in accurately modeling overall aircraft noise.

Aircraft noise is difficult to model, not only because of the geometric complexity but also because of installation and component interaction effects, Reynolds-number effects, turbulent, unsteady, and highly non-linear flow fields, and propagation of the broadband noise in the far field [25]. Modeling a single aircraft component might be useful for understanding noise generated by a specific part and reducing this noise. However, once the component is installed on the aircraft interaction effects with unsteady flows generated by other components might change the far-field noise of the developed component. Thus, noise prediction for complex geometries is difficult and time-consuming, which leads to challenges when facing noise reduction strategies.

2.2.2 Aircraft Noise Chapters

EASA defines noise certification standards for various aircraft types, categorized into twin-aisle, single-aisle, regional, turboprop, and business jets. These classifications are based on several factors, including Maximum Take-Off Weight (MTOW), maximum thrust rating, aircraft type, and noise levels measured at specific certification points. Aircraft are assigned to different noise chapters following the procedure outlined by International Civil Aviation Organization [14] and EASA, EAA, and Eurocontrol [31]. As shown in Figure 2.2, there are three noise certification points for categorizing aircraft: the approach reference point, located 2000 m before the landing threshold; the lateral certification point, 450 m perpendicular to the flight path at the location of maximum noise; and the flyover certification point, 6500 m beyond the Start of Roll (SOR). For all three certification reference points, the Effective Perceived Noise Level (EPNL) L_{EPN} is measured repeatedly under controlled test conditions, which account for factors such as aircraft operation, instrumentation setup, and environmental conditions. During an aircraft's noise certification, several key noise metrics are recorded, including L_{AE} , L_{max} , and L_{EPN} , to support the generation of Noise-Power-Distance (NPD) data (see Section 4.1.2). These measurements are taken for different aircraft configurations

and weights to ensure that the noise data accurately reflects performance across a range of operational scenarios [29].

This categorization by noise chapter is instrumental for airports in managing noise pollution, allowing them to implement measures such as banning noisier aircraft or limiting the number of, for example, Chapter 3 aircraft. Figure 2.3 highlights the progression of noise standards established by ICAO, illustrating a clear trend toward quieter aircraft over the past 30 years. This evolution reflects technological advances and stricter noise regulations, supporting efforts to reduce the environmental impact of aviation noise.

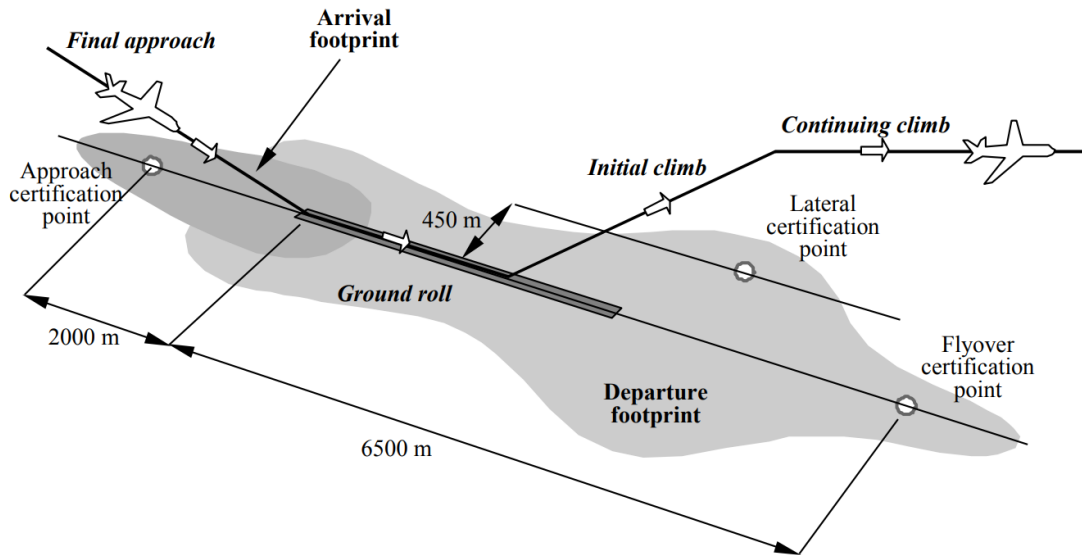


Figure 2.2: Certification reference points for noise chapter certification from ECAC [29]

2.2.3 Aircraft Generations

Aircraft are categorized into different aircraft generations and types, depending on their production year and aircraft size. Eurocontrol [16], which develops aviation forecasts for Europe, and Mott MacDonald Global Aviation [32], which analyses operation and fleet development at Dublin Airport, categorize aircraft depending on their size and passenger capacity. Narrow body aircraft are single-aisle aircraft, the most popular models include Boeing 737, Boeing 757, and A320. The Boeing 767, 777, 787, Airbus 330, 350, and 380 are considered wide body aircraft. These airplanes have twin-aisles and are typically used for long-haul services. Regional aircraft are small one-aisle jets, which are used for short-

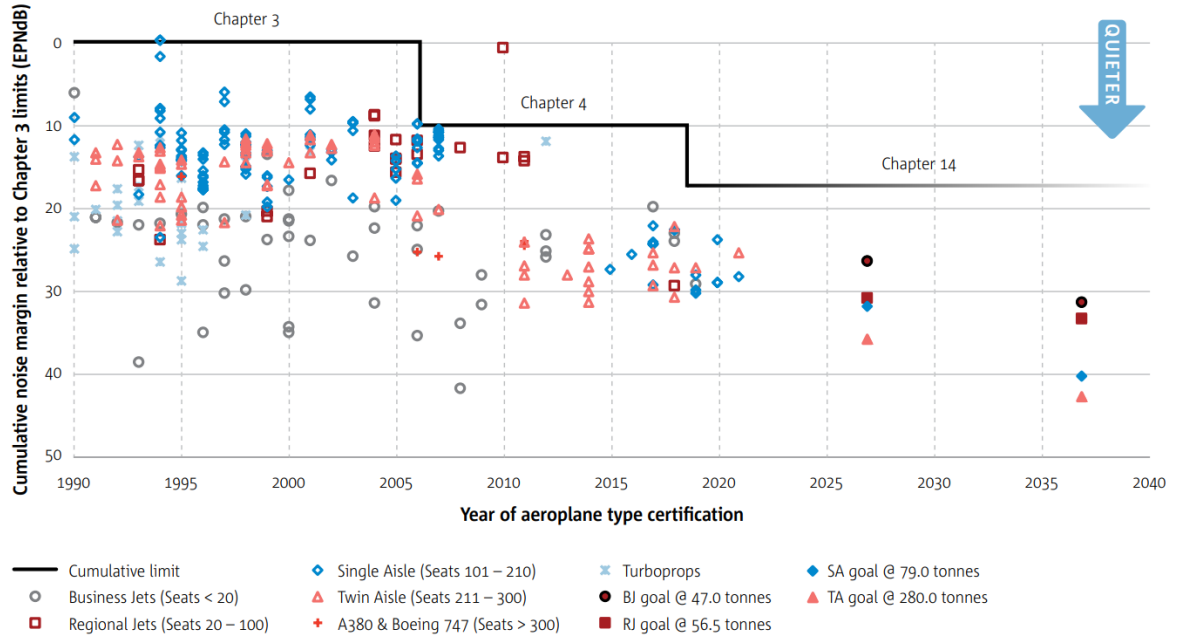


Figure 2.3: Aircraft certification noise levels from EASA, EEA, Eurocontrol [31]

distance flights. The most popular regional jets specifically at Dublin Airport are BAe146, Bombardier CRJ and Cseries, and Embraer RJ.

The commercial aircraft production cycle determines the aircraft generation. Newer generation aircraft are equipped with advanced technology that enhances fuel efficiency and reduces noise. Mott MacDonald Global Aviation [32] displays an overview of aircraft generation, depending on the production and technology (see Table 2.1 and Figure 2.4). Production cycles are important to estimate when aircraft come and leave service and which aircraft might be able to replace them. Aircraft are expected to have an average lifespan of 25 years after which they can stay in service as freighter conversions [32].

Generation 0 aircraft were developed in the 1970s and 1980s and are mostly retired as passenger aircraft at this point [32]. They have been replaced by generation 1 aircraft, which have been developed until the 2000s and are currently in operation. Generation 2 aircraft are in production in the 2020s and are entering the market, production, or are still under development.

Generation 3 aircraft can be considered future aircraft concepts, such as hybrid fuel and electric [16, 33], open-rotor [34], Blended Wing Body (BWB) [4], or braced wing [35] aircraft.

A comparison of the departure noise contour at $L_{max} = 55 \text{ dB(A)}$ of different aircraft generations can be seen in Figure 2.5, with the corresponding values presented in Table 2.2.

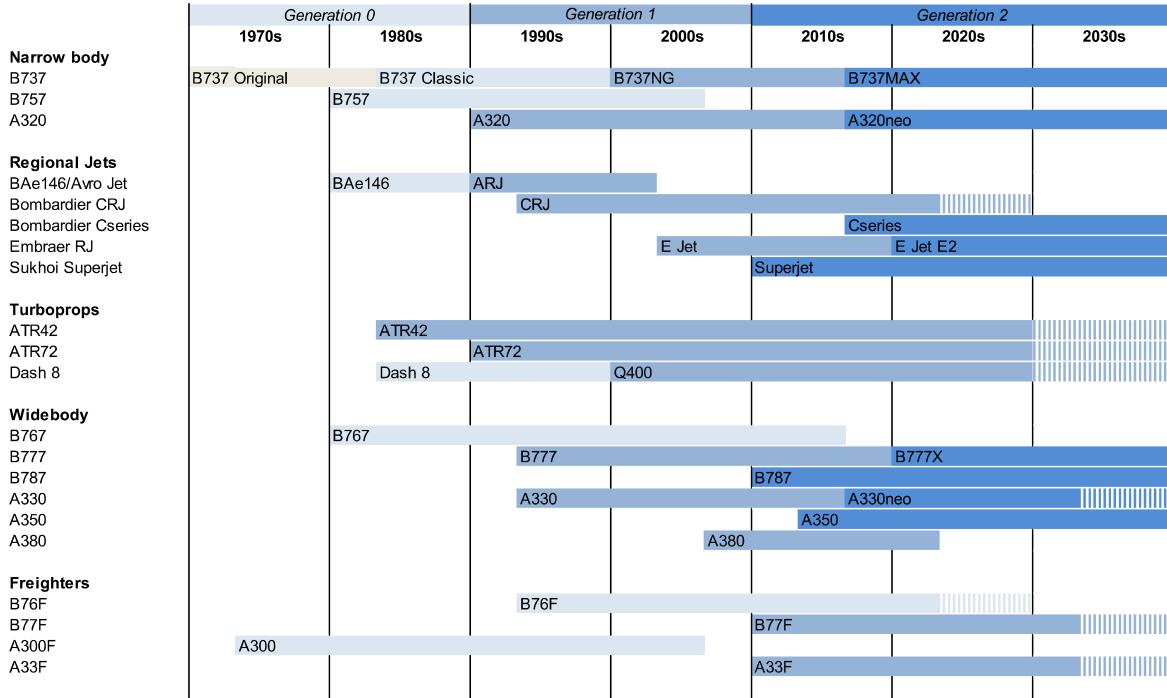


Figure 2.4: Commercial aircraft production cycle (aircraft types in production by generation) from Mott MacDonaldd Global Aviation [32]

As an example of narrow body aircraft, the Boeing 737-800 aircraft is a generation 1 aircraft, which is succeeded by the Boeing 737max8, a generation 2 aircraft. The noise contour at $L_{den} = 55 \text{ dB(A)}$ indicates a 63 % smaller noise footprint for the 787max8. This trend of a smaller noise footprint can also be observed for wide body aircraft such as the Boeing 777 family (including B77W and B778) aircraft and the generation 2 B777X. The B777X has a 40 % reduction in area exposure at $L_{max} = 55 \text{ dB(A)}$ compared to the B77W.

2.2.4 Airport Noise

Overall airport noise includes various ground-based sources, including taxiing aircraft, engine testing, the use of auxiliary power units [20], luggage transport, and ground vehicle noise. These elements are integral to airport operations and might contribute to the overall noise environment. This work will focus specifically on aircraft noise, excluding other ground-based noise sources.

The terminology used in the literature to describe noise related to airports is often inconsistent, with terms like *airport noise*, *aircraft noise*, and *overall airport noise* being used interchangeably or ambiguously. For the purposes of this work, *airport noise* will refer specif-

Generation	Aircraft
Generation 0	aircraft developed in the 1970s or 1980s B737 (classic), B757, B767, A300, A310
Generation 1	aircraft developed in the 1990s or 2000s B737NG, B777, A320, A330, A340, A380, Bombardier CRJ, E-Jets, ATR42, ATR72
Generation 2	aircraft currently entering production/under development B737max, B787, B 777X, A320neo, A350, Cseries, E-Jet-E2, Sukoi Superjet
Generation 3	future aircraft concepts BWB, electric propulsion , braced wing , open-rotor aircraft

Table 2.1: Aircraft generation categorization according to Mott MacDodonald Global Aviation [32] and future aircraft concepts (generation 3 [4, 16, 33–35])

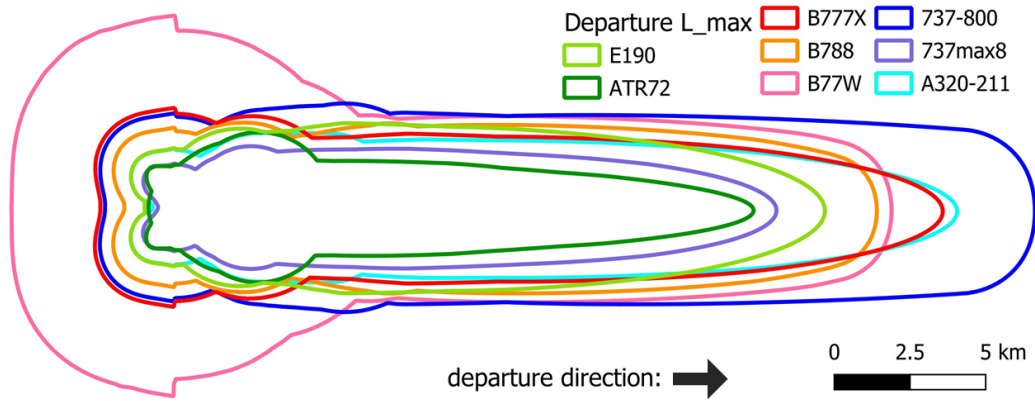


Figure 2.5: Aircraft departure noise footprint contour line at $L_{max} = 55$ dB(A) for different aircraft types

ically to all noise generated by aircraft operations at a single airport over a defined time period, excluding any noise generated from ground operations. *Aircraft noise* typically refers to the noise produced by individual aircraft, whereas *airport noise* encompasses the collective aircraft noise from the airport's operations. This distinction is maintained throughout this thesis for clarity and precision.

Area Exposure for $L_{max} = 55 \text{ dB(A)}$			
Aircraft	Area [km^2]	Aircraft	Area [km^2]
E190	103.70	B77W	211.77
ATR72	56.47	737-800	183.21
B777X	126.40	737max8	68.12
B788	125.55	A320-211	107.45

Table 2.2: Aircraft departure noise footprint at $L_{max} = 55 \text{ dB(A)}$ for different aircraft types

2.3 Influence of Weather on Noise Propagation

Climate change is exerting profound effects on various meteorological parameters, including temperature, precipitation, and wind patterns, thereby significantly influencing air traffic operations. Projections indicate that by 2050, these alterations will substantially impact the aviation sector [36]. Particularly in Europe, where shifts in wind conditions and heightened precipitation levels are expected, the incidence of extreme weather events is expected to increase [37, 38]. This anticipatory rise in extreme wind speeds, coupled with the variability in wind direction across north and central western Europe, holds implications for airport operations, potentially resulting in infrastructure damage and compromised safety measures. Moreover, as atmospheric conditions evolve, aircraft performance is set to transform. Changes in wind patterns may necessitate adjustments in runway lengths, while temperature fluctuations could pose challenges such as heat-induced damage to airport surfaces or increased demands for cooling and heating systems. Consequently, aircraft operators may need to adapt their scheduling practices, opting to deploy heavier aircraft during cooler periods of the day to mitigate potential operational disruptions.

Wind pattern changes might increase crosswinds, which can disrupt or cause changes to aircraft and airport operations. In addition, an increase in turbulence and surface winds could be experienced. A shift in wind direction will cause a change in airport operations. At Dublin Airport wind changes from easterly to westerly cause changes in departure and arrival direction. In the case of crosswinds, the Cross Runway 16/34 can be used [39]. For airports without a cross runway, an increase in crosswinds would cause a reduction in capacity [37].

In addition to wind speed and direction, wind shear and turbulence impact aircraft operations. Variations in headwind during approach can lead to a shallower descent angle or even a climb, or result in reduced lift, potentially causing a short landing. Pilots must take corrective measures to safely operate the aircraft under these conditions [40]. These adjustments may include altering thrust settings and modifying flap or slat angles to maintain the

correct flight path. Changes in wind direction already affect the operation at Dublin Airport. Depending on the wind direction, departure and arrival direction are changed [41].

Humidity, air temperature, and wind speeds significantly affect noise propagation [29, 42]. Depending on meteorological conditions, sound levels can vary by more than 10 dB at distances over several hundred meters. Sound absorption depends on air temperature and relative humidity, with its impact varying based on the sound frequency. For lateral attenuation, fluctuations in wind and temperature cause refraction, altering the direction and intensity of sound reflections.

Atmospheric absorption is influenced by propagation distance and the atmospheric attenuation coefficient, which depends on temperature, relative humidity, and atmospheric pressure. The ground effect involves the absorption or reflection of sound by the ground as it travels from the source to the receiver [42, 43]. This effect is determined by height above the ground, atmospheric conditions, and the acoustic properties of the surface. Factors like water and snow can alter ground absorption. Wind and temperature gradients can scatter sound, causing refraction and altering the sound's propagation path.

Aircraft noise measurements for reference procedures should ideally be conducted under standardized atmospheric conditions, including a constant pressure of 1.013 25 kPa, an ambient temperature of 25 °C, relative humidity of 70 %, and zero wind [14]. However, since achieving these exact conditions is often impractical, noise tests should be performed under acceptable atmospheric ranges. These include relative humidity between 30 % to 90 %, ambient temperatures from 2 °C to 30 °C, average wind speeds below 5.1 m/s, crosswind speeds below 2.6 m/s, and no precipitation during testing. These conditions help ensure the accuracy and consistency of noise data across varying environments.

2.4 Health Effects of Noise

Transport noise is a recognized issue and causes community annoyance [44] up to major health impacts, such as sleep disturbance [45], adverse effects on the endocrine and immune systems [46], and cardiovascular and metabolic diseases [13, 47–49]. However, there is a limited number of studies that focus specifically on the effects of aircraft and airport noise, highlighting the need for further research in this area.

Aircraft noise typically causes greater annoyance than other types of transportation noise at equivalent noise levels [50]. In the context of noise, annoyance refers to the feeling of discomfort, irritation, or disturbance caused by unwanted or disruptive sounds. It is an immeasurable health effect that can lead to various negative health impacts mentioned above, particularly stress, and may contribute to the development of cardiovascular diseases [1]. Among the various sources of noise pollution, the recurrent cycles of aircraft take-off and landing noise have emerged as particularly unwelcome and intrusive in airport vicinity [51]. The risk of exposure to aircraft noise is not equally distributed throughout society, with lower socioeconomic and disadvantaged groups often living closer to airports and experiencing higher noise levels. Consequently, residents in these areas are likely to view noise reduction measures as beneficial for their health and well-being. In contrast, individuals benefiting from airport services might prefer increased air traffic and view noise reduction measures as an unnecessary expense [1]. Furthermore, urban expansion and rising population density around airports exacerbate the issue, and the anticipated increase in air traffic is expected to further negatively impact the well-being of those living in close proximity to airports [3, 52].

World Health Organization (WHO) [1] measures the burden of disease due to environmental noise in Disability-Adjusted-Life-Year (DALY)s, which indicates the extent of lost life years due to disability or premature mortality. The DALYs lost is estimated to be 61 000 years due to Ischemic Heart Disease (IHD), 45 000 years due to cognitive impairment in children, 903 000 years due to sleep disturbance, 22 000 years due to tinnitus, and 654 000 years due to annoyance within western Europe [13]. This amounts to over 1.67 million DALYs in western Europe being due to environmental noise within a single year.

Life Quality

Environmental noise significantly impacts life quality by contributing to annoyance, mental health issues, and overall well-being [53–55]. As an environmental stressor, it can increase stress hormones, such as cortisol, which are linked to the development of anxiety disorders and depression. Annoyance, a psychological stress response, can activate physiological stress hormones and lead to sleep deprivation. Nighttime noise, in particular, is known to disrupt sleep, resulting in fatigue and low mood the following day. This effect can be especially pronounced in children, potentially leading to heightened stress responses, including increased levels of adrenaline and noradrenaline. Moreover, there is growing evidence that mental health problems associated with noise exposure may contribute to hyperactivity symptoms

in children [56–58]. In addition to these effects, multiple studies are able to link aircraft noise specifically to an increased risk of depression, further illustrating the profound impact of environmental noise on mental health.

Communication Interference

Communication can be significantly disrupted by environmental noise, leading to distractions that adversely affect children’s cognitive abilities [1]. Prolonged exposure to sounds from personal listening devices can result in temporary and even permanent hearing threshold shifts, tinnitus, and poor speech communication in noisy environments. Insufficient protection against loud noise at work or during leisure activities further increases the risk of hearing loss and tinnitus. While these findings do not specifically address aircraft noise, they illustrate the broader impact noise can have on communication and cognitive functioning, underscoring the potential relevance to aviation-related noise exposure.

Cardiovascular Diseases

Multiple studies have been conducted on the influence of environmental noise on cardiovascular and metabolic effects. Especially road traffic noise has a significant impact on Ischemic Heart Disease (IHD). Several studies report associations between transportation noise (including aircraft noise) and stroke, diabetes, and obesity [59]. Additionally, evidence suggests that noise-induced annoyance and sleep disturbances can increase the risk of cardiovascular diseases. Insufficient sleep influences inflammatory markers as well as endocrine and metabolic functions, leading to a higher incidence of cardiovascular issues. Leptin, a regulator also closely linked to sleep quality, influences weight control, glucose regulation, and cardiovascular health [60].

Vulnerable Population

Bartels et al. [61] explores the effects of aircraft noise on vulnerable populations, including children, the elderly, and shift workers who sleep during the day. The study finds that for children, aircraft noise can disrupt sleep by fragmenting it and reducing the duration of deep sleep. Although these disturbances may appear minor, they are comparable to the sleep changes observed in childhood obstructive sleep apnea, a recognized sleep disorder. For older adults, nocturnal aircraft noise exposure adversely affects self-reported sleep quality and increases annoyance. The probability of experiencing moderate to high levels of annoyance

correlates with the frequency of aircraft noise events during sleep, with the extended wakefulness common among older individuals potentially heightening their perception of noise and resulting in greater annoyance. Additionally, the study shows that day sleepers exposed to aircraft noise experience a significant increase in non-restorative stage 1 sleep, while night sleepers do not. There is also a trend towards reduced deep sleep duration in those who sleep during the day, with no similar reduction observed in night sleepers. Both day and night sleepers reported increased annoyance and reduced self-rated sleep quality due to aircraft noise exposure.

Hospitals, including those with intensive care units, represent a particularly vulnerable population due to their complex environments and the varying sensitivity of their users to noise. Excessive noise levels in these settings can significantly impact stress levels, sleep quality, and the overall recovery process for patients, potentially leading to sleep disorders [62, 63]. The disruptive effects of noise also extend to interference in communication, increased aggression, and general annoyance [64]. Moreover, constant distractions from noise can contribute to medical errors, further compromising patient care.

In hospitals and care units, patients with dementia are especially vulnerable to noise disturbances [65]. They are highly sensitive to minor disruptions, making a tailored, non-disturbing sound environment crucial for their well-being and quality of life. Effective acoustic design must address both internal noise sources and external environmental noise from road, rail, and air traffic to create a calm and supportive atmosphere for dementia patients.

Children, as part of the vulnerable population, are in a critical phase of cognitive development and rapid growth [66]. During this period, their coping mechanisms are not fully developed, making them particularly susceptible to the adverse effects of environmental noise. The first guidelines to limit noise exposure for children were published in 1999, recommending a maximum level of $L_{Aeq} = 55$ dB for outdoor playgrounds to prevent annoyance and $L_{Aeq} \leq 35$ dB during class to avoid interference with information processing and to protect speech intelligibility [67]. However, some consider these noise limits to be unachievable [66]. Research indicates that noise can directly affect children's cognitive abilities, including impairments in speech perception, listening, and reading comprehension [1]. These effects may also be compounded by additional factors, such as frustration experienced by both teachers and students due to disruptions in teacher-student interactions [68]. Environmental noise can significantly

impact task performance, leading to increased alertness, learned helplessness [69], heightened annoyance and stress [70], and sleep disruption [71].

A study before and after the closure of an airport in Munich [72] showed that cognitive tasks requiring central language processing are particularly sensitive to noise. In children aged 9-12 years, the effects of noise exposure were found to be reversible. After the airport's closure, improvements were observed in tasks involving running memory, with memory span in particular showing notable enhancement. Another stress response associated with environmental noise is diminished mood and performance, along with reduced concentration [66].

Non-acoustic Factors

In addition to acoustic factors (noise levels), aircraft noise annoyance can be linked to non-acoustic factors, such as the mentioned take-off and landing cycles, but also flyovers, the duration and reach of the maximum noise level L_{Amax} , as well as attitudes and feelings towards air traffic [73–75].

Airport and aircraft noise annoyance is influenced not only by noise levels but also by individual and social factors [76]. Personal factors include sensitivity to noise, fear of harm from the source, personal evaluation of the noise, and coping capacity. Social factors encompass the general evaluation of the noise source, trust in authorities, history of noise exposure, and resident expectations. Effective communication and cooperation between airport authorities and communities are crucial. Providing residents with information about the necessity of the noise, the actions being taken to reduce it, and future plans for managing the issue is essential. Additionally, involving residents in discussions about noise abatement programs, such as insulation schemes and operation restrictions, can help address their concerns and improve their overall acceptance of the noise situation.

Given the significant negative health impacts associated with environmental noise, particularly around airports, there is a growing need for effective noise regulation and management. One crucial aspect of this is airport noise mapping, which plays a key role in identifying areas of high noise exposure, guiding regulatory efforts, and implementing targeted noise reduction strategies to mitigate these adverse effects.

2.5 Noise Regulations and Airport Noise Mapping

To reduce the negative impacts of specifically aircraft noise and thus lighten community annoyance in airport surrounding areas, International Civil Aviation Organization (ICAO) proposes a *Balanced Approach* [14, 77]. This includes noise source modification, land-use planning, optimized operation procedures, and operation restrictions (such as nighttime flight restrictions or flight number restrictions).

2.5.1 Balanced Approach

Noise source modification involves the adoption of advanced technologies designed to reduce noise at its origin. This includes innovations such as quieter aircraft engines, which may feature acoustic liners to dampen sound [17, 78, 79], high-lift device design [24] and winglet designs that reduce aerodynamic noise, and landing-gear hub caps that minimize the noise generated [24, 80]. New redesigned aircraft have a high potential to have a smaller noise footprint than conventional aircraft concepts [79]. Fleet evolution is an important aspect, when reducing the airport’s noise footprint, as newer aircraft are usually equipped with the newest and quietest technology.

By implementing these technologies or new aircraft, the overall noise produced by aircraft is significantly decreased if flight numbers do not increase, thereby reducing the noise exposure for airport surrounding communities. These measures are crucial for mitigating the impact of aircraft noise and enhancing the quality of life for residents in affected areas.

During the development of airports and the surrounding areas, the *Balanced Approach* guarantees a way that balances environments, economic, and social concerns [14]. Effective land-use planning and management plays a crucial role in maintaining compatibility between nearby airport activities and aviation. The primary objective of such planning is to reduce the impact of aircraft noise on residents by introducing zoning regulations around airports. Compatible areas, such as those designated for industrial and commercial use, should be situated around airport facilities, while incompatible areas, including schools and residential neighborhoods, should be avoided.

Operation restrictions are noise-related limits and can include curfews, nighttime restrictions, noise quotas and budgets, cap rules, non-addition rules, and restrictions related to the

nature of a flight [14, 77]. In general operation restrictions are measures, which reduce or limit the access of an aircraft to the airport.

The extent of operational optimizations depends on the airport's physical layout and surrounding environment. All optimization procedures must prioritize safety and can include noise-preferential routes and runways, new take-off and landing procedures, and improvements in air traffic management [14]. To reduce noise exposure for communities near airports, preferential runway use can help aircraft avoid noise-sensitive areas. Additionally, optimized operational procedures tailored to specific aircraft types can be implemented [81]. Noise-preferential routes and designated flight corridors further mitigate noise by guiding aircraft along defined paths that steer them away from sensitive areas during arrivals and departures. These measures collectively contribute to minimizing the impact of aircraft noise on nearby communities.

2.5.2 Noise Limits

To maintain health and quality of life, the introduction of noise limits becomes essential. Individuals exposed to $L_{night} \geq 55$ dB(A) may encounter adverse effects, while those exposed to $L_{den} \geq 65$ dB(A) are prone to significant annoyance, potentially leading to negative health outcomes [82]. Beyond these thresholds, there is a discernible health risk associated with increased noise exposure.

Noise levels can be described with a single value, the equivalent continuous A-weighted Sound Pressure Level L_{Aeq} . It is expressed over a specific time interval (usually 8 h or 16 h) and utilizes the instantaneous A-weighted sound level $L_A(t)$ [83].

$$L_{Aeq,T} = 10 \log \left[\frac{1}{T} \int_0^T 10^{\frac{L_A(t)}{10}} dt \right] \quad (2.1)$$

Aircraft noise is typically assessed with the help of the Sound Pressure Level (SPL). This metric is time and frequency weighted (evening and night time penalty, A-weighting). The noise index L_{den} is the official metric adopted by the European Commission, which includes a 5 dB evening penalty and a 10 dB nighttime penalty (Equation 2.2) [29].

$$L_{den} = 10 \log \frac{1}{24} \left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}} \right) \quad (2.2)$$

Airport noise limits are not clearly defined and guidelines often do not include noise limits, which can be enforced. Thus, each country and airport can present results and noise exposure differently [84]. Older airport noise maps present noise contours up to $L_{den} = 70$ dB(A) and $L_{night} = 60$ dB(A) [85], while the Irish Aircraft Noise Competent Authority (ANCA) reports $L_{den} = 65$ dB(A) and $L_{night} = 55$ dB(A) for Dublin Airport [82].

European member countries are required to submit noise maps and noise action plans to the European Commission every five years [86]. These submissions must cover agglomerations with 100 000 or more inhabitants, major roads with over 3 million vehicles per year, major railways with over 30 000 trains per year, and major airports with over 50 000 movements annually. In 2023, Dublin Airport was the only airport meeting this requirement. The next largest airport, Cork Airport, recorded 19 777 movements per year, followed by Shannon Airport with 14 998 movements annually [87]. The purpose of these reports is to present the results of strategic noise mapping and action planning, ensuring that noise management efforts are effectively targeted and implemented.

Under END transport noise is modelled according to the EPA guidelines using the CNOSSOS-EU framework. ECAC Doc 29 is specifically used as the aircraft noise calculation standard within this framework. [88]. Under END noise levels at $L_{den} = 55$ dB(A) and $L_{night} = 50$ dB(A) are the mandatory report thresholds, which are supposed to be published every five years in form of strategic noise maps and noise management action plans [89]. The WHO [1] strongly recommends limiting noise exposure levels to $L_{den} \geq 45$ dB(A) and $L_{night} \geq 40$ dB(A) as sleep disturbance and high annoyance can already occur at noise levels exceeding these limits [13]. At higher noise exposure levels a clear health risk can be observed [82]. It should be noted that long-term noise indicators such as L_{night} and L_{den} may underestimate the impact of individual noise events and associated awakenings, as well as daily and monthly noise fluctuations.

2.5.3 Quantification of non-acoustic Impact

Non-acoustic effects refer to the psychological impacts of noise, including annoyance caused by aircraft flyovers and visual disturbances [90]. Additionally, the repetitive nature of noise events can lead to non-rhythmic noise exposure, further contributing to the overall discomfort and stress experienced by individuals in affected areas. To assess the impact of non-acoustical

events, noise point counters to quantify the number of noise events are proposed by Mietlicki et al. [90]. In combination with weighting for the level of instantaneous annoyance this event might generate for the residents, this metric could help to represent the overall noise impact.

The Intermittency Ratio (IR) characterizes the eventfulness of a noise exposure situation without relying on the overall energetic dose. The method has been tested for road, rail, and airport noise but is still in the development phase [91, 92].

Within ECAC Doc. 29, a Number Above Threshold (NAT) index is defined, which quantifies the number of noise events exceeding a specified threshold [30]. This index can also be tailored for specific time periods throughout the day.

While these approaches for aircraft annoyance exist, assessing airport noise and its impact is complex, and currently there is no universally established metric for measuring aircraft noise annoyance.

2.6 Airport Noise Communication

Acoustic and non-acoustic factors associated with air traffic significantly influence perceptions and attitudes toward airport noise [93]. Thus, effective airport communication strategies are crucial for managing noise pollution from aircraft operations [94]. Successful communication necessitates collaboration among airport authorities, airlines, and local communities to raise awareness and develop solutions that mitigate noise impacts. Implementing strategies from the *Balanced Approach* [14], including noise mitigation procedures, flight path modifications, and community engagement initiatives, can inform residents about aircraft schedules and noise levels. Keeping residents informed about long-term plans, operational changes, and the overall effects of noise fosters positive relationships between the airport and the community. This proactive communication supports a balance between increasing air traffic and community well-being. While communication and engagement present substantial opportunities for effective noise management [95], their potential remains largely unfulfilled. These methods are often perceived as secondary tasks rather than essential components that enhance the design and implementation of noise management initiatives.

The following section examines the communication strategies employed by selected airports in relation to Dublin Airport (229 756 annual aircraft movements and 33 259 959 passengers in 2023 [87]).

Since 2018, Frankfurt Airport (430 346 annual aircraft movements and 59 359 539 passengers in 2023 [96]) has published detailed monthly reports for 29 NMTs, including metrics such as L_{eq} , L_{Amax} , and the number of flights, along with operational modes and downtime [97, 98]. These reports also provide a comprehensive overview of noise sources associated with aircraft and the influence of weather conditions on aircraft noise. Frankfurt Airport also charges a noise charge per aircraft, depending on its noise category. Similarly, Dublin Airport offers real-time noise level data for its NMTs [99]. Furthermore, Dublin Airport has been publishing quarterly noise monitoring reports [100].

Zurich Airport (247 456 annual aircraft movements and 28 885 506 passengers in 2023 [101]) actively monitors flight paths and initiates investigations when aircraft deviate from prescribed routes without valid reasons, such as storm clouds or air traffic control instructions [102]. These investigations often result in discussions with airline pilots. Additionally, Zurich Airport employs noise NMTs and has constructed a soundproofed hangar for ground engine testing. Noise charges are levied based on aircraft noise categories, which motivate airlines to invest in and operate quieter aircraft. Furthermore, Zurich Airport is obligated to cover the costs of noise insulation measures for communities around the airport that are excessively exposed to aircraft noise. Dublin Airport also operates a noise insulation scheme to reduce the impact of aircraft noise on affected residential areas [39].

Heathrow Airport (450 193 annual aircraft movements and 79 200 000 passengers in 2023 [103]) employs online communication and publishes schedules for runway alternation to periodically alleviate communities from aircraft noise [104]. While adopting Heathrow's model of runway alternation may not be directly applicable to Dublin Airport, effective public communication regarding expected aircraft noise is crucial. Particularly for areas experiencing high fluctuations in noise exposure, proactive communication about anticipated noise levels in the coming weeks would be beneficial. Dublin Airport has already initiated steps by announcing runway maintenance work [105]; however, the potential impact on surrounding residents' noise exposure is not adequately addressed. It would be advantageous to inform residents that increased noise levels can be expected during specific time frames and in specific areas, facilitating informed community engagement and mitigation efforts.

Narita International Airport's (209 927 annual aircraft movements and 32 705 995 passengers in 2023 [106]) noise levels from 103 Noise and Traffic Monitoring Stations (NTMS) are evaluated by an independent, neutral party. The results are compiled into annual reports, which

are then made publicly available [107]. This process ensures transparency and provides a clear record of noise exposure levels over the year. Narita International Airport also offers subsidies for soundproofing projects not only for residential areas but also for public facilities like schools, hospitals, and nursing homes. All noise measurement data from the 103 monitoring stations around the airport is accessible to the public. To facilitate open communication, consultation centers are located at five sites around the airport, where residents can share their concerns and opinions on environmental issues, including aircraft noise and airport operations.

Dublin Airport has established a dedicated website for submitting noise complaints. Complaints can be linked to the real-time NMT system and submitted through an online form, by mail, or via a freephone service [108].

Haneda Airport (464 910 annual aircraft movements and 78 719 302 passengers in 2023 [109]) prioritizes open dialogue with residents by actively engaging in various community outreach efforts [110]. This includes studying new flight paths through explanatory meetings held across Japan, where the opinions of many individuals are carefully considered. Additionally, the airport ensures the careful provision of information by conducting briefing sessions in areas affected by the new flight paths. An integral part of this process is the ongoing dialogue with local residents, which is regarded as the most important aspect of their approach. To address noise concerns, Haneda Airport implements soundproofing measures and enhances its noise measurement practices, providing transparent monitoring results to the public.

2.6.1 Best Practice Airport Noise Communication

According to Heyes et al. [111] effective communication between airports and the surrounding communities plays a critical role in managing the environmental and social impacts of airport operations—particularly those related to aircraft noise. The primary goal of airport communication is to build and maintain trust and confidence among residents, especially in contexts where noise and other externalities affect daily life. Establishing credibility through transparent, consistent dialogue enables airports to function not only as infrastructure providers but as responsible actors within their communities. Communication efforts should also serve to inform the public of existing challenges, such as air traffic congestion, noise exposure, or changes in flight routes. Providing this context helps residents understand that such issues are often complex and shaped by operational, environmental, and regulatory factors. Moreover,

airport communication should highlight possible solutions being explored or implemented to address these challenges. This includes explaining noise mitigation measures, technological upgrades, and procedural changes in a manner that is accessible to non-specialists. Clearly outlining these steps empowers residents to evaluate the consequences of both the problems and the proposed interventions, contributing to a more informed and constructive dialogue. An essential aspect of communication is also its function in resolving conflicts between the airport and the public. Through engagement platforms, dialogue sessions, and proactive outreach, airports can listen to concerns, clarify misunderstandings, and foster a mutual sense of understanding. Ultimately, well-designed communication strategies can transform potential opposition into cooperation by involving the community in developing shared solutions and reinforcing the airport's commitment to responsible operations.

Many airports have implemented noise mitigation measures, but often fall short in effectively communicating with surrounding communities. Clear, consistent, and accessible communication is crucial to maintain trust and reduce frustration among residents [111, 112]. One key step is the regular publication of understandable reports from NMTs. These reports should not only present data but also address the specific concerns of nearby communities, offering explanations in plain language that can be understood by non-experts.

Noise maps are another important tool for transparency [113], yet they are often presented without adequate explanation. Visual aids, such as noise contour lines, for instance, are frequently misunderstood by the general public. Airports should therefore take additional steps to educate residents about how to interpret these maps and about the broader health impacts of noise exposure. Raising awareness of the long-term consequences of noise pollution can help communities better understand the importance of mitigation efforts.

Equally important is providing residents with direct communication channels to the airport's noise management team. A dedicated hotline or at least an email service should be in place, allowing residents to ask questions, report unexpected disturbances, or express concerns. As discussed in Chapter 5, flight routes do not always adhere to planned paths and can unexpectedly affect different neighborhoods. In these cases, it's essential for the airport to be responsive and listen to those impacted. Airports expecting changes in flight paths or having recently undergone such transitions may also benefit from setting up local communication centers. These centers allow for in-person dialogue, giving residents the opportunity to express concerns and receive timely explanations.

Most airports already offer noise insulation schemes for highly affected areas. However, eligibility criteria and the application process are often poorly communicated. Airports should ensure that this information is easy to find and clearly explained, so that those in need of support can access it without unnecessary barriers.

Beyond noise-specific measures, general information about airport operations can foster greater understanding within the community. A clear overview of how flight procedures vary with weather, wind conditions, or time of day can help demystify why certain decisions are made. This transparency can reduce confusion and prevent misinterpretations of normal operational changes as avoidable nuisances.

Finally, all noise mitigation strategies in place, such as bans on louder aircraft, the use of noise-preferential routes or corridors, and adjusted take-off and landing procedures, should be clearly communicated to the public. Explaining these efforts in a way that is meaningful and easy to understand allows residents to recognize the airport's attempts to balance operations with community well-being.

When thoughtfully applied, these communication strategies can significantly improve the public's understanding of airport noise and help build stronger, more cooperative relationships between airports and the communities they serve.

2.7 Contribution of the Thesis

While annual noise maps are commonly used, they often fail to capture monthly noise fluctuations, particularly in aircraft noise, which is highly sensitive to weather conditions and wind patterns. This thesis addresses this gap by providing a more detailed analysis of noise variations over shorter time periods, thereby enhancing the accuracy of noise impact assessments. In the context of land-use planning (part of the *Balanced Approach* to noise management), this research offers forward-looking insights that support long-term planning. By incorporating detailed noise data, the thesis equips the public, policymakers, and planners with valuable information to make informed decisions about land use and potential communication strategies.

The noise forecasts in this thesis combine air traffic growth with a detailed analysis of fleet evolution and technology uptake up to 2050. A novel aspect of this work is the incorporation of NPD data for generation 3 aircraft, which provides a more accurate representation

of future noise levels. Until now, only aircraft substitution tables have been used for newer aircraft configurations, typically relying on proxy aircraft data. By using actual NPD data for generation 3 aircraft, this research offers a more precise and innovative approach to forecasting future noise impacts in 2050. This proactive approach ensures that noise management strategies are more responsive to actual conditions and better suited to mitigate the impacts on affected communities.

2.8 Summary

This chapter reviewed the literature on noise pollution, focusing on environmental and aircraft noise, its health effects, and regulatory measures, including the Balanced Approach. It began with an examination of environmental noise, detailing its sources and characteristics, before addressing aircraft noise, which was found to be notably more disruptive due to its high intensity and intermittent nature. The chapter then explored the health effects of noise exposure, linking it to cardiovascular diseases, cognitive impairment, sleep disturbances, and general annoyance, with emphasis on its disproportionate impact on populations near high-noise areas. The chapter also addressed noise regulations and airport noise mapping, detailing European requirements for noise assessment and action plans aimed at mitigating noise impact through the Balanced Approach. It discussed the limitations of annual noise maps and their inability to capture fluctuations in noise levels. Finally, it highlighted the importance of effective communication strategies between airports and surrounding communities as critical for improving land-use planning and enhancing noise mitigation efforts.

Chapter 3

Dublin Airport

3.1 Introduction

In this chapter, Dublin Airport is introduced as the central case study for the thesis. Given its proximity to Trinity College Dublin, using Dublin Airport provides a relevant and accessible focus for this research. Located on the east coast of Ireland, Dublin Airport serves as a major hub for both short- and long-distance international flights and is well-connected in terms of flight routes [2]. The chapter begins with an exploration of the airport's historical context, followed by an overview of past and current runway operations, including operational limits. Additionally, it examines the weather and flight patterns for 2023, providing a current snapshot of airport activity. The chapter also explores the population density of areas surrounding the airport and analyzes the existing noise map. Finally, the current communication strategy employed by the airport is discussed, exploring how the airport engages with the community regarding noise management and other operational concerns.

3.1.1 Historical Context

The building of Dublin Airport began in 1936 [114, 115]. It was placed in the vicinity of 16 km of Dublin's city center on open and flat land. The commercial airport, initially called Collinstown Airport, opened on January 19, 1940, operating a single flight to Liverpool from a curved terminal [116, 117]. Since then more than 600 million passengers have traveled through the airport [118]. The original terminal building was built to accommodate 100 000 passengers annually. In 1948 and 1950 new concrete runways were extended and finished and passenger numbers reached around 200 000 annually. The first transatlantic flight was operated in 1958. Within 20 years of its opening the terminal building was not able to handle the increasing amount of passengers. In June 1959, a new North Terminal was completed, initially intended to handle all European and US flights. However, it ultimately served as the arrival terminal for all passengers. Due to increasing aircraft sizes new departure gate piers were added by the 1960s. To meet the needs of increasing passenger numbers Dublin Airport expanded again with a new terminal building, departure gate piers, runway, and taxiway in June 1972. By 1989 the passenger numbers increased to 5 million and reached more than 10 million in 1997. Within 21 years Dublin Airport reached 23.5 million passengers in 2008. Dublin Airport's capacity to handle more than 30 million passengers annually was ensured by the completion of Terminal 2 in November 2010, which was granted planning permission in 2007 [119]. The

planning permission for the North Runway was submitted in 2004 [39], approved in 2007, and was originally expected to be completed in 2021 [119]. Due to the economic situation, the project was deferred until 2016 [39]. In 2016, when passenger numbers exceeded 30 million for the first time, the decision was made to proceed with plans for the North Runway. The third runway at Dublin Airport was opened on August 24th, 2022 [41].

In 2017 Dublin Airport supported around 97 400 jobs and contributed around 4 % to Ireland's GDP [39]. In 2018 63 passenger airlines had aircraft movements scheduled at Dublin Airport [119]. From 2006 to 2015 Dublin Airport's national market share has grown from 73 % to 84 %. As aircraft capacity increased, the number of passengers per aircraft movement has also increased, which is a continuing trend due to more modern aircraft at Dublin Airport.

The planning permission of the North Runway included planning conditions, which also state operation restrictions [39]. One of the operating conditions for the opening of the North Runway was that it would only be in operation from 07:00 to 23:00, with a limit of 65 aircraft movements per night (23:00 to 07:00). Due to the operation restrictions of the airport's overall nighttime operation, the Dublin Airport Authority (DAA) has requested to change these conditions. In a public consultation for airport surrounding communities in 2016 possible mitigation measures, the development of a new community fund, and future flight paths were discussed. Noise contour maps were developed for the different flight routes, divided into day and night contours. Before the operation of the North Runway, nighttime flights came to an average of 100 aircraft movements per night.

3.1.2 Current Situation

Currently, Dublin Airport operates in a mixed mode with a parallel runway system and preferred runway usage (see Section 3.2, Option 7b). To address the noise problem, several noise mitigation measures in line with the *Balanced Approach* [14] have been implemented. For noise reduction at the source, Dublin Airport has banned Chapter 2 aircraft, and by 2015, nearly 95 % of all aircraft movements were from Chapter 4 aircraft [39]. To incentivize the adoption of newer, quieter aircraft, noise charges were introduced [120]. Operational procedures such as reverse thrust and ground run-ups are restricted, and NPRs have been established. According to the North Runway Report, these operational restrictions are considered a "last resort".

All departing aircraft must follow Noise Preferential Routes, specific flight paths designed to minimize noise over densely populated areas [39]. These routes are up to 1.8 km wide and extend to an altitude of approximately 3000 ft (914.4 m).

For land-use planning and management, insulation schemes were developed for residential buildings exposed to 63 dB and schools exposed to 60 dB (information for time interval missing in the report) [39]. The combined Home Sound Insulation Programme (HSIP) and Residential Noise Insulation Scheme (RNIS) insulation schemes cover an area of almost 20 km².

Contour	Area [km²]	Houses	People
Insulation scheme	19.64	433	837

Table 3.1: Extend of combined HSIP and RNIS insulation schemes

The 2019 Dublin Airport Local Area Plan was developed to guide airport growth for six years from 2018 onward, while also considering long-term planning objectives. Additionally, an extension of the Dublin Area Rapid Transit (DART) system was proposed to improve public transport connections from the city center [119].

3.2 Runway Operation

As air traffic is growing, it is important that runway operation balances economic, logistic, and safety issues. On top of that, the goal is to use the full runway capacity of the airport [121]. To plan runway operation growth forecasts and ground procedures have to be taken into consideration.

Dublin Airport has three runways as of 2022: the South Runway (10R/28L), the Cross Runway (16/34), and the newest addition, the North Runway (10L/28R) [122]. Figure 3.1 shows the dimensions of the currently operating runways of Dublin Airport. The North Runway is longer than the old Cross Runway or the South Runway and is able to accommodate larger aircraft types [39]. The Cross Runway has the shortest runway length (2072 m) and a width of 61 m, as wide as the North Runway. The South Runway has a width of 45 m and a length of 2637 m. The North Runway is the longest runway at Dublin Airport with a length of 3110 m.

Until 2022 all aircraft movements at Dublin Airport were operated from the South and the Cross Runway [39]. Departures from the South Runway had to maintain a straight course

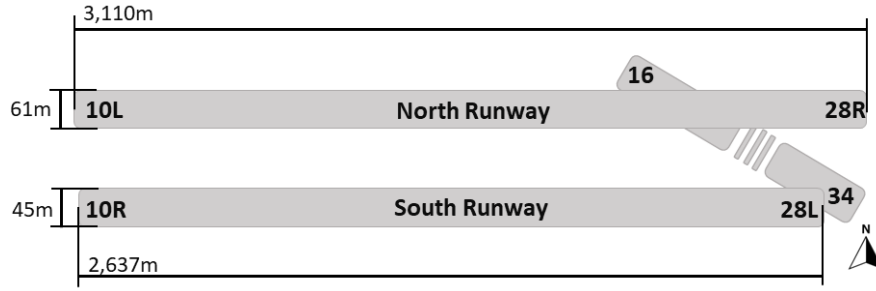


Figure 3.1: Runways and runway dimensions at Dublin Airport

for around 9 km before turning. Departures from the South Runway to the east had to fly at least 11 km before turning to the south.

The third runway at Dublin Airport enables a parallel runway system of the North and the South Runway, which can accommodate more aircraft movements than two intersecting runways. There are two different operation modes for aircraft movements on a parallel runway system, such as Dublin Airport (using the North and the South Runway).

The mixed mode, in which the runway is used for approach and departure, and the segregated mode, where the runway is only used for approach or departure maneuvers. The segregated mode requires at least two runways at the airport. Aircraft movements at the airport are restricted by a minimum safe separation distance between aircraft [123]. Depending on the operation mode, terminal capacity, and separation of aircraft movements, the runway capacity can vary. These operational restrictions are influenced not only by runway conditions but also by environmental noise regulations, which impact operating hours. In addition, a safe distance must be maintained between aircraft during movements, with the required separation depending on the leading and following aircraft. Departure-departure separation also takes into account wake vortex interactions.

3.2.1 Current Runway Operation

As of August 24th, 2022, Dublin Airport operates with three runways [41] and in accordance with Option 7b from the North Runway Report [39]. The North Runway and South Runway typically operate separately or in semi-mixed mode, with the Cross Runway reserved for strong crosswinds [124]. Before the opening of the North Runway, analysis of wind patterns indicated that western operations would prevail approximately 70 % of the time. Under these conditions, aircraft departures were scheduled from the North and South Runways, while

arrivals preferably utilized the South Runway (Figure 3.2(a)). Conversely, during easterly operations, departures favored the South Runway, with arrivals allocated to the North and South Runways (Figure 3.2(b)) [125].

The parallel runway operation led to a 99 % reduction of Cross Runway use, meaning highly populated areas such as Dublin City are rarely overflowed [126]. The planning per-

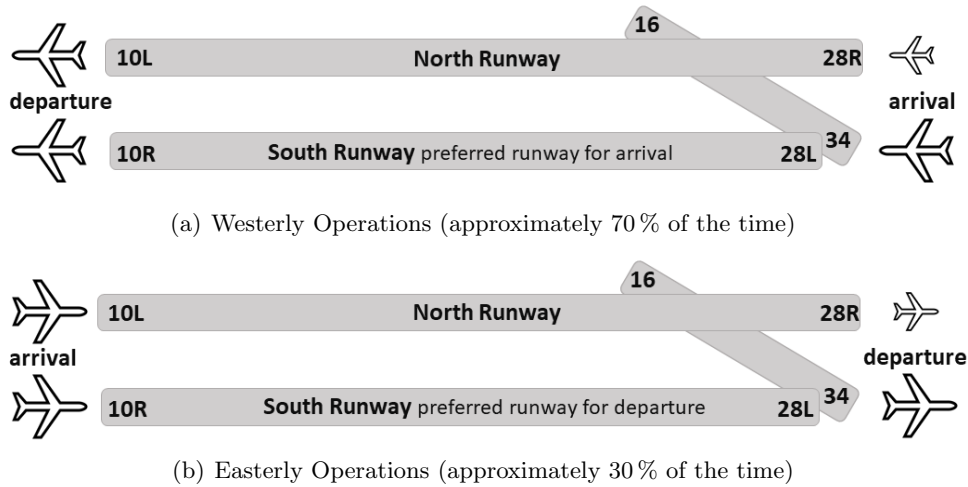


Figure 3.2: Dublin Airport runway operation mode, depending on wind direction (Option 7b) according to Dublin Airport [124]

mission for the North Runway included a reduction in nighttime flights from 100 to 65 per night, as well as a prohibition on using the North Runway during nighttime hours [39, 125]. Dublin Airport has argued that these restrictions limit the number of services and routes it can operate, resulting in higher fares and a projected loss of approximately 1.1 million passengers by 2025. To address these issues, a planning application was submitted to An Bord Pleanála in 2020. The proposal seeks to extend the North Runway’s operational hours from the current 07:00–23:00 to 06:00–00:00 [127]. It also proposes replacing the nighttime flight limit with a noise quota count system between 23:30 and 06:00, along with the introduction of a noise insulation grant scheme for residents most affected by the changes.

Dublin Airport operates under a passenger limit of 32 million annually across both terminals, a figure which was already exceeded in 2023 (33.3 million passengers [87]). The DAA submitted an infrastructure application to raise the limit to 40 million passengers per year [128, 129]. At the same time a forecast from the North Runway Report predicts that passenger numbers will reach 50 million by 2037 [39].

During the first months of operation after the opening of the North Runway, aircraft departing to the west of the North Runway and making a right turn (to the north) diverted from the planned flight routes. This unexpected change in flight paths led to increased flyovers of several local communities, resulting in significant noise exposure for residents. In response, the DAA conducted a review of the flight paths and updated instrument flight procedures to reconcile them with the previously communicated information [126, 130]. The flight paths were adjusted in February 2023, which resulted in better alignment with the planned flight paths proposed in 2016. This initial change in flight routes increased noise exposure in communities that were not originally expected to be impacted by high levels of aircraft noise from the North Runway.

3.2.2 Noise Charges

Dublin Airport introduced noise charges based on aircraft noise certification in July 2022, which were updated for 2024 [120]. These charges are determined by the aircraft type and configuration and are calculated per tonne based on the Quota Count (QC) value of the aircraft. The QC value is calculated separately for arrivals and departures, depending on the noise classification. For arriving aircraft, the noise classification is determined by subtracting 9 dB from the approach Effective Perceived Noise in Decibels (EPNdB). For departing aircraft, the classification is based on the difference between the average lateral noise EPNdB and the take-off EPNdB. The QC value, is obtained from a table corresponding to the noise classification.

The EPNdB values for noise certification levels are published by European Union Aviation Safety Agency (EASA) [131].

3.2.3 Proposed Noise Quota System

The DAA applied for an amendment to the 2007 planning conditions to limit nighttime flights to 65 per night, with a preference for South Runway use during these hours [132]. The proposed changes include replacing these conditions with a Noise Quota System and permitting the use of the North Runway for an additional hour at night (23:00 to 00:00) and in the morning (06:00 to 07:00). The Noise Quota System aims to limit the number of noisier

aircraft operating at night (23:00 to 07:00) by assigning Quota Count (QC) values based on aircraft noise classification.

The noise classification for the Noise Quota System is calculated similarly to the method used for noise charges, with the QC value determined from a table [133]. Aircraft with a QC value of four or more are prohibited from operating during nighttime hours. Only aircraft with a QC value of less than two are allowed to land at night. The maximum annual limit of noise quota points is capped at 16 260, with no limit on the number of movements.

This Noise Quota System is not unprecedented. Similar systems have already been implemented at UK airports, including Heathrow [134], Gatwick [135], and Stansted [136]. However, unlike the proposed system, all three of these airports have also imposed a movement limit during nighttime hours.

The proposed Noise Quota System for Dublin Airport has faced significant criticism due to its high noise quota point limit and the absence of a movement limit [137, 138]. Although the system favors the operation of quieter aircraft, it fails to impose an effective nighttime restriction. The noise quota point cap is set too high, and without a movement limit, the system does not adequately address individual noise events [90], which are not captured by existing noise assessment metrics or reflected in a reduction of overall noise quota points.

King [137] suggests implementing a lower noise quota point limit along with seasonal adjustments. Additionally, a movement limit, similar to those at UK airports, should be introduced to enhance the effectiveness of the system. Currently (September 2024), this Noise Quota System is not in place, and Dublin Airport must operate under its existing planning conditions.

In September 2024, a proposal was made for an addition to the proposed noise quota system aimed at mitigating the negative effects of sleep disturbance due to nighttime flights [139]. The proposed system would introduce a movement limit on nighttime flights. It includes a seasonal movement limit, with restrictions on the number of nighttime flights: during the busy summer period (March to October), 70 % of the time, the cap would be set at 100 aircraft per night. For the remaining period of the year, the average number of nighttime flights would be limited to 14 per night. Furthermore, the proposal suggests extending the housing insulation scheme to all households affected by $L_{Amax} \geq 80$ dB during the nighttime period (23:00–07:00).

3.3 Communication Strategy

Effective communication and collaboration between airport authorities and local communities are vital [76]. It's important to keep residents informed about why the noise is necessary, the measures being implemented to mitigate it, and future strategies for managing the noise issue. Therefore, good communication and collaboration between the airport authorities and residents are vital. Engaging residents in conversations about noise reduction initiatives can address their concerns and enhance their overall acceptance.

3.3.1 Population around Dublin Airport

Dublin Airport is situated close to the city of Dublin, making it susceptible to noise pollution that can affect a large number of residents [140]. Figure 3.3 illustrates the number of dwellings around Dublin Airport, highlighting the high population density in Dublin City itself (blue). Dublin Airport is located in L:M6 in Figure 3.3. Notably, areas such as Swords (M3:O5), Seabury (O4:P5), and Malahide (Q:R5) to the northeast of the airport exhibit significant population concentrations, with Swords housing approximately 43 000 residents and Malahide around 13 500. To the southwest, Blanchardstown (G8:J9) stands out as a highly populated area with a population of approximately 74 500. Additionally, several communities with notable population densities can be found to the northwest of the airport, including Dunshaughlin (C2:D3), with about 6000 residents; Ratoath (F2), with around 11 000 residents; and Ashbourne (H1:I2), which also contributes to the overall demographic landscape.

Figure 3.3 also highlights the planned residential areas from the Development Plan 2023-2029 [142]. These new communities focus on providing access to public transport and cycle links. The plan promotes a mix of housing types and sizes, ensuring access to necessary social and physical infrastructure.

3.3.2 Current Noise Maps and Noise Monitoring

From 2019 on, ANCA provides the annual noise maps for Dublin Airport in a map viewer online [144]. In addition, Dublin Airport has published monthly reports since 2021 with varying amounts of detail regarding flight and passenger numbers, runway and track usage, wind direction, and noise complaints [100].

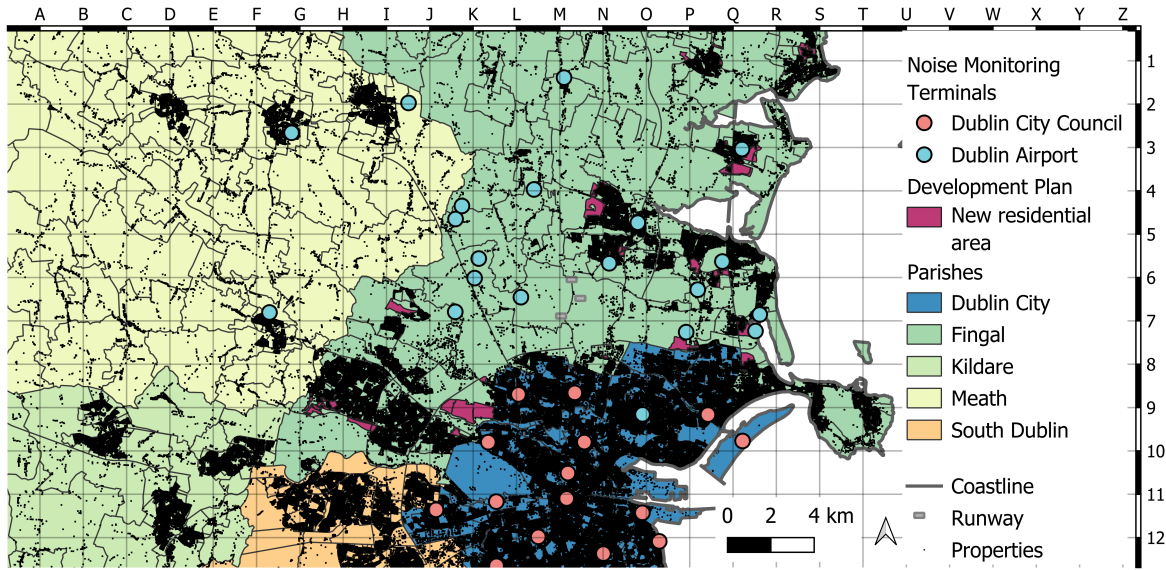


Figure 3.3: Population around Dublin Airport with parishes from Census 2022 [140], dwellings from Geo Directory [141], planned residential areas from Fingal County Council [142] and Noise Monitoring Terminals from Dublin Airport [99] and Dublin City Council [143]

Dublin Airport provides annual airport noise maps for 2020 and 2021 through Webtrak [99], and for 2023 via Aircraft Noise Competent Authority (ANCA) (Dublin City) [145]. However, despite monthly noise complaint reports being published [100], there is currently no provision of monthly noise maps or educational resources that address the long-term health impacts of aircraft noise for affected communities. This issue is not unique to Dublin Airport; a similar lack of publicly available noise level data is common. Comparisons can be drawn with the communication strategy of other international airports from differing jurisdictions. Dublin Airport analyzes wind and weather patterns to optimize flight operations; however, this information is only limitedly available to the public.

Dublin Airport offers real-time noise level data via WebTrak [99] at 19 fixed locations. The airport also publishes quarterly noise monitoring reports and, since 2024, has provided monthly statistics and maps of noise complaint areas. These reports reveal that most complaints come from the area north of Dublin Airport, stretching out to the east and northwest of the airport [100]. Dublin City Council also has 15 Noise Monitoring Terminal (NMT)s spread across the city; however, these terminals are not within or near the monthly noise contour lines of Dublin Airport. The noise readings from these terminals are stored and available online [143].

In addition, mid-term noise maps projecting to 2035 were published by Mott MacDonald Global Aviation [32] in the 2021 Development Report for Proposed Noise Measures. However, these maps are of insufficient quality to accurately interpret specific noise levels or to clearly identify highly exposed areas. Furthermore, long-term projections extending to 2040 or 2050 are currently not available.

3.4 Summary

Dublin Airport, located near Dublin City and highly populated areas, opened in 1936 and has undergone several extensions, serving over 30 million passengers annually today. The airport features a parallel runway system with three runways, typically operated in mixed mode, with about 70 % of operations directed westerly. To address noise concerns, Dublin Airport implements various mitigation measures, including noise preferential routes, noise charges, and operational restrictions during nighttime. Specifically, the North Runway is not used at night, and the number of flights is limited during these hours. An insulation scheme is also in place to help reduce noise impact on surrounding communities.

A noise quota system, which classifies aircraft based on their noise emissions, was proposed in conjunction with a nighttime flight restriction in 2024.

Since 2019, Dublin Airport has reported annual noise maps and developed land-use planning guidelines for new residential areas. Monthly reports detailing noise complaints and flight numbers have been available, and starting in 2024, these reports will also include data on runway usage and wind conditions. However, no monthly noise maps are available, which can display monthly fluctuations in area and population noise exposure.

Chapter 4

Methodology

4.1 Noise Mapping Process

Environmental noise modeling is a crucial tool for understanding and managing aircraft noise exposure at the population level. This section outlines the process for generating, calculating, and post-processing aircraft noise data, with a focus on the methodology used in Europe. Noise modeling not only helps assess the current impact of aviation on surrounding communities but also forecasts future noise scenarios, incorporating factors such as new flight paths, changes in fleet composition, and advancements in noise-reducing technologies. Furthermore, this section discusses the use and generation of Noise-Power-Distance (NPD) curves. Aircraft noise in this work is modeled according to noise assessment methods defined in ECAC Doc. 29 under CNOSSOS-EU. This section details the entire noise modeling process, from input data generation through to the final outputs used for policy and planning. Ground noise sources such as APU usage, ground service vehicles, general airport operational noise, and aircraft taxiing are classified as industrial noise and, therefore, are not included in the noise modeling conducted in this thesis [29].

The Environmental Noise Directive (END) mandates EU member states to publish environmental noise maps for road, rail, industry, and aircraft noise (see Section 2.5.2). For a common noise assessment among all countries, the European Commission has developed a strategic noise mapping framework, known as Common Noise Assessment Methods in Europe (CNOSSOS-EU). It defines the main noise indicators (L_{den} and L_{night}) and establishes a method by which strategic noise maps are to be produced [146].

The CNOSSOS-EU method is valid for aircraft noise ranging from 63 Hz to 4 kHz, with a possible extension to 8 kHz. The framework is designed for precision and reproducibility, ensuring accuracy when comparing calculated noise levels to measurements, as well as computational speed, flexibility (especially for terrain), and simplicity [146]. However CNOSSOS-EU does not develop its own model for aircraft noise, instead it refers to ECAC Doc. 29.

Aircraft noise within CNOSSOS-EU is modeled according to European Civil Aviation Conference (ECAC) Doc. 29. The decision was between ECAC Doc. 29 and the German Anleitung zur Berechnung von Lärmschutzbereichen / Instructions on the Calculation of Noise Protection Areas (AzB) 2008 method, which have different noise and performance database structures [146]. ECAC Doc. 29 utilizes the Aircraft Noise and Performance database. The framework also provides guidance on how to adapt and extend the ANP database to ac-

count for new aircraft, meteorological conditions such as temperature and humidity, as well as ground noise.

The AzB 2008 method relies on octave band spectra for emission data and employs a spectral 2-dimensional directivity function [147]. In contrast, Doc. 29 utilizes Noise-Power-Distance (NPD) data, spectral classes, and a semi-empirical dipole model that incorporates corrections for installation effects, resulting in lateral directivity [29, 30]. However, Doc. 29 does not account for ground noise sources such as taxiing and Auxiliary Power Units (APU).

One of the key advantages of Doc. 29 is its greater flexibility in generating flight paths, making it particularly useful for noise mitigation studies and optimizing flight procedures [29, 30]. It is important to note that Doc. 29 does not address helicopter operations or ground activities. Both models describe air and ground absorption using the same empirical approach, although neither explicitly models meteorological effects.

Figure 4.1 illustrates the noise mapping procedure as outlined in the ECAC Doc. 29. This figure presents the overall workflow, including the input data components, pre-processing steps, noise modeling phases, and post-processing outputs.

All calculations for this project are conducted on an *Alienware Aurora R12* computer, equipped with an *11th Gen Intel(R) Core(TM) i9-11900KF* processor.

4.1.1 Input Data

The input data used in noise mapping is specific to each airport and includes details such as airport geometry, runway information (e.g., coordinates), air traffic statistics, aircraft types and quantities, flight tracks, and operational data [29]. Additionally, temporal data indicating when specific aircraft take off or land is included.

Airport-Specific Data

Airport-specific data is critical for noise mapping and modeling. It includes reference coordinates, runway geometry, topography, meteorology, and aircraft operations. Reference coordinates consist of the aerodrome reference point at the aerodrome reference altitude. Runway geometry includes the reference point, length, mean gradient, direction, start-of-roll position, and landing threshold. These parameters define aircraft movements during take-off and landing. Topography and surface cover are represented by terrain elevation variations relative to the airport reference elevation, using a grid of x, y, and z coordinates with a spec-

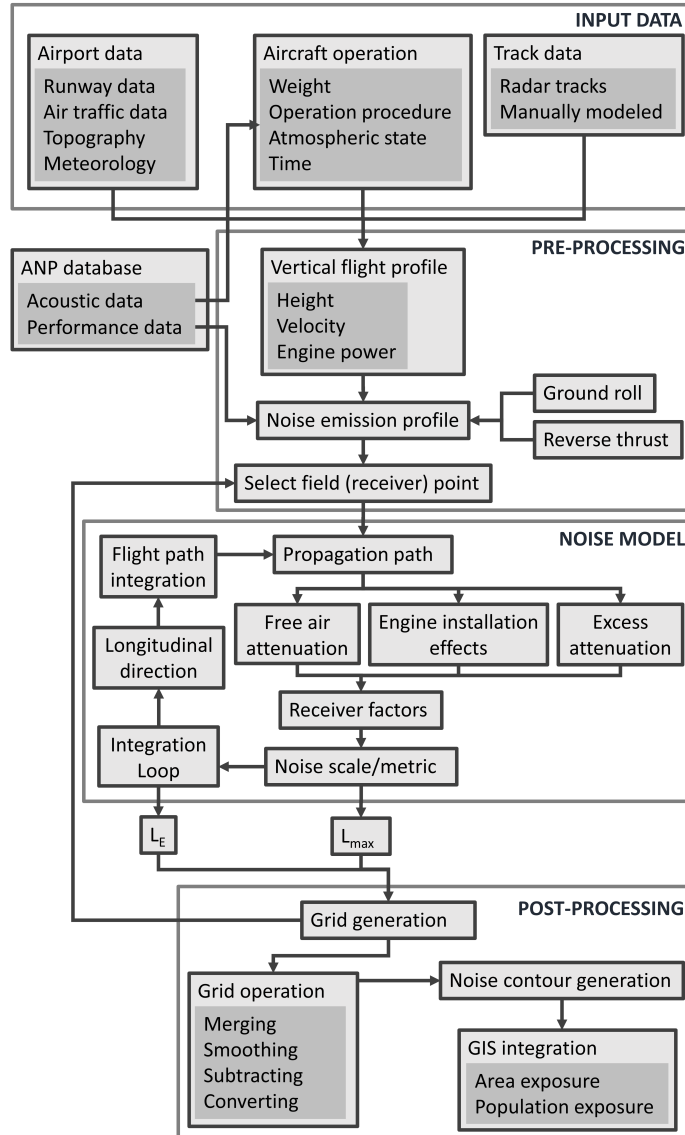


Figure 4.1: ECAC Doc. 29 noise mapping procedure based on ECAC [29, 30, 148]

ified mesh size. This allows for accurate modeling of noise propagation over varied terrain [149]. Meteorological conditions, such as temperature, relative humidity, wind speed, and wind direction, influence sound propagation [29, 30]. Average conditions at the location are typically used. Wind conditions can significantly affect runway usage and flight paths.

Track Data

Track data is divided into two components: ground track and vertical profile [29, 30]. The ground track consists of a sequence of coordinates that can either represent individual aircraft movements or follow a nominal center-line, known as a *backbone* track. Additionally,

the ground track includes the runway from which the aircraft movement originates. The vertical profile can be provided in two forms: default fixed-point profiles or procedural profiles. Default fixed-point flight profiles, which are available in the ANP database, are derived from data supplied by local aircraft operators. These profiles consist of flight segments with predefined parameters for altitude, flight speed, and engine power. Each default flight profile is also associated with a standard take-off weight, determined as a function of the flight distance. Procedural profiles, on the other hand, are based on the actual flight paths flown by aircraft. These profiles are composed of consecutive segments, each representing specific flight phases such as take-off, climb, and acceleration. The flight profile is calculated by combining these phases with the target altitude reached at the end of each segment. The resulting profile is influenced by speed, altitude, and thrust, which is dependent on the aircraft's proximity to the ground.

Aircraft Operation Data

Aircraft operation data is essential for calculating the full flight profile of each aircraft [30]. This data is retrieved from the Aircraft Noise and Performance (ANP) database and includes key parameters such as aircraft-specific aerodynamic and engine characteristics (e.g., jet thrust and flap coefficients for different flight phases), weight, and operational procedures. The operational procedure outlines the steps for both arrival and departure profiles, detailing power settings, forward and vertical velocity, flight configuration, number of engines, atmospheric conditions, and operation times. These factors collectively determine the performance and noise characteristics during each phase of the flight.

4.1.2 Noise-Power-Distance Data

The Aircraft Noise and Performance (ANP) database consists of aircraft-specific data, such as power settings, airspeed, and flight profiles in the form of fixed-point or procedural profiles [30]. It also includes Noise-Power-Distance (NPD) tables, which contain noise levels depending on slant distance and engine power setting (engine power parameter). NPD curves show the relationship of different engine power settings at defined distances resulting in various noise events. From those curves, the noise level of the aircraft can be determined. NPD curves give information about the aircraft's noise at a specific distance with defined engine

power. The NPD data displays at least two noise metrics, SEL and L_{Amax} , with EPNL and PNLTM being additional metrics.

NPD tables consist of noise metrics at the defined heights (60.96 m, 121.92 m, 192.02 m, 304.8 m, 609.6 m, 1219.2 m, 1920.24 m, 3048 m, 4876.8 m, 7620 m (200 ft, 400 ft, 360 ft, 1000 ft, 2000 ft, 4000 ft, 3600 ft, 10 000 ft, 16 000 ft, 25 000 ft) [30]) for different engine power settings (corrected net thrust) at reference atmospheric conditions (atmospheric pressure = 101.325 kPa, precipitation: None, wind speed ≤ 8 km/h, local terrain: flat, soft ground no reflecting objects [30]).

NPD Data for Current Aircraft

The predefined heights of the noise measurements are called slant distance d_m [30]. It is the distance that is perpendicular to the aircraft's flight path, as seen in figure 4.2. Aircraft sound measurements are taken at 1.2 m above the ground and can be considered comparable when the air temperature near the surface ≤ 30 °C, wind speeds are ≤ 8 m/s, and the product of the air temperature in °C and the relative humidity in % is ≥ 500 .

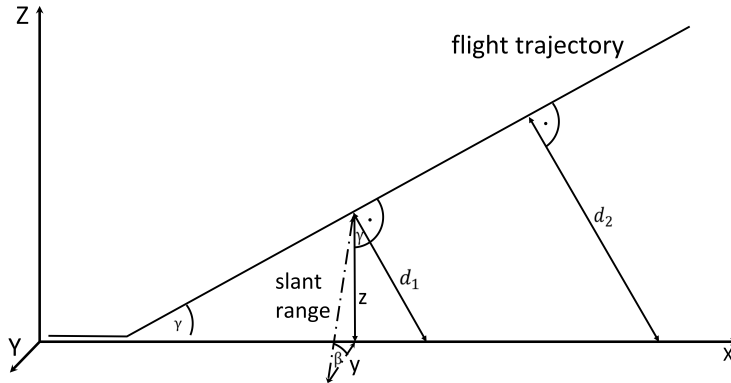


Figure 4.2: Slant distance of a take-off flight trajectory based on ECAC [30]

Future Aircraft NPD Data Generation

Airport noise mapping requires NPD data to simulate flight paths and the corresponding noise levels of each aircraft. This section outlines the procedure for generating NPD data for new aircraft concepts that exist only as theoretical designs. These concepts, which have not yet reached the prototype stage, can be evaluated through simulations to determine their potential for noise reduction before further development is considered.

NPD data for current and future general aircraft are generally sourced from the ANP database and ANP aircraft substitution tables [150, 151]. In the case of new configurations or aircraft models, a similar existing aircraft or the previous model is typically used as a baseline.

A proxy aircraft with a similar engine category and the same number of engines, engine installation, MTOW, ICAO noise certificate, airframe, engine manufacturer, and thrust-to-weight ratio needs to be identified. For aircraft categorized under noise Chapters 2, 3, 4, and 14, corrections for approach and departure noise levels are applied to account for performance differences. These corrections are based on noise levels measured at the three certification points (lateral, approach, and flyover) detailed in Section 2.2.2 and are computed using Equations 4.1 and 4.1 (*miss* for missing aircraft and *proxy* for the substituting aircraft [29]).

$$\Delta_{dep} = \frac{L_{flyover,miss} + L_{lateral,miss} - L_{flyover,proxy} - L_{lateral,proxy}}{2} \quad (4.1)$$

$$\Delta_{arr} = L_{approach,miss} - L_{approach,proxy} \quad (4.2)$$

The proxy aircraft is listed in the substitution table with the corresponding departure and approach correction for the missing aircraft. Aircraft types not referenced in the ANP aircraft substitution tables are obtained from the Civil Aviation Authority (Aircraft substitution data for future aircraft and modernized generation 2 aircraft: Boeing 737maxG2 variations, Boeing 787G2 variations, A320neoG2 family variations, A350G2 variations, and E170/190G2) [152] and the Dublin Airport Authority (Aircraft substitution data for A330-900neo, A350-900, Boeing 777X, and E190-E2) [153].

For new aircraft concepts with futuristic designs such as a Blended Wing Body (BWB), no real-world data yet exists. For these cases, usually one turns to parametric tools, used in the concept stage of aircraft development. In this study, the ONERA in-house system noise prediction tool Codes Acoustiques par Rayons pour la Modélisation et l'Estimation de Nuisances / Ray-Based Acoustic Codes for Modeling and Estimation of Nuisances (CARMEN) was used to calculate all configurations that were necessary for the NPD data generation. NPD data and departure and arrival profiles of the future aircraft concept, the BWB aircraft, are combined in the noise mapping software SoundPLAN (Figure 4.3). The SoundPLAN model incorporates airport-specific details and the topography in the calculation area. Post-

processing of the noise data is conducted in QGIS, where building and population data are combined.

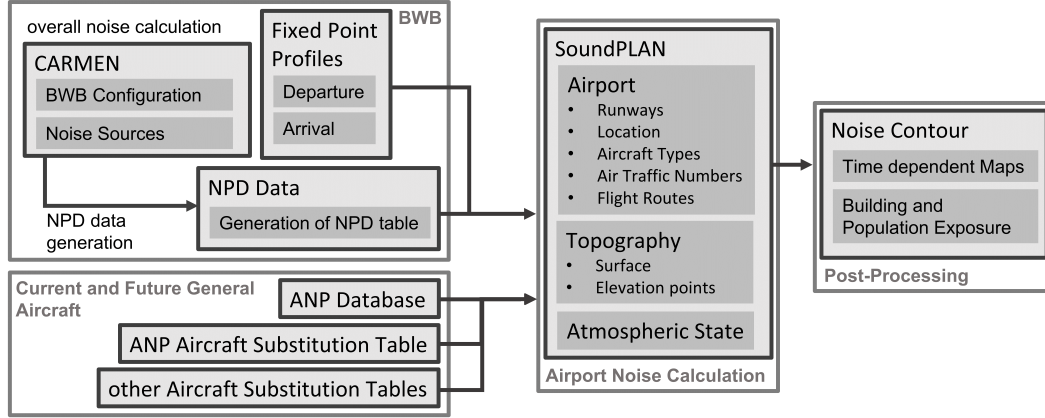


Figure 4.3: Airport noise mapping procedure with future aircraft concepts

CARMEN is a parametric tool comprising three modules: the calculation of noise sources, their installation, and their propagation toward the ground. It has been validated for conventional tube-and-wing aircraft [154] and is primarily used in the concept stage evaluation of new aircraft designs, as well as, more recently, for assessing the impact of drone fleets.

The BWB concept, assumed to act as a proxy for generation 3 aircraft in this study, was developed by Roma Tre University (Figure 4.4) as part of the Horizon 2020 research project Aircraft Noise Reduction Technologies and related Environmental iMpact (ARTEM) [155]. For this study, an optimized layout featuring two turbofan engines with a Bypass Ratio (BPR) of 12 and a fan diameter of 3.75 m is used. Technical details of the aircraft can be found in [156–158]. In CARMEN, all major noise sources are calculated using semi-



Figure 4.4: Roma Tre University BWB concept BOLT developed in H2020 ARTEM project

empirical or analytical noise models at discretized time steps along the aircraft's trajectory, providing directivity and noise spectra in the far field. For this study, the primary noise

sources considered for the BWB configuration include jet and fan noise, as well as landing gear and flap noise.

A key feature of the flying wing design, in terms of outdoor acoustics, is the use of the fuselage as a masking obstacle for noise sources radiating toward the ground. By positioning the engines on top of the fuselage, a significant noise reduction can be expected below the aircraft. Therefore, accurately accounting for installation effects is a crucial step in the noise assessment methodology. As described in [156], for the low-frequency range, an ONERA in-house boundary element method tool BEMUSE is used to calculate the masking, reflection, and diffraction caused by the fuselage. For frequencies above 1 kHz, a simplified integral method based on the Kirchhoff approximation [159] and the Maggi-Rubinowicz formulation of Kirchhoff diffraction theory [160] is employed.

Finally, the sound is propagated via ray tracing toward receivers on the ground, taking into account the Doppler effect, atmospheric absorption, and geometrical spreading. While meteorological phenomena can be included in more detailed analyses, this study assumes a standard atmosphere for generating NPD data. Specifically, the standard atmospheric conditions are defined by SAE-AIR-1845 as: sea level pressure of 101.325 kPa, ambient temperature of 77°F, relative humidity of 70 %, and zero wind.

All input data required for the calculation of noise contours were derived from the ARTEM study [156]. Within the scope of this project, several aircraft configurations were tested for both departure and landing scenarios. The flight simulation environment, based on the FRIDA software developed by Roma Tre University [161], was used to estimate realistic trajectory profiles and associated engine parameters. These profiles served as inputs to RWTH's GasTurb software [162, 163], which generated the necessary data for the noise source models. The study focused on two turbofan engines with bypass ratios of 8 and 12, which were compared as part of the ARTEM framework. Additionally, a set of noise reduction technologies evaluated by ARTEM partners were applied as delta noise levels to the major noise sources on the aircraft. These technologies included fan inlet and outlet linings, as well as jet porous materials for the engines. For airframe noise, a combination of main landing gear noise reduction and new trailing-edge technology was implemented. Further details on these noise reduction technologies and the engine parameters can be found in [156, 158].

Figure 4.5 illustrates an example of the noise emission sphere for one thrust-altitude configuration, showing the impact of installation effects caused by the aircraft fuselage. The

figure highlights the significant masking effects, particularly for fan inlet noise, which results in a reduction of noise radiated toward the front of the aircraft.

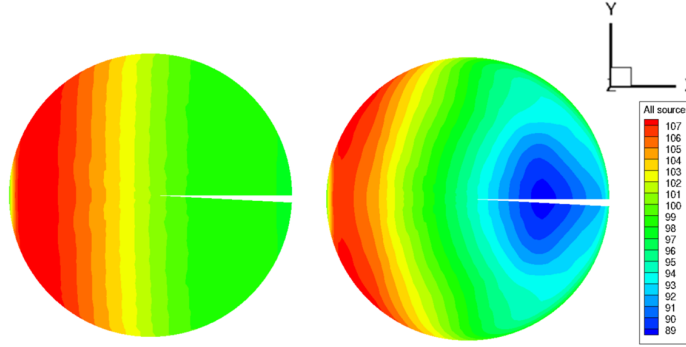


Figure 4.5: need to fix subfigures View below of noise emission sphere without (left) and with (right) shielding effects, flight direction in the positive x-direction, configuration 860 000 lb, 122 m

The efficiency of the masking effect due to the engines' location on top of the fuselage, combined with new generation turbofan engines and the set of noise reduction technologies was evaluated and led to possible noise reductions at certification points. The quietest option (with the turbofan engine of bypass ratio 12 and the complete set of noise reduction technologies) is estimated to reduce L_{Amax} values at the flyover certification point by more than 10 dBA, using the calculation with CARMEN. This version was chosen to be the one implemented into SoundPLAN.

The Noise-Power-Distance (NPD) data is generated through a simulation involving the BWB aircraft, flown at predefined heights (see Section 4.1.2) under various power settings (Figure 4.6) by ONERA. During the simulation, a simulated microphone at a height of 1.2 m records noise levels at 0.5-second intervals over a 60-second duration. Here only direct propagation and no ground reflection were considered.

Following this, SEL, L_{Amax} , PNLTM, and EPNL, as per calculation procedure outlined in the documentation ICAO [14], are computed. Subsequently, tables are generated for each power setting at different heights, presenting the computed values for the four distinct noise metrics.

The calculation procedure for the Sound Exposure Level (SEL) L_{AE} (Equation 4.4) involves augmenting the Sound Pressure Level (SPL) $L(t)$ with an A-weighting factor on a per-frequency and per-timestep basis. Subsequently, the overall SPL is computed for each timestep, and the cumulative result is obtained across all timesteps. In the context of aircraft

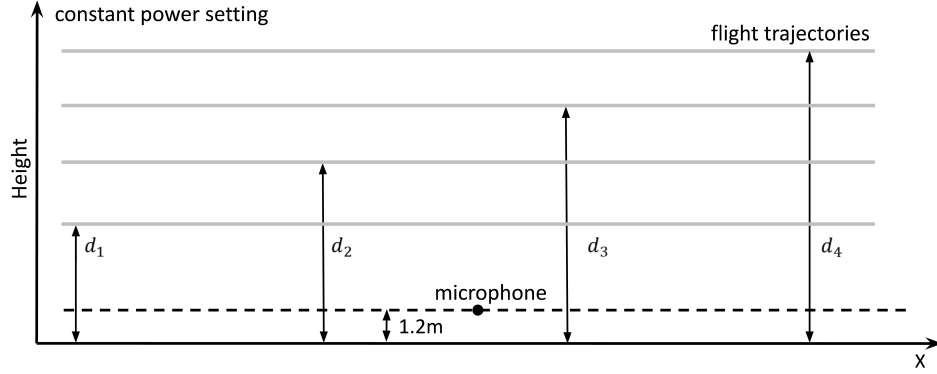


Figure 4.6: Noise-Power-Distance (NPD) Data generation for simulated aircraft; flight repeated for different heights (flight trajectories) and different power settings

noise L_{Amax} represents the maximum of the A-frequency-weighted sound level during the run [14].

$$L_E = 10 \log \left[\frac{1}{t_o} \int_{t_1}^{t_2} 10^{\frac{L(t)}{10}} \right] \quad (4.3)$$

$$L_{AE} = 10 \log \left[\frac{1}{t_o} \int_{t_1}^{t_2} 10^{\frac{L_A(t)}{10}} \right] \quad (4.4)$$

The instantaneous Perceived Noise Level (PNL) denoted as $PNL(k)$ is computed by converting the SPL in each one-third octave band i spanning 50 Hz to 10 000 Hz to perceived noisiness $n(i, k)$ using the noy table given in ICAO [14]. Afterward, the noisiness values are combined by equation 4.5, and the PNL values are determined by using equation 4.6.

$$N(k) = 0.85 n(k) + 0.15 \sum_{i=1}^{24} n(i, k) \quad (4.5)$$

$$PNL(k) = 40.0 + \frac{10}{\log 2} \log N(k) \quad (4.6)$$

A tone correction factor $C(k)$ is added to Perceived Noise Level (PNL) to capture the annoyance of tones. The maximum Tone Corrected Perceived Noise Level (PNLT), denoted as $PNLTM$ is then determined from the instantaneous values. In order to determine the Effective Perceived Noise Level (EPNL), a duration penalty in the form of a duration correction factor D , is calculated according to ICAO [14] and applied.

PNLTM is calculated according to Algorithm 1 with the help of noy and correction factor tables. The unit for the tone-corrected noise metrics is TPNdB instead of dB [14].

Algorithm 1 PNLTM Generation according to ICAO [14]

```

1: procedure CALCULATE PNLTM
2:   for  $k$  = each timestep do
3:     for  $i$  = each frequency do    ▷ for one-third octave band frequencies from 50 -
      10 000 Hz
4:       get  $n(k, i)$  for  $SPL(k, i)$           ▷  $n(k, i)$  = corresponding noy value
5:     end for
6:      $N(k) = 0.85n(k) + 0.15 \sum_{i=1}^{24} n(i, k)$           ▷ total noisiness
7:      $PNL(k) = 40.0 + \frac{10}{\log 2} \log N(k)$ 
8:     get  $C(k)$  from table          ▷ correction factor
9:      $PNLT(k) = PNL(k) + C(k)$ 
10:  end for
11:   $PNLTM = \max(PNLT(k))$ 
12: end procedure

```

$$EPNL = PNLTM + D \quad (4.7)$$

EPNL is calculated according to Equation 4.7. A duration correction D is added, which is dependent on PNLTM and is calculated according to Algorithm 2 [14].

Algorithm 2 Duration Correction Calculation according to ICAO [14]

```

1: procedure CALCULATE D
2:   if  $PNLTM > 100$  TPNdB then
3:      $t(1) = \text{first point after } PNL > PNLTM - 10$ 
4:      $t(2) = \text{first point after } PNL \text{ constantly } < PNLTM - 10$ 
5:   else if  $PNLTM < 100$  TPNdB and  $PNLTM \geq 90$  TPNdB then
6:      $t(1) = \text{first point after } PNL > 90$  TPNdB
7:      $t(2) = \text{first point after } PNL \text{ constantly } < 90$  TPNdB
8:   else if  $PNLTM < 100$  TPNdB and  $PNLTM < 90$  TPNdB then
9:      $D = 0$ 
10:  end if
11:   $D = 10 \log \left[ \left( \frac{1}{T} \right) \int_{t(1)}^{t(2)} \text{antilog} \frac{PNLT}{10} dt \right] - PNLTM$     ▷  $T$  = normalizing time constant
12: end procedure

```

To compile a complete NPD table, the procedure must be repeated for each combination of power setting and slant distance, represented by the flyover height. To finalize the NPD data for the ANP database, it is essential to include additional aircraft information such

as the lateral directivity identifier, the number of engines, MTOW, maximum static thrust, maximum landing distance, and spectral classes. Moreover, takeoff and approach procedure profiles must be provided, along with jet thrust and flap coefficients. If these coefficients are not available, fixed-point profiles should be supplied instead. This is part of the input data and will be used in the noise model to calculate the overall aircraft noise [29, 30].

Proxy Aircraft

Many aircraft configurations of one aircraft type have no significant difference in the overall noise footprint, therefore it is advantageous to group individual or similar aircraft types together [29]. Airports might be dominated by the same aircraft type and the different configurations will often not show any practical significance. The modeling effort can be reduced by using aircraft categories, MTOW, engine type, number of engines, engine installation, sound levels, operation type, and performance, and the ICAO noise certificate. Aircraft can be considered equivalent when the noise footprint is comparable. In addition, non-significant aircraft types, which do not dominate the airport's overall noise footprint, can be grouped.

4.1.3 Pre-Processing

The pre-processing phase plays a critical role in ensuring the accuracy of aircraft noise modeling. It involves preparing and organizing the input data, which directly influences the quality of the noise predictions. This includes categorizing aircraft movements, determining atmospheric conditions, and essential data such as aircraft weight, operational procedures, and flight paths. Additionally, the integration of databases like the ANP ensures that the model can accurately simulate noise emissions at various stages of flight.

The accuracy of noise modeling is directly tied to the quality and detail of the input data [29]. Detailed input data is essential for achieving high-quality results, though less detailed data can still produce acceptable outcomes for broader assessments. In some cases, lower-quality data and scenario simplifications can reduce the time and effort needed to generate aircraft noise contours. Flight path data is especially critical and requires careful attention to ensure precise noise prediction. Terrain data for example can be obtained in high resolution, which can increase model quality but also the computation time. To minimize computational time aircraft grouping, e.g. by not distinguishing between different configurations, and flight path clustering can be applied. ECAC [29] defines aircraft operation and ground tracks as

part of the pre-processing procedure. The initial step is to categorize the movement of each aircraft as either a departure or an arrival. For each movement, the atmospheric conditions, aircraft weight, and operational procedures must be determined. The ANP database provides the necessary information regarding the noise and performance characteristics of the aircraft. Additionally, ground track data for each aircraft is required to accurately model the flight path. A vertical flight profile, in combination with the aircraft's speed and engine power, is then used to compute the slant distance to each receiver point. This vertical profile can be either derived from predefined points in a default flight profile (such as a fixed-point or step profile) or obtained from radar data, depending on the available information.

Finally, all relevant noise data, including those from ground roll and reverse thrust, are aggregated into a comprehensive noise emission profile. The aircraft's noise emissions are highly dependent on factors such as engine power, ground distance, and aircraft weight. Taxi noise is excluded from aircraft noise modeling and defined as ground noise [29].

4.1.4 Noise Model

The aircraft noise modeling procedure follows the guidelines set out in ECAC Doc 29, Volume 1 [29]. The objective is to simulate aircraft noise emissions during both departure and arrival phases by incorporating key operational parameters, atmospheric conditions, and aircraft characteristics. The model accounts for essential factors such as engine power, aircraft weight, and flight path to estimate noise levels at various stages of flight. To calculate the overall noise emissions and subsequent noise footprint, flight path segmentation and the interpolation of NPD data are applied, and these processes are also discussed in this section.

Using NPD data and a simple directivity model allows for the modeling of variable flight paths, including turns, by dividing the path into segments. The addition of spectral data enables adjustment of NPD data in case of non-reference atmospheric conditions [30]. Implementing the Advanced directivity model enhances segmentation accuracy. This best-practice model incorporates advanced segmentation algorithms and straightforward simulation procedures [29].

To further improve the models, a 3D directivity noise source model as a function of frequency, which accounts for various engine power and configuration combinations, could be implemented [29].

Flight Path Segmentation

For noise calculations, each aircraft's flight path is divided into segments [30]. Each segment specifies the start and end values for ground track distance, aircraft height, ground speed, bank angle, and the power parameter (or power setting as given in the NPD tables). For procedural profiles, the path is segmented into steps: take-off, climb, and accelerate for departure; and descend-idle, level-idle, descend, land, and decelerate for arrival. Interpolation of the NPD data is required to accurately fit each aircraft's flight path.

NPD Data Interpolation

For an exact flight event, NPD values must be interpolated if the power and slant distance values do not match those in the NPD data [30, 164]. Linear interpolation is used for thrust levels, while logarithmic interpolation is applied for slant distances. Figure 4.7 illustrates the interpolation process for a NPD curve.

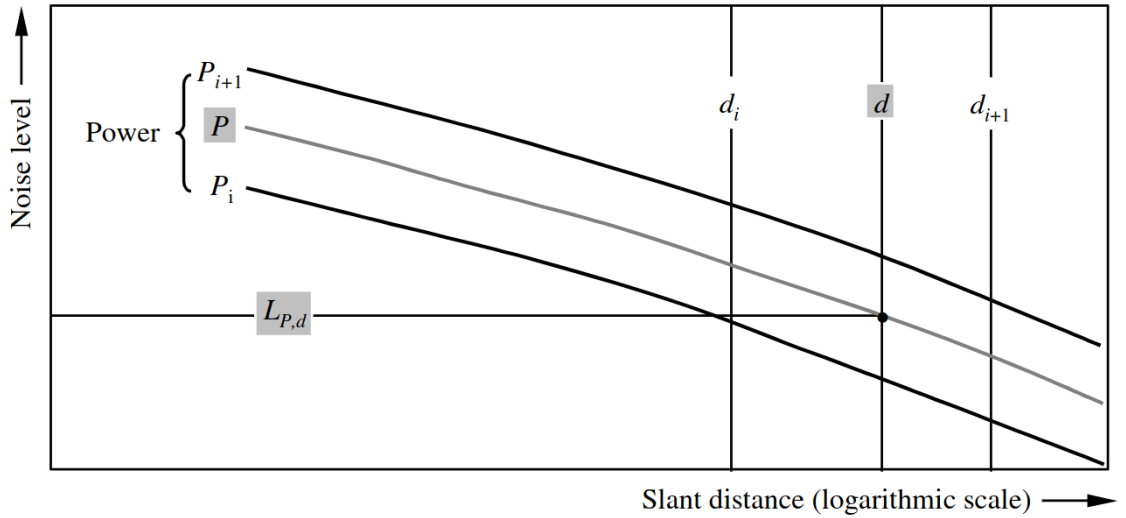


Figure 4.7: Noise-Power-Distance curve interpolation from ECAC [30]

Noise Level Calculation at the Observer

Noise levels $L_{\max}$ and L_E at the observer are calculated according to Equation 4.8 and 4.9. While atmospheric absorption and distance correction are already embedded in the NPD data for Doc. 29 [147], both noise levels depend on propagation distance and engine power. For $L_{\max}$, an engine installation correction is applied to account for reflection and refraction effects caused by the airframe, which results in variations in lateral directivity

[30]. Lateral attenuation, a ground effect correction, addresses the interaction between direct and reflected sound waves at low angles to the ground. The duration correction for L_E is a velocity adjustment for scenarios where aircraft speed deviates from the reference speed [30]. Additionally, the finite segment correction includes propagation effects and incorporates the dipole model for noise source directivity.

P	Engine Power Parameter
V	Velocity
y	Lateral Distance perpendicular to Aircraft's Ground Flight Track
z	Height
β	Elevation Angle
ϕ	Lateral Radiation Angle
γ	Geometric Aircraft Flight Path Angle
ℓ	Perpendicular Distance from an Observation Point to the Ground Track
φ	Depression Angle
d	Propagation (Slant) Distance
Λ	Lateral Attenuation
Δ_I	Engine Installation Correction
Δ_V	Duration (Speed) Correction
Δ_F	Finite Segment Correction

$$L_{\max} = L_{\max}(P, d) + \Delta_I(\phi) - \Lambda(\beta, \ell) \quad (4.8)$$

$$L_E = L_{E,\infty}(P, d) + \Delta_I(\phi) + \Delta_V(V) - \Lambda(\beta, \ell) + \Delta_F \quad (4.9)$$

The engine installation correction is applied to enhance the accuracy of sound propagation directivity, particularly in the lateral directivity around the roll axis [165]. Figure 4.8 illustrates the differences in lateral directivity for wing-mounted engines, rear-fuselage-mounted engines, and propeller aircraft before correction. This two-dimensional model assumes that directivity does not vary with the longitudinal distance of the observer from the aircraft. However, this simplification of a three-dimensional model is justified by the fact that the overall noise level is predominantly influenced by sideward noise radiation [29, 30].

The engine installation correction is calculated using Equation 4.10, where the variables a , b , and c depend on the specific engine installation [30]. This installation is primarily

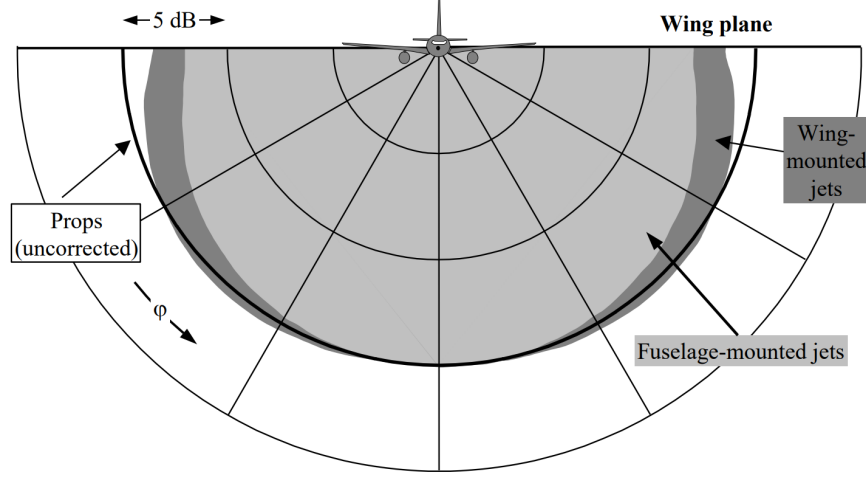


Figure 4.8: Engine installation: lateral directivity from ECAC [30]

influenced by the depression angle, defined as the angle between the wing plane and the propagation path. As shown in Figure 4.8, the correction $\Delta_I(\varphi) = 0$ for propeller aircraft.

$$\Delta_I(\varphi) = 10 \cdot \log \left[\frac{(a \cdot \cos^2 \varphi + \sin^2 \varphi)^b}{c \cdot \sin^2 2\varphi + \cos^2 2\varphi} \right] \quad (4.10)$$

Lateral attenuation refers to the phenomenon where the noise level at a lateral position is generally lower than at the same distance directly below the aircraft [29, 30]. The sound level decreases more rapidly with distance than predicted by the NPD curves, due to excess lateral attenuation. This attenuation is primarily a reflection effect, resulting from the interference between directly radiated sound and sound reflected off surfaces. The extent of lateral attenuation depends on the surface nature and can lead to substantial reductions in observed sound levels, particularly at low elevation angles. Additionally, sound refraction, steady and unsteady, caused by wind, temperature gradients, and turbulence, which are influenced by the surface presence, significantly impact lateral attenuation.

For non-turning flights, lateral attenuation is calculated by subtracting the engine installation correction for the elevation angle β from the total lateral directivity Λ_T (Equation 4.11), relative to the propagation distance d [30]. However, an empirical approximation, incorporating a distance factor $\Gamma(d)$ and long-range air-to-ground lateral attenuation $\Lambda(\beta)$, as shown in Equation 4.12, is recommended.

$$\Lambda(\beta, l) = \Lambda_T(\beta, l) - \Delta_I(\beta) \quad (4.11)$$

$$\Lambda(\beta, l) = \Gamma(l) \cdot \Lambda(\beta) \quad (4.12)$$

Longitudinal directivity primarily affects the timing of noise events rather than the overall noise footprint along most of the flight path [29]. It represents the direction of noise emissions relative to the aircraft's longitudinal axis, which is typically directed toward the rear. While longitudinal directivity does not significantly alter the overall noise footprint, it can influence the shape and size of individual aircraft noise contours, making it particularly relevant for detailed noise contour analysis.

To account for the longitudinal directivity an energy fraction term is included in the finite segment correction. Equation 4.13 [30], describes the finite segment correction. α is dependent on the flight path segment length λ and the scaled distance d_λ . For segments behind every take-off ground-roll, $\alpha_1 = 0$, while $\alpha_2 = 0$ for every landing ground-roll segment.

$$\Delta_F = 10 \cdot \log_{10} \left[\frac{1}{\pi} \left(\frac{\alpha_2}{1 + \alpha_2^2} + \arctan \alpha_2 - \frac{\alpha_1}{1 + \alpha_1^2} - \arctan \alpha_1 \right) \right] \quad (4.13)$$

Cumulative Noise Level Calculation

The cumulative noise level is calculated according to ECAC [30]. The time-weighted equivalent sound level is described by Equation 4.14. It represents the sum of all noise events, N , occurring within the time period T_0 , for each noise event i . A decibel weighting, Δ_i , is applied to each noise level $L_{E,i}$, which accounts for evening or nighttime penalties (see Section 2.5.2). The constant C can serve as a normalizing factor, a seasonal adjustment, or a different predefined constant.

$$L_{eq,W} = 10 \cdot \log \left[\frac{t_0}{T_0} \sum_{i=1}^N 10^{(L_{E,i} + \Delta_i)/10} \right] + C \quad (4.14)$$

The average maximum noise level is calculated using Equation 4.15. It is independent of time and considers the maximum noise level from each individual noise event.

$$\bar{L}_{\max} = 10 \cdot \log \left[\frac{1}{N} \sum_{i=1}^N 10^{L_{\max,i}/10} \right] \quad (4.15)$$

Using the weighted number of operations M_{ij} , the cumulative noise level $L_{eq,W}$ is expressed by Equation 4.16. This equation incorporates the number of operations N_{ij} for each aircraft category i and each flight track j , across every flight track segment k , with a time-period weighting factor g applied to each noise event $L_{E,ijk}$. The calculation of $L_{E,ijk}$ can be described by Equation 4.3.

$$L_{eq,W}(x, y) = 10 \cdot \log \left[\frac{t_0}{T_0} \cdot \sum_i \sum_j \sum_k M_{ij} \cdot 10^{L_{E,ijk}(x,y)/10} \right] + C \quad (4.16)$$

$$M_{ij} = (g_{\text{day}} \cdot N_{ij,\text{day}} + g_{\text{evening}} \cdot N_{ij,\text{evening}} + g_{\text{night}} \cdot N_{ij,\text{night}}) \quad (4.17)$$

Multiple noise events can be generated by a single aircraft at a given grid point or observer location. Consequently, the cumulative maximum noise level is determined in one of three ways: (1) based on the maximum sound level across all noise events at that specific location, (2) considering only the noise events that exceed a given noise threshold at that location, or (3) by identifying the absolute maximum noise level, represented by a single noise event.

In the first scenario, the maximum noise level at location (x, y) is calculated using Equations 4.18 and 4.19.

$$\bar{L}_{\max}(x, y) = 10 \cdot \log \left[\sum_i \sum_j \sum_k 10^{L_{\max,ijk}/10} \cdot u(k) \right] - 10 \cdot \log \left[\sum_i \sum_j \sum_k M_{ij} \cdot u(k) \right] \quad (4.18)$$

$$L_{\max,ijk} = \begin{cases} \text{if is maximum,} & u(k) = 1 \\ \text{if is not maximum,} & u(k) = 0 \end{cases} \quad (4.19)$$

If a threshold L_T is defined, the average maximum noise level is determined by whether the maximum noise level at the observer location exceeds this threshold, as shown in Equation 4.20.

$$L_{\max,ijk} = \begin{cases} L_{\max,ijk} \geq L_T & u(k) = 1 \\ L_{\max,ijk} < L_T & u(k) = 0 \end{cases} \quad (4.20)$$

The highest maximum noise level at the location can be calculated according to Equation 4.21.

$$L_{\max(x,y)} = \max(L_{\max,ijk}) \quad (4.21)$$

4.1.5 Post-Processing

The number of grid points influences the accuracy of the noise contours when they are calculated by interpolation between the grid points. The grid resolution can be increased to reduce interpolation errors. However, this can also increase computation time. Local mesh tightening can be used to calculate more accurate results and use computation time efficiently. This way, the whole grid does not need to be refined, but only the critical cells are refined. In this work, a grid spacing of 50 m was employed.

Aircraft noise contours tend to be symmetrical along the ground track. However, when the ground track is not aligned with the calculation grid, asymmetric results may occur. An improved grid resolution can solve this problem but will result in higher computational time. Rotating the calculation grid parallel to the main ground tracks could resolve this issue.

Post-processing involves generating and smoothing noise contours, as well as performing grid operations [30]. It often integrates noise data with Geographic Information System (GIS) to visualize noise impacts on specific areas or communities (see Section 4.2), which is crucial for urban planning and enforcing noise regulations. The processed data is used to create noise contour maps, highlighting high-noise areas and aiding in the identification of problem zones and the evaluation of mitigation measures. In some cases, monthly data is modeled separately for detailed analysis. During post-processing, annual noise contours are calculated by applying grid operations to the individual monthly results. These operations may involve converting, merging, subtracting, or adding different noise maps.

Post-processing includes generating strategic noise maps to estimate population and area exposure [166]. This process encompasses detecting and analyzing high-noise areas and identifying and developing noise mitigation and management measures. These measures aim to protect quiet zones and reduce the number of people affected by noise.

4.2 Quantifying Airport Noise

Quantifying environmental noise is complex. Typically, population exposure is used, but this method complicates comparisons between cities or countries. Therefore, area exposure should also be considered. Noise contours provide the average noise exposure level but do not account for the harmful effects of individual noise events [91, 92].

Additionally, annual noise maps, which depict specific noise levels along with corresponding population exposure figures, do not capture hourly, daily, or monthly fluctuations in noise exposure. To address this, Section 4.2.3 outlines a strategy for displaying and analyzing monthly fluctuations in noise exposure.

4.2.1 Area Exposure

Area exposure is effective for comparing noise levels across different airports, as it is independent of population exposure, which varies significantly between locations. This makes area exposure a valuable metric for assessing different aircraft routes and overall airport operations. Additionally, it is useful for predicting aircraft noise when precise population exposure models are not available, as it does not depend on highly accurate population data.

Sometimes it is complicated to estimate the number of people exposed to excessive amounts of noise, since they could be exposed to a combination of noise sources. To avoid this issue, noise maps for different environmental noise sources should be combined, rather than summing the exposed population, as doing so could result in double counting [166].

Area exposure will be calculated in QGIS for contour lines of $L_{den} = 55 \text{ dB(A)}$ or $L_{den} = 45 \text{ dB(A)}$, and $L_{night} = 50 \text{ dB(A)}$ or $L_{night} = 40 \text{ dB(A)}$, in accordance with CNOSSOS-EU [42] and WHO recommendations [13]. The noise map is filtered to specific noise levels to display contour lines, and the area within each contour line is then calculated.

4.2.2 Population Exposure

The accuracy of population exposure to environmental noise highly depends on the accuracy of the dataset, which includes dwelling locations and population numbers.

For this study, the case of Dublin Airport, a 1 km grid with population data from 2022 [140] is combined with residential properties from 2023 [141] to analyze population exposure around Dublin Airport. The population in each km^2 is equally distributed and projected onto the buildings from Geo Directory [141] in QGIS. The two datasets are merged using the *add vector join* function. Subsequently, the noise contour lines are projected onto the population data. The *query builder* within the *filter* function is utilized to display a single contour line corresponding to the specified decibel level. The generated noise contour lines are then overlaid onto the population data. The population dataset is clipped using the contour lines as an overlay layer in the *vector overlay clip* function, allowing for the calculation of the number of houses and the population within each noise contour. The resulting file, which contains the houses and the number of people per house located within the noise contour, can be exported as a *.csv* file. This data can then be aggregated to determine the total number of people exposed to noise at or above the predefined decibel level. This procedure can also be executed as part of a batch run.

The burden of disease due to environmental noise can be calculated using Equation 4.22, and is measured in DALYs (Disability-Adjusted-Life-Years) [167]. The total burden is composed of two components: Years Lived with Disability (YLD) and Years of Life Lost (YLL). The YLD represents the years lived with disability, and is calculated using the number of incident cases I , the corresponding disability weight DW , and the average duration of the condition D . The YLL, or years of life lost, accounts for premature mortality and is calculated using the number of deaths N , differentiated by sex (male m or female f), and the standard life expectancy at the age of death L .

$$DALY = YLL + YLD \quad (4.22)$$

$$YLL = \sum (N_i^m \cdot L_i^m + N_i^f \cdot L_i^f) \quad (4.23)$$

$$YLD = I \cdot DW \cdot D \quad (4.24)$$

For the calculation of noise-induced annoyance and sleep disturbance, DALYs are estimated using the Absolute Risk (AR), based on the Relative Risk (RR) as shown in Equation 4.25 [167].

$$DALY = \sum (I \cdot DW \cdot D) AR \quad (4.25)$$

The absolute risk is calculated according to World Health Organization [1], and is shown below for Highly Annoyed (HA) and Highly Sleep Disturbed (HSD).

$$RR_{HA} = -50.9693 + 1.0168 \cdot L_{den} + 0.0072 \cdot L_{den}^2 \quad (4.26)$$

$$RR_{HSD} = 16.79 - 0.9293 \cdot L_{night} + 0.0198 \cdot L_{night}^2 \quad (4.27)$$

4.2.3 Change of Monthly Noise Exposure

In addition to analyzing area and population exposure, changes in noise exposure can be effectively illustrated by mapping the monthly noise exposure. This metric is based on area exposure and requires the use of a grid. In this thesis, 1 km grid tiles are utilized. For a specific contour line (e.g., $L_{den} = 45$ dB(A)), the area exposure per tile is calculated. The subsequent change in area exposure per tile is then determined using equation 4.28. As illustrated in figure 4.9, the scale of change in area exposure (expressed as a percentage) is color-coded from white to red, with darker shades of red indicating a greater increase in area exposure for that tile.

$$\Delta A_{ex, \max} = \max(A_{ex}) - \min(A_{ex}) \quad (4.28)$$

This analysis is insightful as it reveals the monthly fluctuations in airport noise, highlighting that certain areas may experience significantly higher noise exposure during specific months while remaining relatively quiet during others. Annual noise maps, which only depict the average noise levels over a year, fail to capture these seasonal variations.

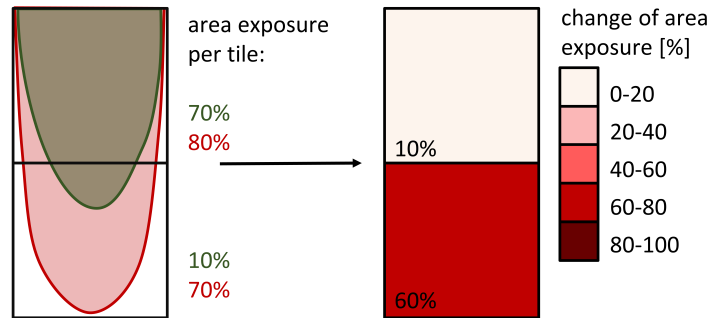


Figure 4.9: Area exposure per tile

4.3 Summary

In summary, terrain data, aircraft track data, and airport coordinates are used as input data. During pre-processing, a vertical flight profile is calculated for each aircraft based on its track data and information from the ANP database. The ANP database contains performance and acoustic data in the form of NPD tables, as well as procedural or fixed-point departure and arrival profiles. The NPD data provides noise emission levels for different power settings and pre-defined altitudes. Most current noise-certified aircraft are represented in the ANP database, but for new aircraft configurations or future models, ANP substitution tables are used. These tables use a proxy aircraft, applying decibel corrections for departure and arrival profiles.

For future aircraft concepts that cannot be represented by existing aircraft in the ANP database using departure and arrival corrections, new NPD data must be generated. This requires an aircraft noise calculation tool such as CARMEN.

Within the SoundPLAN noise model, noise metrics are calculated for each grid point. Noise data from the NPD tables is interpolated, with corrections applied for engine installation, duration, finite segment adjustments, and lateral attenuation.

During post-processing, noise maps and contour lines are generated. Airport noise levels can be quantified by assessing area or population exposure for specific decibel thresholds. When monthly noise maps are available, it is useful to display changes in monthly noise exposure to illustrate fluctuations in noise levels over time.

Chapter 5

Noise Mapping Dublin Airport 2023

5.1 Introduction

Dublin Airport, Ireland's primary gateway for national and international travel, is critical to the country's connectivity [2]. Air traffic has surged, returning to pre-pandemic levels sooner than expected [168]. This recovery reflects the increasing demand for air travel and underscores the airport's essential role in supporting Ireland's economy and global transport links. In 2023, Dublin Airport handled 229 756 flights and 33 259 959 passengers [87], surpassing expectations, as these figures were not projected to be reached until 2025 [32]. Dublin Airport is required to undergo noise mapping every five years, in accordance with environmental regulations set by EPA under END [86]. However, the current practice only produces an annual noise map, which fails to capture monthly fluctuations. These variations are heavily influenced by weather conditions, as evident in the shifting runway operation directions at Dublin Airport [39].

In addition, Dublin Airport now operates with a parallel runway system, incorporating the newly commissioned North Runway, which became operational under specific conditions. These conditions impose restrictions on nighttime traffic [125]. Furthermore, wind conditions dictate the operational mode of the runways and determine the direction of departures, with a preferred runway designated for either departures or arrivals based on weather patterns [39].

In this section, Dublin Airport's air traffic is modeled on an annual and monthly basis, illustrating the fluctuations in noise contours throughout the year and emphasizing the need for more detailed noise maps. The analysis includes an assessment of population and area exposure to noise, as well as identifying the maximum changes in area exposure due to varying traffic patterns and runway operations.

5.2 Input Data

The calculation area for Dublin Airport spans 1570.74 km^2 with a grid spacing of 50 m, encompassing 540 472 buildings and a population of 1 252 284. The coordinates of Dublin Airport and its runways, provided in Table 5.1, are essential for spatial analysis and modeling accuracy. Environmental conditions are set to a headwind of 8 kn (4 m/s), a temperature of 15°C , and a humidity level of 70 %. The terrain data used in this study is sourced from open

data provided by Open Street Map [169], enabling a detailed and reliable assessment of the region's characteristics.

Name	Dublin Airport		Cross Runway	
Code	EIDW		16/34	
Coordinates	x	y	x	y
Project coordinates [m]	682397.107	5923479.348	682303.60	5923435.86
Distance of RRP to ARP [m]	-	-	-93.51	-43.49
Name	South Runway		North Runway	
Code	10R/28L		10L/28R	
Coordinates	x	y	x	y
Project coordinates [m]	681426.88	5922609.31	681888.76	5924299.80
Distance of RRP to ARP [m]	-970.23	-870.04	-508.35	820.45

Table 5.1: Airport and runway UTM coordinates for Dublin Airport (EPSG: 4326)

Flight tracks are implemented from local aircraft tracking [170]. To incorporate the effects of terrain [149], elevation data [169] was included in the analysis.

5.2.1 Operations

In 2023 over 210 000 flights were operated at Dublin Airport in westerly and easterly operation mode. Table 5.2 shows the monthly percentages of western operations at Dublin Airport in 2023, with 72 % of arrivals and 74 % of departures adhering to this operational mode. Regarding flight numbers, this study relies on open-source data from aircraft tracking [170], which under-reports the actual flight numbers by around 8 %. Table 5.3 presents the quarterly discrepancies between the official flight numbers reported by the Central Statistics Office (CSO) [87] and the tracked flight numbers [170]. The largest difference occurs in the third quarter, which includes August and September, key months in the summer travel season. These months show a notably low number of tracked flights (as seen in Table 5.2), highlighting a significant under-reporting during a peak travel period. Radar track data from Dublin Airport is not available for this analysis.

During months characterized by high westerly winds, such as January, February, July, November, and December, the proportion of westerly operations at Dublin Airport in 2023 surged significantly beyond the 70 % average mark. For instance, in January, westerly winds accounted for 61.3 % of the wind conditions, with no recorded north, north-east, or easterly winds during this period, leading to nearly 100 % westerly operations. In contrast, June 2023

Month	Flights	Westerly Arrival	Operations [%] Departure	South Runway Closure [night]	night flights [daily avg.]
Jan	16228	98.54	98.95	2	64
Feb	13085	79.43	79.97	2 ^a	54
Mar	17728	68.50	68.07	4	67
Apr	18871	51.17	49.88	-	77
May	21793	60.34	61.63	-	92
Jun	20163	39.74	41.83	-	92
Jul	21541	83.99	83.56	3	64
Aug	14428	71.21	78.71	-	67
Sep	12918	67.15	80.76	4	63
Oct	20888	67.04	68.40	-	89
Nov	15637	90.49	89.83	5	64
Dec	17234	81.34	88.64	1	66
Avg.	17543	71.58	74.19	1.75	72
Total	210514	-	-	21	

Table 5.2: Tracked flight numbers [170], share of westerly operations, South Runway closure days [105], and average monthly nighttime flights at Dublin Airport, 2023

^a plus additional 90 min South Runway Closure during daytime [105]

2023 Quarter	Flight Numbers		Difference
	CSO	Tracked	[%]
1	48 515	47 041	3.04
2	61 287	60 827	0.75
3	65 020	48 887	24.81
4	54 934	53 759	2.14
total	229 756	210 514	8.37

Table 5.3: Quarterly Flight numbers for 2023 at Dublin Airport (tracked [170] vs. CSO [87])

exhibited a lower percentage of westerly operations, approximately 40 %, characterized by a wind pattern comprising 43 % easterly winds and only 20 % direct westerly winds. These fluctuations in wind patterns significantly impact the monthly noise contour lines, as discussed in Section 5.3.2.

5.2.2 Runway Maintenance

Vital maintenance tasks, including the application of critical safety markings, surface up-keep, and grassland management, are imperative for the integrity of operations at Dublin Airport's South Runway. Consequently, during these activities, all air traffic is rerouted to the North Runway, with the South Runway temporarily closed to aircraft operations [105].

Typically, maintenance activities are scheduled during nighttime hours to minimize disruptions to air traffic flow. Notably, Dublin Airport demonstrates a preference for utilizing the South Runway during nighttime operations, as this mitigates the impact of departure and arrival noise on local communities [39]. The airport provides information regarding runway maintenance schedules via its official website. In 2023, a total of 21 nighttime closures of the South Runway were recorded, typically occurring between 23:30 and 04:30 hours (Table 5.2). The peak number of South Runway closures was observed in November 2023. Additionally, in February 2023, an extra 90-minute closure of the South Runway was scheduled between 14:00 and 16:00 hours.

While Dublin Airport restricts nighttime flights to 65 per night [171], the closure of the South Runway for maintenance work significantly impacts nighttime noise contour lines. The effects of the South Runway closure during March, July, September, and November 2023 are evident in the nighttime contour lines, as elaborated in Section 5.3.2.

5.2.3 Noise Monitoring Terminals

Dublin Airport offers real-time noise level data via WebTrak [99] at 19 fixed locations. This data plays a crucial role in Dublin Airport’s communication strategy by allowing the airport to actively monitor and respond to noise-related concerns from the surrounding communities. Additionally, the airport publishes quarterly noise monitoring reports and, since 2024, provides monthly statistics and maps of noise complaint areas [100]. These reports reveal that most complaints originate from the area north of Dublin Airport, extending to the east and northwest.

Dublin City Council also has 15 Noise Monitoring Terminal (NMT)s spread across the city; however, these terminals are not within or near the monthly noise contour lines of Dublin Airport. The noise readings from these terminals are stored and available online [143].

Weather conditions such as rainfall, wind, wind speed, and temperature significantly influence sound propagation, affecting the accuracy of outdoor noise monitoring. Rainfall, in particular, tends to increase SPL, especially at mid-frequency ranges, leading to higher background noise detected by NMTs [172]. This variation highlights the strong dependence of noise measurements on weather conditions. Additionally, when wind gusts or air turbulence become too intense, they can produce noise levels that overshadow the actual noise intended to be measured, further complicating accurate assessments.

5.2.4 Weather

The operational dynamics of Dublin Airport are highly influenced by wind direction, necessitating flexible runway management to ensure safe and efficient flight operations [121].

Changes in wind direction already influence operation at Dublin Airport. Depending on the wind direction, departure and arrival direction are adapted [41, 124]. Dublin Airport has two main runways: the North Runway *10L/28R* and the South Runway *10R/28L*. Dublin Airport is mainly operated in segregated mode, dedicating one runway exclusively to departures while the other facilitates arrivals. On occasion, it is operated in a semi-mixed mode, in which one runway prefers departures or arrivals, while the other runway allows both. At Dublin Airport the South Runway operates arrivals and departures. During periods of westerly winds, known as westerly operation, the North Runway prioritizes departures to the west. Conversely, during easterly wind conditions, designated as easterly operation, the North Runway facilitates arrivals from the west.

Table 5.4 presents an overview of the monthly and annual rainfall and wind patterns recorded at Dublin Airport in 2023 [173]. Throughout the year, an average of 2.9 mm of rainfall was registered daily, with July 2023 peaking at a daily average of 4.8 mm, while February stood as an exceptionally dry month, with 0.6 mm daily average. The correlation of precipitation and wind dynamics is portrayed in Figure 5.1, which illustrates the fluctuations in rain and wind speeds over the course of the year. Notably, the winter months (January, February, March, and December) exhibit a surge in wind speed, coinciding with a dip in precipitation levels. Table 5.4 displays the wind direction at Dublin Airport, which directly influences departure direction and thus the noise contour lines. As shown, the distribution of monthly wind directions underscores distinct seasonal patterns. In this study, westerly winds encompass those originating from the northwest, west, and northeast, while easterly winds encompass the opposing directions. Notably, the winter months are characterized by a dominance of westerly winds. Conversely, April sees a notable shift, with predominantly southeastern winds characterized by subdued speeds. In contrast, both May and June record low wind speeds, with May predominantly featuring westerly winds at approximately 45 %, while June experiences a notable increase in easterly winds, constituting around 63 % of the total wind distribution for the month. July stands out with predominating westerly winds, accounting for almost 68 % of the total wind flow, accompanied by gusts reaching speeds of up to 53 kn (27 m/s).

In contrast to previous years, Dublin Airport experienced an increase in rainfall in 2023, while the average overall wind speed decreased [173, 174]. Averaged weather data for the past 30 years indicate a monthly rainfall average ranging from 51 mm to 69 mm [175], whereas in 2023, the monthly average varied between 15.4 mm to 149.2 mm. However, the rainfall pattern for 2023 follows the average rainfall pattern for the last 30 years, showing lower rainfall in May and September, while January, July, August, and December exhibit high precipitation (Figure 5.1) [173, 175].

Over the last three decades, the prevailing wind direction at Dublin Airport has predominantly been from the west-south-west, occasionally shifting to the south [175], a pattern consistent with the overall wind direction observed in 2023.

Month	Average			Wind Direction [% per month]							
	day	month	day	NE	E	SE	S	SW	W	NW	N
	Rain		Wind								
	[mm]		Speed								
			[knots]								
January	1.3	41.2	10.0	0.0	0.0	3.2	16.1	9.7	61.3	9.7	0.0
February	0.6	15.4	9.3	0.0	10.7	7.1	14.3	10.7	39.3	10.7	7.1
March	3.8	119	9.8	12.9	6.5	9.7	29.0	6.5	19.4	6.5	9.7
April	2.6	77.6	8.7	10.0	10.0	36.7	3.3	0.0	23.3	13.3	3.3
May	1.2	35.9	7.4	16.1	19.4	12.9	3.2	0.0	32.3	12.9	3.2
June	3.7	49.4	8.4	10.0	43.3	10.0	6.7	3.3	20.0	6.7	0.0
July	4.8	149.2	8.9	3.2	3.2	9.7	12.9	9.7	51.6	6.5	3.2
August	3.9	119.4	9.1	0.0	12.9	12.9	6.5	6.5	45.2	9.7	6.5
September	4.5	134	8.0	3.2	25.8	9.7	6.5	12.9	25.8	6.5	9.7
October	4.1	125.7	7.8	6.5	22.6	16.1	6.5	16.1	29.0	3.2	0.0
November	2.2	65.1	9.3	6.7	10.0	6.7	3.3	3.3	53.3	16.7	0.0
December	2.2	68.5	12.1	3.2	0.0	6.5	6.5	19.4	48.4	12.9	3.2
Ann. Average	2.9	83.4	9.1	6.0	13.7	11.8	9.6	8.2	37.4	9.6	3.8

Table 5.4: Monthly and annual averages for rain, wind speed, and wind direction at Dublin Airport in 2023 [173]

5.2.5 Computation Time

All calculations are conducted on an *Alienware Aurora R12* computer, equipped with an *11th Gen Intel(R) Core(TM) i9-11900KF* processor. Table 5.5 shows the computational time for the noise calculation of each month. The times are not only dependent on the complexity of the model and the number of flights in each month but also on background tasks and other

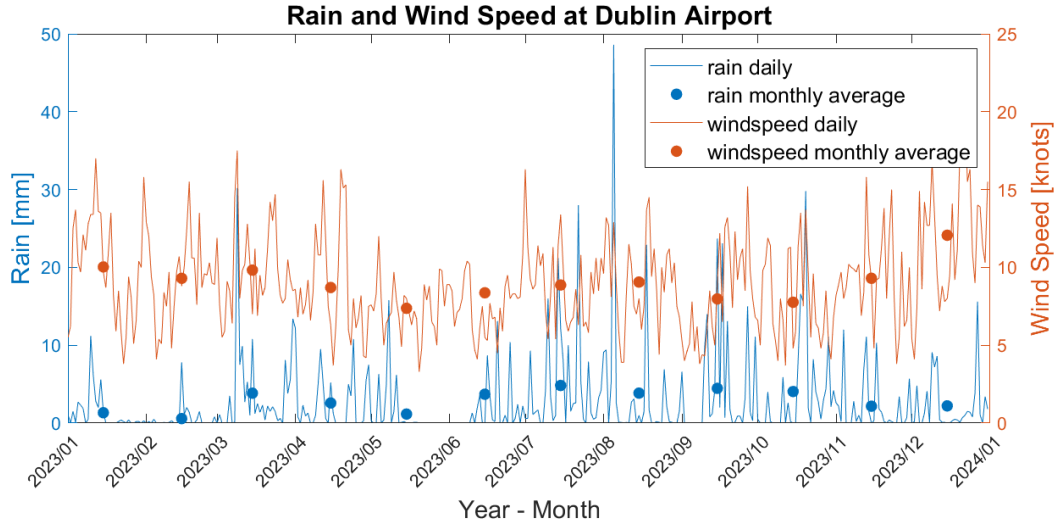


Figure 5.1: Rain and wind speed at Dublin Airport for 2023 with data from [173]

calculations being run in parallel on the computer. On average each calculation took under 17h totaling over 8.5d of computational time for the full year of 2023.

Month	Computational Time [hh:mm:ss]	Month	Computational Time [hh:mm:ss]
January	18:40:52	July	14:05:42
February	14:43:46	August	15:33:57
March	15:06:59	September	14:37:35
April	15:04:55	October	21:18:13
May	14:22:00	November	17:48:47
June	19:11:42	December	19:40:36
Average	16:41:15 [hh:mm:ss]		
Total	08:15:04 [dd:hh:mm]		

Table 5.5: Computational time for monthly aircraft noise calculations at Dublin Airport

5.3 Results

The monthly and annual noise contour lines for Dublin Airport in 2023 are presented in Figures 5.2 to 5.6, with corresponding calculations of area and population exposure. Additionally, the maximum change in monthly contour lines is analyzed to capture variations in noise impact. To determine this value for each 1 km^2 grid tile, the maximum area exposure over the 12 months of 2023 was calculated as a percentage and then subtracted by the min-

imum area exposure. For instance, in grid tile G6, the maximum area exposure occurred in May 2023 at approximately 59 %, while from June to December 2023, the area exposure was 0 %, representing the minimum exposure for this tile. Consequently, the maximum monthly area exposure change in this area is 59 %.

5.3.1 Annual Noise Maps

Figure 5.2 displays the annual noise contour lines for $L_{den} = 55$ dB(A), $L_{night} = 50$ dB(A), $L_{den} = 45$ dB(A), and $L_{night} = 40$ dB(A).

It displays, how the noise contours are just shy of highly populated areas, such as Malahide (U3:V4), Seabury (S:T3), and Swords(O1:Q4) northeast of Dublin Airport (see Figure 5.2). Overall, the L_{den} noise contour shows, that the North Runway was used slightly more, while during nighttime, the extension of the L_{night} noise contour to the west indicates, that the South Runway was mainly used. The variation in runway usage between day and night aligns with Dublin Airport’s planned operational mode, which restricts nighttime flights on the North Runway [39]. In addition to area and population exposure in Table 5.6.

Table 5.6 displays area and population exposure in 2023. Annually over 93 300 people are affected by aircraft noise from Dublin Airport. As the South Runway is mainly used for nighttime movements, the 2023 contour line shifts to the south and results in a higher population exposure during nighttime at a threshold of $L_{night} = 40$ dB(A). In the overall noise contour line L_{den} a right turn from the North Runway during westerly departures (G1:K4) is very visible. The noise during this right turn mainly affects a low-populated area, mitigating the effects of noise exposure in highly populated areas.

Using the disability weightings from World Health Organization [1] and the relative risk calculations from Chapter 4.2.2, the estimated burden of disease due to noise from Dublin Airport is substantial. For a noise level of $L_{den} = 45$ dB(A) and $L_{night} = 40$ dB(A), the calculated DALYs are as follows: $DALY_{sleep\ disturbance} = 211$, $DALY_{annoyance} = 507$, and $DALY_{ischemic\ heart\ disease} = 342$ per year. At $L_{night} = 40$ dB(A), approximately 10,547 individuals are classified as highly sleep disturbed, representing around 11% of the exposed population. Overall, this results in a total burden of over $DALY_{total} = 1,060$ per year from sleep disturbance, annoyance, and ischemic heart disease attributable to environmental noise from Dublin Airport alone.

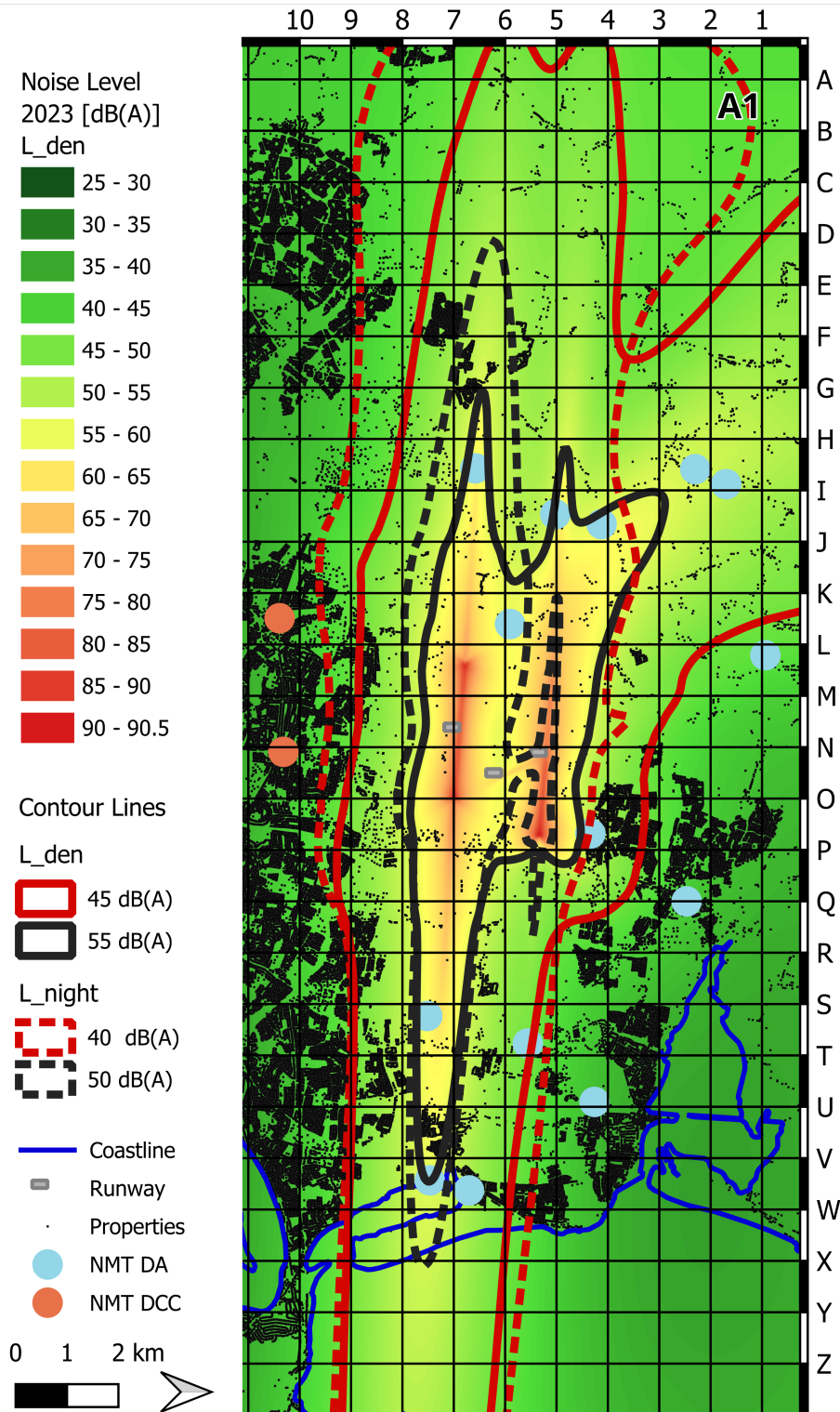


Figure 5.2: Annual noise contours for Dublin Airport 2023 with L_{den} noise footprint as background and Noise Monitoring Terminals for Dublin Airport (DA) and Dublin City Council (DCC)

Contour	Area [km ²]	Houses	People
$L_{den} = 55$ dB(A)	29.35	1296	2771
$L_{night} = 50$ dB(A)	29.65	2555	6012
$L_{den} = 45$ dB(A)	171.48	30334	77377
$L_{night} = 40$ dB(A)	165.66	38083	93352
Insulation schemes	19.64	433	837

Table 5.6: Annual area and population noise exposure for different noise contour lines and the extend of the HSIP and RNIS insulation schemes at Dublin Airport, 2023

5.3.2 Monthly Noise Maps

Figures 5.3 and 5.5 illustrate the monthly day, evening, and nighttime noise contour lines at $L_{den} = 55$ dB(A) and $L_{night} = 50$ dB(A) for air traffic at Dublin Airport. Additionally, the extent of monthly noise changes is displayed in Figure 5.4 and 5.6. In addition, the limit lines of the two main noise insulation schemes Home Sound Insulation Programme (HSIP) and Residential Noise Insulation Scheme (RNIS) are shown along with the NMTs of Dublin Airport and Dublin City. Table 5.7 shows the monthly area and population exposure for 2023 at Dublin Airport for $L_{den} \geq 55$ dB(A) and $L_{night} \geq 50$ dB(A).

Month	Area [km ²]		Houses		People	
	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}
Jan	27.5207	26.2754	1253	2337	2307	5335
Feb	26.4899	23.9757	1320	2198	2460	4888
Mar	29.6165	28.1118	1271	2500	2870	6118
Apr	31.3230	27.9900	1644	2833	4701	7754
May	37.0741	35.5935	2402	3856	6366	9760
Jun	32.3237	33.6768	1943	3621	5403	9931
Jul	24.8231	22.9262	655	1940	1335	4129
Aug	26.7526	27.1714	577	2370	1257	5525
Sep	23.1068	24.9885	468	1953	884	4360
Oct	31.9839	33.2093	1419	2916	3285	7103
Nov	28.5854	29.7024	972	2461	2097	5882
Dec	30.6262	30.1337	1366	2836	2826	6830
Avg.	29.1855	28.6462	1274	2652	2983	6468
Annual	29.35	29.65	1296	2555	2771	6012

Table 5.7: Monthly area and population noise exposure for $L_{den} \geq 55$ dB(A) and $L_{night} \geq 50$ dB(A) at Dublin Airport, 2023

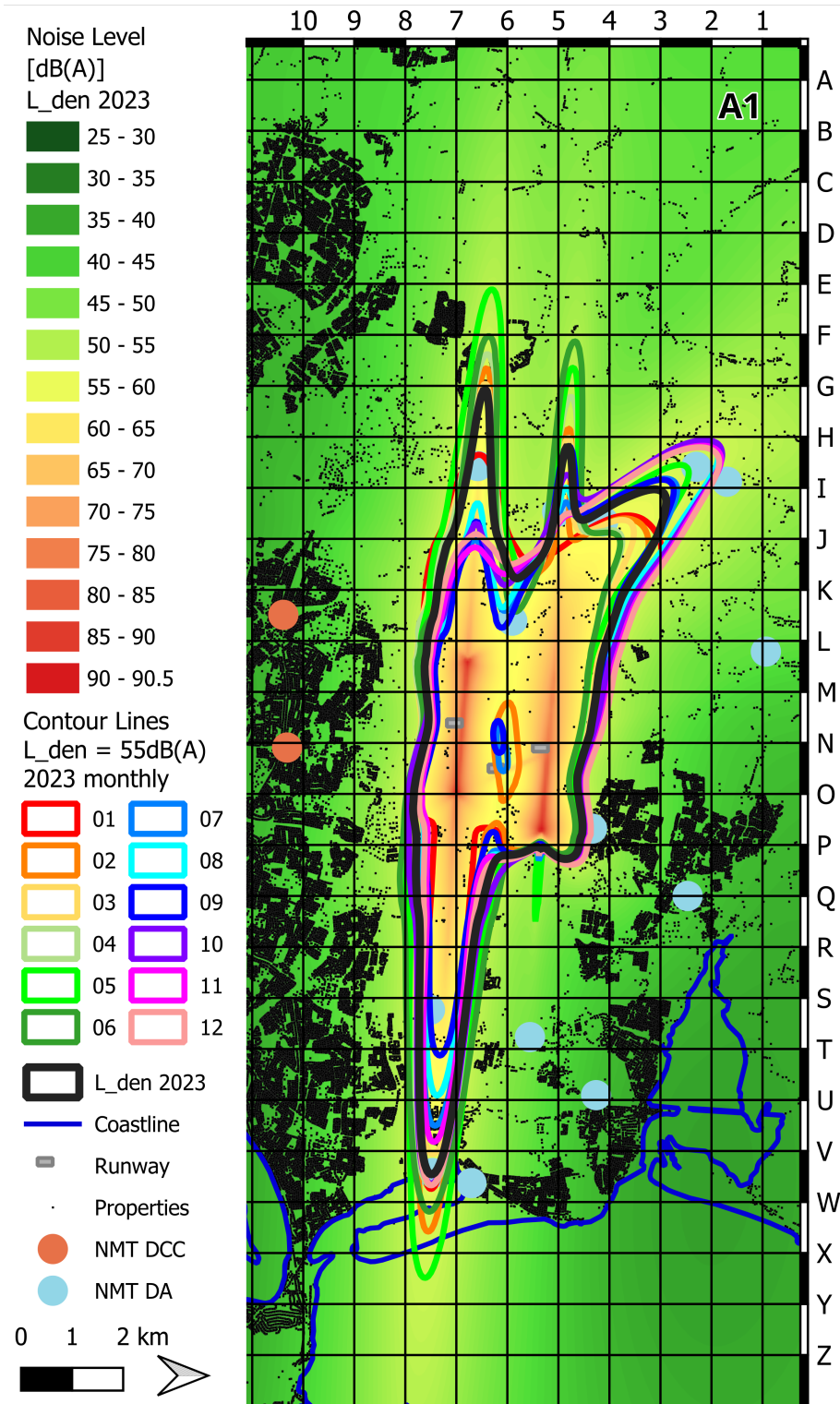


Figure 5.3: Monthly noise contours for $L_{den} = 55\text{ dB(A)}$ for 2023 at Dublin Airport with L_{den} noise footprint as background and Noise Monitoring Terminals for Dublin Airport (DA) and Dublin City Council (DCC)

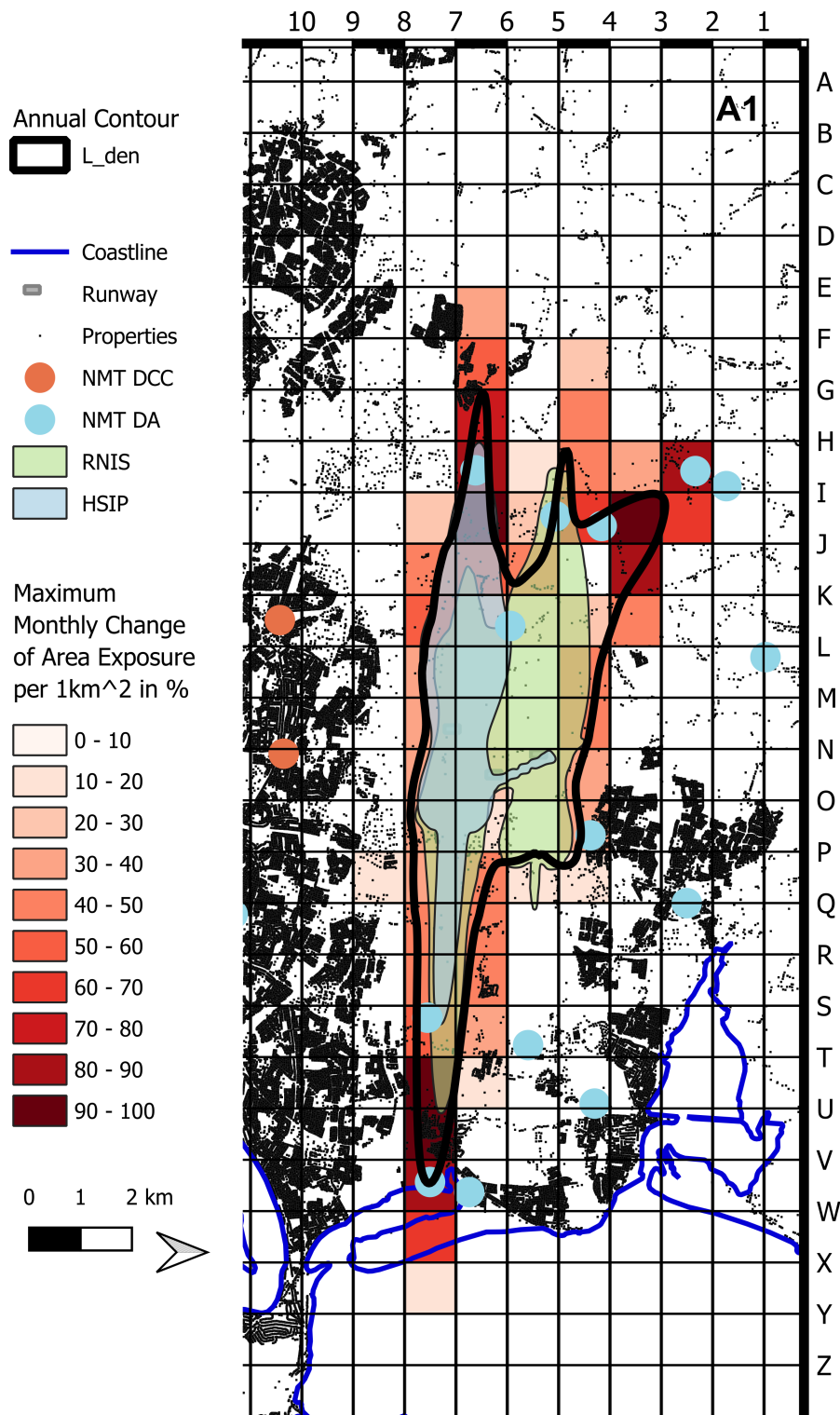


Figure 5.4: Severeness of monthly changes of noise contours in % in comparison to the annual noise contour for $L_{den} = 55\text{ dB(A)}$ for 2023 at Dublin Airport and Noise Monitoring Terminals for Dublin Airport (DA) and Dublin City Council (DCC) and insulation schemes

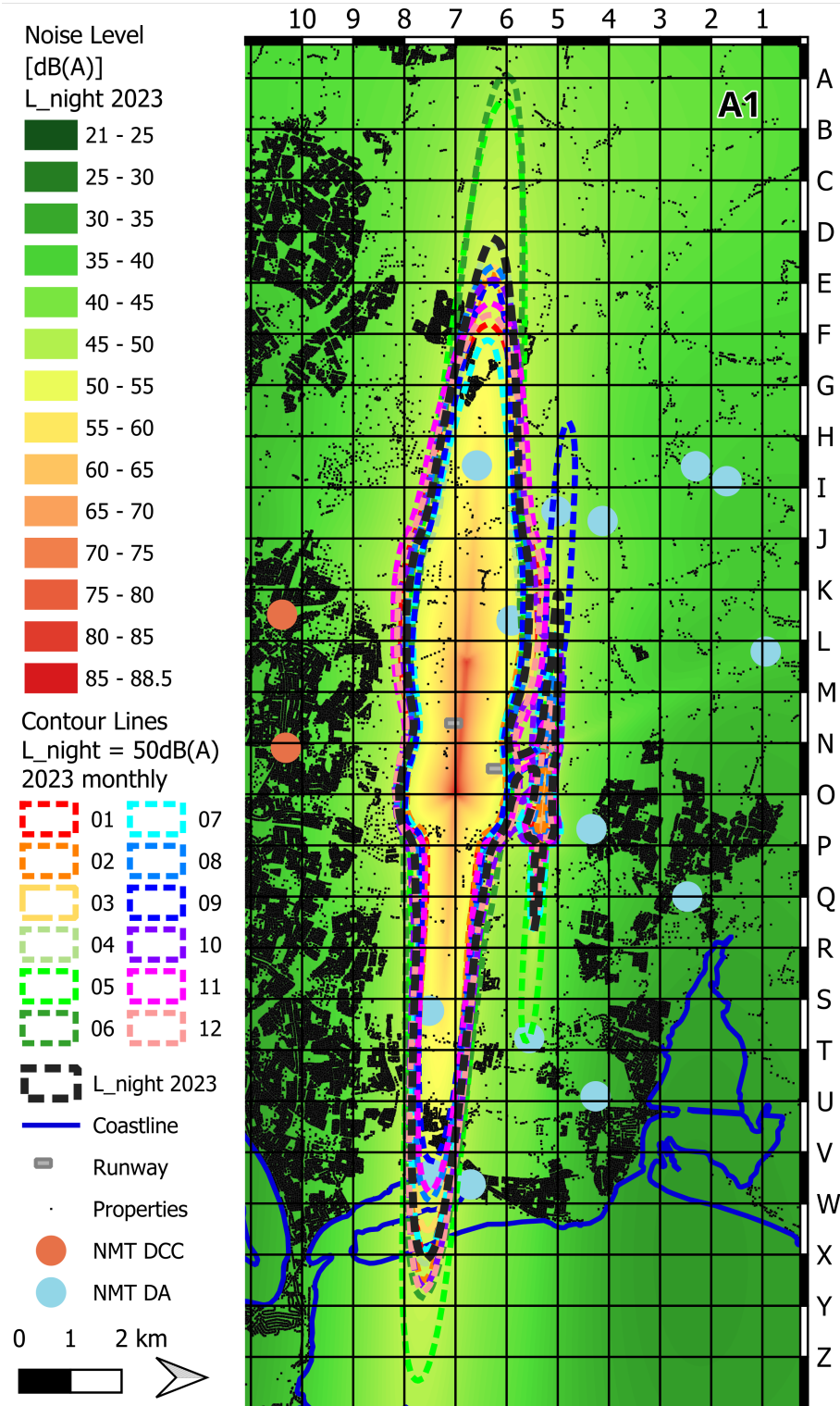


Figure 5.5: Monthly noise contours for $L_{night} = 50\text{dB(A)}$ for 2023 at Dublin Airport with L_{den} noise footprint as background and Noise Monitoring Terminals for Dublin Airport (DA) and Dublin City Council (DCC)

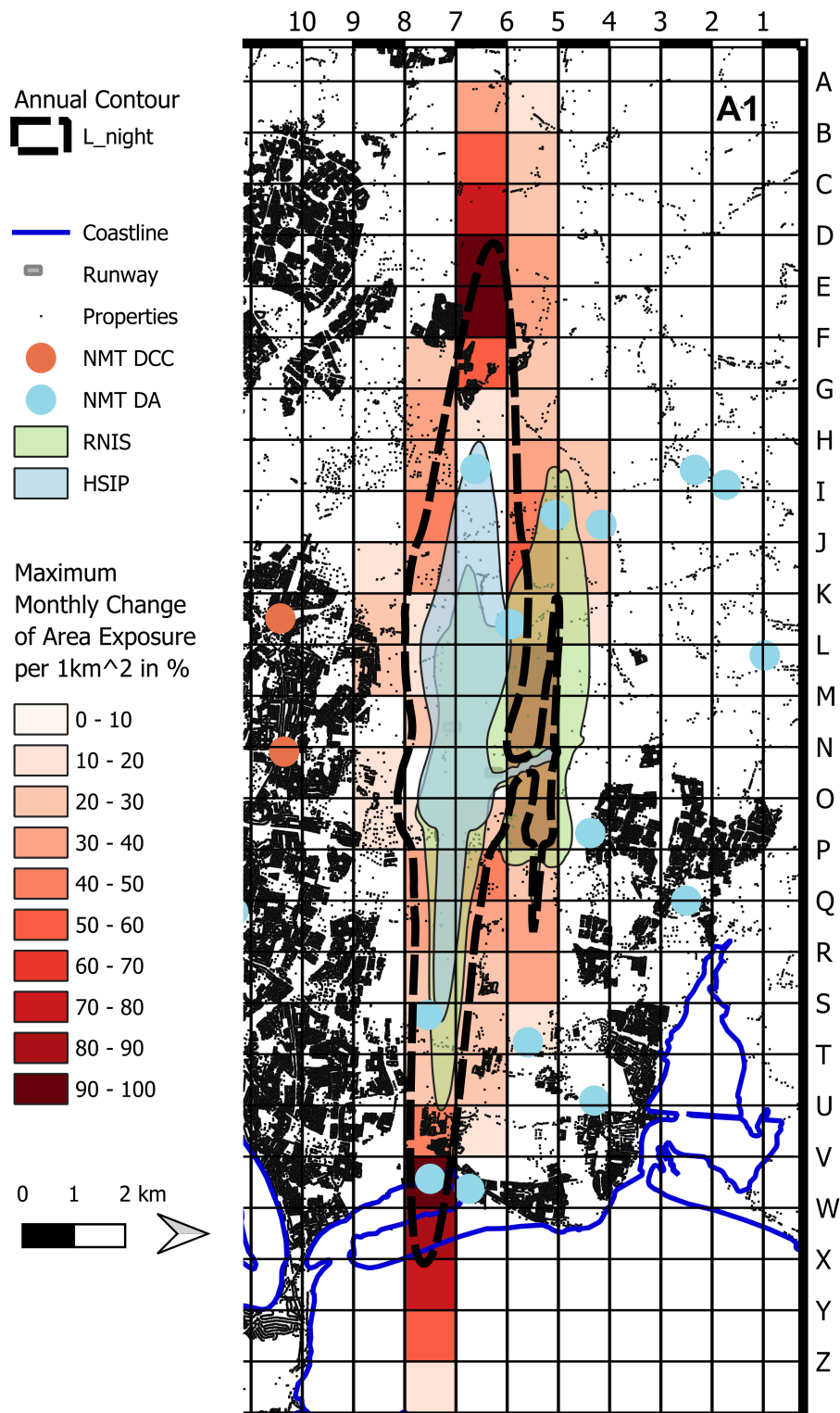


Figure 5.6: Severeness of monthly changes of noise contours in % in comparison to the annual noise contour for $L_n = 50$ dB(A) for 2023 at Dublin Airport and Noise Monitoring Terminals for Dublin Airport (DA) and Dublin City Council (DCC) and insulation schemes

5.4 Discussion

Figure 5.3 displays the overall monthly noise contour lines at Dublin Airport at $L_{den} = 55$ dB(A). In January, nearly all departures were westerly from both runways, with the South Runway preferred for arrivals. In late February 2023, Dublin Airport adjusted flight routes, delaying the right turn of departing aircraft from the North Runway (I3:K4) [176, 177]. Flight numbers increased from March to May 2023, while westerly winds decreased on average, resulting in an extension of the noise contours along both main runways (E:G7, F:G5, W8). May recorded the highest flight numbers in the first two quarters of 2023, with westerly arrivals and departures occurring approximately 60 % of the time due to wind from the west for a majority of the time. The westerly departures are evident from the spikes in the contour lines to the west of the North and South Runways (F4:I4 and E6:I6), as well as the right turn after the North Runway (H2:J4). Since 40 % of all departures in May 2023 were easterly, primarily from the South Runway, the May contour line also extends significantly to the east of the South Runway (R6:X7). Despite April having a higher relative amount of easterly departures, the nearly 3,000 additional flights in May resulted in a larger overall noise contour line. From July onward, the right turn after westerly departures from the North Runway (H2:K3) became more pronounced, indicating that most westerly departures were from the North Runway. Consequently, the extent of the contour lines to the west of the South Runway (I6:J6) is barely visible. Throughout 2023, fluctuations in noise contour lines caused some areas to shift in and out of the contour lines, with inclusion varying by up to 100 %. (Figure 5.4). Areas close to the airport show little change in noise exposure, as expected since all air traffic must arrive or depart from one of the three runways. The highest change in noise exposure is seen in the right turn from the North Runway in the westerly departure direction (J3, I2, and K3). During the first three months of 2023, the right turn was less pronounced, leading to low area exposure. However, as air traffic numbers increased, the contour line extended, resulting in high noise exposure in this area. Additionally, the extent of departure and arrival noise to the east of the South Runway showed high fluctuation throughout 2023. The area P6:W7 experienced a change in area exposure ranging from 10 % to 95 %. The maximum change was observed in grid tile U7, which can be attributed to the small extension of the noise contour line in September 2023, while in May, the extent increased due to the high number of eastern departures from the South Runway.

Nighttime flights at Dublin Airport are limited to 65 flights per night and are typically restricted to the South Runway. However, in 2023 nighttime flights averaged 72 arrivals and departures per night, during peak month reaching an average of 92 flights during the night. As a result, the $L_{night} = 50 \text{ dB(A)}$ contour line for each month predominantly stretches along the South Runway (Figure 5.5). This also leads to the annual noise contour exceeding the threshold required for eligibility under the noise insulation schemes. During periods of nighttime closure for the South Runway, the North Runway was used instead, which is evident in the contour lines for January, February, March, July, September, November, and December 2023. Interestingly, the May L_{night} contour line also extends to the North Runway, suggesting unplanned or unannounced maintenance work on the South Runway. Overall, the contour lines for May and June along the South Runway show the largest area exposure due to the highest number of flights during these months (A6:X8), followed closely by October and December. Generally, the nighttime contour lines along the North and South Runways follow similar patterns, aligning with departure and arrival directions without significant deviations or early turns. This consistency can be attributed to the limited number of nighttime flights at Dublin Airport in 2023.

The changes in nighttime noise exposure are visualized in Figure 5.6. The most significant change, up to 96 %, is observed along the South Runway, where some months show larger $L_{night} = 50 \text{ dB(A)}$ contour lines than others (E:F6, W:Y7). Notably, changes along the North Runway (M:P5) highlight nighttime work on the South Runway. Most notable are high noise levels along the North Runway during July and September. May also shows a significant amount of nighttime flights from the North Runway (L:S6), even though no runway closure was communicated by Dublin Airport. These fluctuations in nighttime noise are particularly concerning as the maps represent long-term monthly averages, potentially underestimating real-time noise exposure for individuals. Individual experiences of noise events, such as awakenings during aircraft flyovers, depend on the frequency of flights, time of day, flight paths, and weather conditions [178].

The annual $L_{den} = 55 \text{ dB(A)}$ contour line surpasses the boundaries of both noise insulation schemes established in 2016 [179] and 2021 [180]. Notably, the area impacted by the right turn after westerly departures from the North Runway (F3:I4), as well as densely populated regions to the east (R7) and west (D6), are not covered by any existing noise insulation schemes despite experiencing significant L_{den} noise exposure fluctuations. Additionally, the

nighttime contour line extending from the South Runway exceeds the limits of the noise insulation schemes, exposing residents to high levels of nighttime noise, particularly to the east and west of the airport. The insulation schemes should ideally be revised to cover the full extent of the $L_{den} = 55$ dB(A) contour line and, if possible, also encompass the $L_{night} = 40$ dB(A) contour line to reduce the negative health effects associated with noise exposure. In comparison to the $L_{den} = 55$ dB(A) contour line, the $L_{den} = 45$ dB(A) contour line has a significantly larger extent, resulting in a greater area and higher population exposure. As shown in Figure 5.2, high-density population zones, such as K:U8 and N4:P5, are affected, as well as smaller communities located along the extension of the South Runway near E7. Additionally, the noise monitoring terminals are primarily located within the $L_{den} = 45$ dB(A) contour line or in densely populated areas. This contour line also highlights the right turn after a westerly departure from the North Runway.

Table 5.6 presents the area and population exposure corresponding to the WHO noise limits of 40 dB(A) and 45 dB(A). The area exposed under the WHO contour lines is more than four times larger than the commonly reported contours. Similarly, the population affected increases from 2771 to 77 377 for L_{den} and from 6012 to 93 352 for L_{night} . This sharp increase (around 150 % for L_{den} and 270 % for L_{night}) is expected, as populated areas tend to avoid airports and major flight paths.

The stricter contour lines proposed by the WHO [13] illustrate the full extent of the population affected by aircraft noise. Even at lower noise levels, the continuous cycles of aircraft flyovers can have adverse health effects [1, 13]. The comparison of the annual noise contour line $L_{den} = 55$ dB(A) with the maximum change in area exposure for L_{den} , as illustrated in Figure 5.4, reveals several areas (E2, C6, S:T7) that experience temporary high levels of noise exposure but fall outside the annual noise contour line. While some of these areas are not densely populated, their identification is crucial for land-use planning. The annual noise contour lines suggest that these regions are not subject to high noise exposure; however, monthly noise maps indicate that high-flight months, such as May and June, extend the noise contour line further. This seasonal extension, occurring primarily during spring and summer when people are more likely to spend time outdoors, highlights a period of significant aircraft noise exposure that is not adequately reflected by the annual contour line. Additionally, although areas with fluctuating high noise exposure are mostly covered by the L_{night} contour line, they are not included in the current insulation schemes. This discrepancy underscores the need

for a more comprehensive approach to noise management that accurately reflects varying exposure levels throughout the year.

While it is convenient and less time-consuming to calculate noise exposure on an annual basis rather than mapping each month individually, the annual noise contour line fails to encompass all highly exposed areas. As a result, populations residing in regions with significant noise fluctuations remain vulnerable to elevated noise levels that are not accurately represented in the annual assessment.

All figures also illustrate the placement of Noise Monitoring Terminals from Dublin Airport [99], strategically positioned along common flight paths. While the north and east regions of Dublin Airport are adequately monitored, the west and south regions would benefit from additional NMTs to better capture and document excessive aircraft noise levels.

Selected Months To provide a clearer overview, the discussion highlights the similarities and differences between selected months, as shown in Table 5.8, before transitioning to a seasonal and chronological review of each month. The table compares two pairs of months with similar flight numbers but differing population exposures. For this comparison, day, evening, and nighttime noise levels are presented with noise contour limits for $L = 55$ dB(A). $L_{\text{den}} = 55$ dB(A) is calculated according to EPA NG4 guidelines with penalties resulting in $L_{\text{day}} = 55$ dB(A), $L_{\text{evening}} = 50$ dB(A), and $L_{\text{night}} = 45$ dB(A) [84].

Month	Flights		Area [km ²]			
	nighttime	total	L_{day}	$L_{\text{ev.}}$	L_{night}	L_{den}
Feb	1566	13085	34.67	21.23	9.79	26.49
May	2852	21793	47.50	31.45	14.58	37.07
Jul	1984	21541	31.10	26.01	9.36	24.82
Sep	1890	12918	28.75	23.76	9.27	23.11

Month	Houses				People			
	L_{day}	$L_{\text{ev.}}$	L_{night}	L_{den}	L_{day}	$L_{\text{ev.}}$	L_{night}	L_{den}
Feb	1627	1698	155	1320	3372	1757	246	2460
May	3117	3316	712	2404	8131	3569	834	6366
Jul	1344	778	164	655	2997	1083	260	1335
Sep	618	455	148	468	1357	649	230	884

Table 5.8: Day-, evening-, and nighttime noise comparison for $L = 55$ dB(A) for February, May, July, and September, at Dublin Airport for 2023

February and September 2023 both recorded approximately 13 000 flight operations. February had 79 % westerly operations, while September had 67 %, along with four nights

of South Runway closure, versus two in February. September also experienced higher winds from the east. The L_{den} contour line comparison reveals that the contour lines in February extend further from the South Runway. This greater extension is likely due to an average of nine extra nighttime flights in September, which extended the nighttime contour line. This also has a significant impact on evening and nighttime noise exposure. While area exposure remains relatively similar, population exposure is significantly higher in February, when the nighttime contour line extends further to the east, extending into densely populated areas (F:J7 and U:V8). This results in only a slightly smaller overall area exposure in September. However, the shape of the L_{den} contour lines exposes nearly three times as many people to aircraft noise above the 55 dB(A) threshold in February. Additionally, September had significantly higher precipitation than February, despite having similar average wind speeds.

May and July 2023 each had approximately 21 000 flights. May had 60 % westerly operations for both departures and arrivals, with no reported runway closures. However, aircraft tracking [170] and the generated contour lines indicate some nighttime activity on the North Runway. May also average 92 flights per night, well above the planned threshold of 65 flights per night. Rainfall and wind speed were below average. Similar to the February and September comparison, May's L_{den} contour line extended further to the east and west of the South Runway than July's, leading to increased population exposure in densely populated areas (F:H7 and U:V8).

In contrast, July 2023 had over 80 % westerly operations, with wind speeds below and precipitation well above the annual average. Despite the high overall flight numbers, nighttime flights in July were primarily conducted on the South Runway, with only three nights on the North Runway. This resulted in a smaller nighttime area and population exposure, affecting only 260 people at $L_{\text{nightgeq } 55 \text{ dB(A)}}$. As shown in Figure 5.3, populated areas, marked in black, were largely unaffected by westerly departures from the North Runway, which primarily overflowed sparsely populated regions. The arrival route from the east to the South Runway contributed most to population exposure during westerly operations at Dublin Airport. The increased use of the South Runway in May extended noise exposure, resulting in higher population exposure across all periods compared to July.

Full Year 2023 The following paragraphs discuss the monthly changes in noise exposure in both seasonal and chronological order, highlighting the most notable and interesting observations.

November, December, and January 2023 had over 80 % of westerly operations at Dublin Airport, with February just below 80 %. These months also experienced above-average wind speeds and below-average precipitation for the year. In winter months, January, February, November, and December had flight numbers below the annual average of 17 543, resulting in generally lower area exposure. However, December was an outlier, showing a large noise contour extension due to the right turn after westerly departures from the North Runway and significant nighttime noise contours. Consequently, in December, 2826 people were exposed to $L_{den} \geq 55$ dB(A).

March 2023 was an average month in terms of flight numbers (17 728), westerly departures (68.5 %), area (29.6 km²), houses (1271), and population exposure (2870). However, wind speed and precipitation were above average, as were the number of days the South Runway was closed.

The number of monthly flights generally correlates with area exposure, though June and July are exceptions. In June, despite a high number of flights (20 163), the L_{den} area exposure (32.3 km²) was significantly lower than in other months. Similarly, July, with the second-highest number of flights, showed unusually low noise exposure. This discrepancy might be due to strong headwinds causing aircraft to climb quickly, thus shortening the ground track and reducing the contour line extension.

June stood out with high flight numbers, approximately 40 % westerly departures, and significant area and population exposure. The high number of departures to the east from the South Runway extended the contour line not only eastward but also north and south due to the shape of the noise contour from departing aircraft. This resulted in a high overall population exposure. The nighttime contour line for June also extended more towards the east and west of the South Runway, resulting in a very high area exposure and leaving around 9930 people exposed to $L_{night} \geq 50$ dB(A). Although August 2023 had a higher overall area exposure than July, it had a lower overall population exposure due to the population distribution patterns explained earlier.

The comparison of area and population exposure highlights the significant impact of population density on the number of people exposed to noise levels above a certain threshold. While area exposure is determined by the size of the noise contour and can be useful for comparing airport noise, population exposure varies for each airport and must be factored into flight route planning. Mitigating aircraft noise pollution requires a multifaceted approach

involving collaboration between aviation authorities, local communities, and policymakers. The *Balanced Approach* [14, 181] addresses airport noise issues by incorporating operational, technological, and land-use planning measures. This approach aids in effectively managing and reducing the impact of aircraft noise on the population surrounding airports.

The Noise Monitoring Terminal (NMT)s from Dublin City Council [143] are not close enough to Dublin Airport [99] to be relevant for the displayed monthly noise contour lines. For the NMTs from Dublin Airport, it would be beneficial to store the recorded noise levels for each monitor like Dublin City Council, ensuring the data is accessible and easy to analyze for the public. These noise readings not only highlight areas of high noise exposure but also identify regions with low noise exposure, which are potential sites for new community developments. This information is essential for policymakers involved in land-use planning, following the principles of the *Balanced Approach* [14, 181].

Just as airport noise fluctuates seasonally and monthly, road traffic noise is also likely to vary with the seasons. For instance, good weather typically results in increased bike and pedestrian traffic, while poor weather conditions lead to higher levels of car traffic. Research on road traffic redirection has highlighted differences in resident noise exposure [182], and significant reductions in traffic noise were observed during the COVID-19 lockdown [183], demonstrating the impact of traffic patterns on overall noise levels.

5.5 Communication Strategy

As illustrated in the noise maps and discussed in Chapter 3, existing noise insulation schemes and Noise Monitoring Terminals (NMTs) provide essential tools for managing airport noise. However, there is a need for enhanced communication strategies to ensure that these measures, and any changes to them, are effectively conveyed to the public. Clear, transparent communication about noise exposure, mitigation efforts, and future projections is key to building trust and reducing uncertainty for communities affected by airport noise.

It would be beneficial to add new NMTs to the west and south of the airport to better monitor the expanding noise contours in these areas. Additionally, the NMT data should be made accessible in tables or downloadable files to facilitate the analysis of noise levels. The monthly noise contour lines and noise fluctuation maps from Section 5.3.2, display a clear need for monthly aircraft noise analysis and communication. It would be beneficial for

Dublin Airport to consider publishing these analyses, including short and long-term expectations for easterly or westerly operations, along with projected monthly flight numbers. This transparency would enable nearby communities to plan events with reduced noise exposure whenever possible. While these forecasts cannot provide perfect accuracy, they can significantly contribute to public understanding and acceptance of aircraft noise, as well as efforts to minimize high noise exposure instances.

Considering international best practices, airports should adopt several practices to effectively manage noise impacts on surrounding communities. They should provide monthly reports that include comprehensive statistics such as Noise Monitoring Terminal data, flight numbers, flight directions, radar tracks if possible, and noise contours. Additionally, information on the negative health effects of noise should be made available to the public. Compensation or noise insulation measures should be offered to affected residents to mitigate the impact.

To assist residents in planning, airports should show trends from past years and provide monthly predictions of weather conditions and their implications for noise contours. Runway closure times should be announced as far in advance as possible, along with clear explanations of their consequences for local communities.

Airports should also encourage airlines to operate quieter aircraft through measures such as noise charges and adapt flight routes to avoid densely populated areas. Active community engagement through consultations and feedback sessions ensures that noise concerns are addressed and that mitigation efforts are well-informed. By implementing these practices, airports can significantly enhance noise monitoring, reporting, and mitigation, leading to more effective management of noise impacts.

Airports should consolidate all relevant information about airport noise in a single, easily accessible location, using clear and non-technical language, so that the public can understand it without requiring expert knowledge. As discussed in Section 5.3.2, monthly noise maps show the variations in noise contours throughout the year, while annual maps provide an average. Monthly data is crucial to highlight noise extremes, which are necessary for assessing eligibility in noise insulation programs and other mitigation measures. It also informs the public when their area experiences peak noise levels and when there is a reduction. If strategically positioned, NMTs could effectively replace the need for frequent noise mapping

while still providing reliable data. Monthly noise maps can help identify optimal locations for placing NMTs, potentially reducing the need for continuous monthly noise modeling.

Clear and simple guidance on noise insulation schemes, including how to apply and the criteria for eligibility, should be readily available. This process should be transparent, allowing residents to easily determine their eligibility. In terms of reporting metrics, L_{max} is rarely used to display airport noise contour lines. However, with respect to noise insulation schemes, it can be a useful indicator, as it captures the peak noise level that residents may experience during a single aircraft overflight. Therefore, it may be beneficial to consider a threshold of at least $L_{max} \geq 55$ dB(A), if not lower, for determining eligibility in insulation programs. This would allow such schemes to target households exposed to the loudest and most disruptive noise events, which are often the most intrusive during daily life and rest periods. Nevertheless, L_{max} also has significant limitations. It represents only the maximum noise level of a single event and does not account for the frequency or cumulative impact of repeated exposures. Consequently, buildings in areas with slightly lower L_{max} values but subject to high overflight frequency may be excluded from insulation support, despite experiencing considerable overall noise burden. This limitation can be addressed by complementing L_{max} with cumulative exposure metrics such as L_{den} or L_{night} , which are designed to reflect long-term exposure and the associated health impacts. Overall, while L_{max} is effective for identifying extreme noise events, it does not reflect broader exposure patterns. As such, it should be used in combination with L_{den} and L_{night} when determining the scope and eligibility of noise insulation schemes.

Residents in areas surrounding airports should also be kept informed about fluctuations in monthly flight numbers, flight directions, and changes in flight routes. Providing explanations for aircraft routing decisions and variations in noise levels can help foster public understanding. Additionally, access to detailed noise data, including downloadable historical information from the NMTs located around the airport, would improve transparency and engagement with the community.

Airports should provide forecast information indicating which areas will be affected by future operations and what flight numbers are expected. This should include detailed explanations of what these forecasts mean for the surrounding population, especially with respect to increasing flight volumes and nighttime operations. Projections should also account for

fleet development and clearly outline the mitigation measures being implemented to address rising noise levels.

Comprehensive and easily understandable information on noise preferential routes, noise charges, bans on noisy aircraft, nighttime and daytime operational restrictions, and insulation schemes should be centralized and readily accessible.

Long-term planning is crucial not only for the airport but also for nearby residents. Forecasting should extend well beyond short-term horizons, such as 2025 or 2030, as seen in the North Runway Report [39], and include projections up to at least 2050. While precise predictions are not possible, long-term forecasts can reveal trends in airport noise and show which areas may be impacted, aiding in land-use planning and management. Long-term noise maps can help identify highly exposed areas and potential future flight paths.

In addition, long-term planning should apply to aircraft operations, flight routes, and operational restrictions. For instance, in the case of North Runway planning, many people built homes in areas that were not initially affected by noise, expecting to reside there for many years. However, the frequent changes in airport operational policies place a significant burden on surrounding residents, creating uncertainty and mental strain as they face the possibility of further changes in the future. Clear and consistent policies are essential to alleviate this burden.

5.6 Summary

In conclusion, wind direction is the key factor in determining operation direction at Dublin Airport, with around 70 % of operations following westerly patterns in 2023 as expected. The annual noise contour lines display the extent of aircraft noise, affecting up to 93 352 people during nighttime for $L_{night} = 40$ dB(A). However, monthly noise maps reveal notable fluctuations in noise exposure for nearby communities throughout 2023. westerly operations varied from approximately 40 % to nearly 100 %, resulting in area exposures ranging from 23 km² to 37 km² for noise levels exceeding $L_{den} = 55$ dB(A).

The difference maps, illustrating the severity of monthly noise exposure fluctuations, revealed variations of up to 100 % in the areas considered. This highlights how different wind directions significantly influence runway operations and modify both population and area exposure at Dublin Airport. Overall, annual noise maps fall short of evaluating the impact

of highly weather-dependent aircraft noise, as observed at Dublin Airport. However, they provide an overview of noise levels over time, aiding in long-term trend analysis and strategic planning for noise mitigation measures.

This study underscores the benefits of implementing monthly noise maps to address significant fluctuations in noise exposure. Clear communication strategies from airports are essential for fostering better acceptance of aircraft noise and integrating it into community event schedules. Providing monthly noise predictions tailored to different communities based on anticipated weather patterns and flight volumes would enhance airport communication with the public, facilitating informed planning and mitigation of noise impacts.

In addition, this chapter demonstrates that area exposure is dictated by noise contour size and facilitates airport noise comparisons. Population exposure varies among airports and must be considered in flight route planning for each airport individually.

Chapter 6

Airport Noise Prediction to 2050

6.1 Introduction

Long-term planning is crucial for policy development, flight route design, airport operations, and land-use management. It affects not only the airport's ability to plan for future expansions and growing passenger numbers, but also informs surrounding residents about where to build, whether to invest in additional noise insulation, or whether relocation is necessary to avoid excessive noise exposure.

Future noise predictions cannot be 100 % accurate; instead, the most likely scenarios are calculated for each year. Predicting airport noise involves multiple variables, with air traffic growth being only one factor. Additionally, flight routes and traffic across different time periods must be forecasted. One of the most complex and influential factors is technology uptake, which significantly affects noise levels alongside air traffic growth. Technology uptake depends not only on the introduction of newer aircraft generations but also on the overall fleet composition. This chapter provides predictions based on the combination of air traffic growth and technology uptake.

For the purposes of this work, annual noise maps have been generated, as they are time-consuming to produce but provide a clear overview of the trends for each year. These annual maps effectively illustrate the overall noise trends. However, for a more detailed analysis, it would be beneficial to also consider extreme monthly scenarios, reflecting periods of both high and low flight numbers, in combination with variations in airport operations. This would allow for a better understanding of the possible fluctuations in noise exposure throughout the year, as discussed in Chapter 5.

6.2 Input Data

The noise forecast model used in this study builds upon the model from the previous chapter, with all input data remaining unchanged except for the flight track data. Unlike radar-based flight tracks, the tracks for this area are manually modeled in accordance with the North Runway Report [39]. Flight numbers and aircraft fleet composition for 2030, 2040, and 2050 are determined in Section 6.3. All vertical take-offs (helicopters) at Dublin Airport are excluded from this study. This modeling approach does not include aircraft taxi noise, which can contribute to the overall airport noise [184].

The future operation of air traffic at Dublin Airport is described and displayed in the North Runway Report [39]. Westerly operations are expected to account for 70 % of all aircraft movements at Dublin Airport. The Cross Runway is anticipated to not be in operation, leaving 30 % for easterly operations [39]. The North Runway Report also shows proposed operating conditions for Dublin Airport, disclosing North and South Runway occupancy as well as day and nighttime flight numbers. Table 6.1 displays the percentage values of proposed air traffic operation at Dublin Airport according to the North Runway Report. This operation table forms the base of the 2030 and 2040 air traffic forecast for Dublin Airport.

In addition, the number of nighttime flights is not to exceed an average of 65 flights per night in 2023 [39]. However, in the planning phase of the North Runway, an increase to 95 flights was discussed [171]. With the flight number increasing until 2030 and 2040, it is realistic that the 65 nighttime flight cap will be increased. It is important to emphasize that this

Operation	North Runway				South Runway			
	departure		arrival		departure		arrival	
time	day	night	day	night	day	night	day	night
movement [%]	9.63	1.76	34.26	0.56	34.72	3.98	7.87	7.22
total [%]	11.39		34.81		38.70		15.09	

Table 6.1: Proposed air traffic operation at Dublin Airport according to Dublin Airport [39]

study does not account for population growth or the expansion of residential areas, meaning that the projections for 2040 may be an underestimate of actual exposure. Nonetheless, the comparison with the current population distribution provides valuable insights.

6.3 Traffic and Fleet Prediction

This section analyzes the aircraft fleet at Dublin Airport in 2023 and projects flight numbers and technology uptake for 2030, 2040, and 2050. For each factor, three scenarios (low, base, high) are developed and combined in the following sections.

To enhance clarity, the following abbreviations will be used for the different scenarios:

Acronym	Meaning	Acronym	Meaning
LA	Low Air Traffic Increase	LTU	Low Technology Uptake
BA	Base Air Traffic Increase	BTU	Base Technology Uptake
HA	High Air Traffic Increase	HTU	High Technology Uptake

6.3.1 2023 Fleet

From July 2022 to March 2023 96 different aircraft types were recorded at Dublin Airport. However, only 8 aircraft types were holding an average movement rate of over 1 %. Figure 6.1 displays the most popular aircraft types at Dublin Airport during this time period. The Boeing 737800 is the aircraft with the most movements (average of 32 %), followed by Airbus 320-211 at an average movement rate of 22 %. The Boeing 7378max, which is the successor of the 737800 has a share of 11 % average movements during these nine months. ATR76 is a turboprop aircraft, which had an average of 7 % of all arrivals and departures at Dublin Airport. Aircraft with $1\% < \text{movement rate} < 5\%$ are the A330, Boeing 787, A319 and A321. All other aircraft types at Dublin Airport are represented less than 1 % and summarized as *other* aircraft at 19 %. Notable is, that all aircraft movement shares over 10 % are narrow body aircraft. A330 and Boeing 787 are wide body aircraft (5.6 %).

Aircraft Fleet	Share [%]
narrow body	75.7
wide body	9.1
regional jet	6.9
turboprop	8.3
total	100

Table 6.2: Aircraft fleet shares at Dublin Airport 07/2022 - 03/2023

Aircraft Generation	Share [%]
not defined	1.62
generation 0	38.54
generation 1	40.91
generation 2	18.93
total	100

Table 6.3: Aircraft generation shares at Dublin Airport 07/2022 - 03/2023

Table 6.2 shows the fleet distribution at Dublin Airport from 07/2022 to 03/2023. In this time period, the share of narrow body aircraft at Dublin Airport was 76 %, while the average in western Europe was 64 %. Wide body aircraft had an overall share of 9 % of air traffic at Dublin Airport, while the report stated an overall of 22 % of wide body aircraft in 2023 in western Europe. This is a demonstration of how airport-specific the air traffic is and thus,

general forecast scenarios need to be adapted to individual airports [185]. Turboprop aircraft had a movement share of 8.3 % at Dublin Airport, followed by regional jets at 6.9 %.

Table 6.3 displays the aircraft generation share in 2023. Most of the aircraft arriving or departing at Dublin Airport in 2023 are generation 0 or generation 1 aircraft (almost 80 % total). Generation 2 aircraft make up 18.9 %. Vertical take-offs and aircraft whose aircraft type cannot be identified solely by radar track data are displayed as *not defined* and makeup 1.6 % of the overall share. From October 2022 to September 2023 the average runway operation mode at Dublin Airport was 71.5 % westerly and 27.7 % easterly Operations. The remaining flights were operated from the Cross Runway 16/34, only when wind dictates [132].

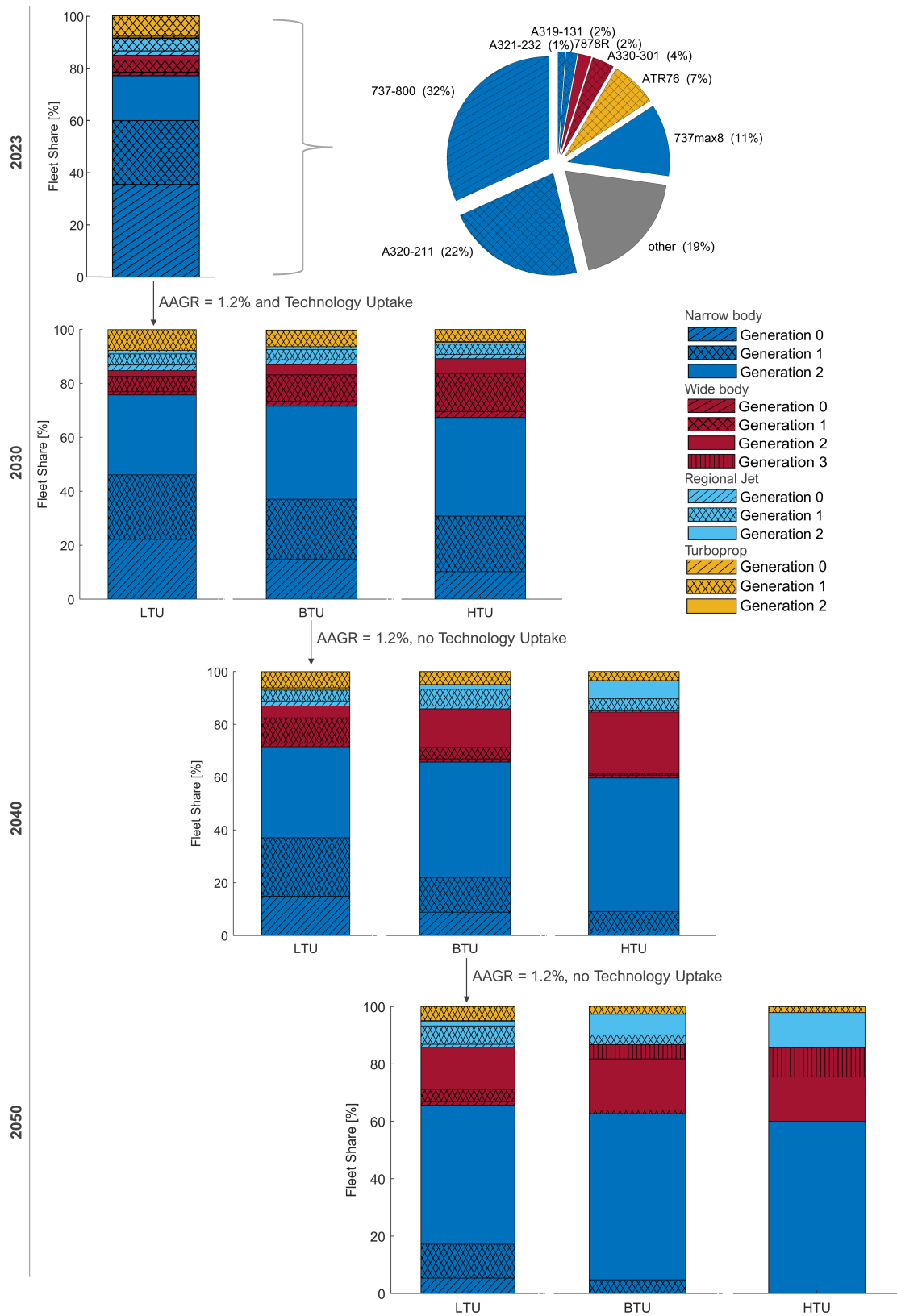


Figure 6.1: Technology update scenarios from 2030 to 2050

Low Technology Uptake (LTU), Base Technology Uptake (BTU), High Technology Uptake (HTU)

6.3.2 Dublin Airport Air Traffic Increase

Air traffic increase is predicted by Eurocontrol for European countries [3]. For Ireland, Eurocontrol distinguishes between low, base, and high air traffic growth scenarios. The Republic of Ireland lies in the average of the European air traffic forecast. In the scenario for low air traffic increase, air traffic will continue to increase at a slow rate of 0.6 %. The base air traffic increase scenario for Ireland is an AAGR of 1.2 %, while the high growth scenario expects a maximum AAGR of 1.8 % (see Figure 6.2).

Eurocontrol published an AAGR of 2.1 % in 2018 [16]. This growth rate is not used in this work, as it was a pre-Covid-19 pandemic estimate. This leaves Dublin Airport in 2030 with 244 635, 2040 with 275 527, and 2050 with 310 548 flights for the Base Air Traffic Increase (BA) scenario annually.

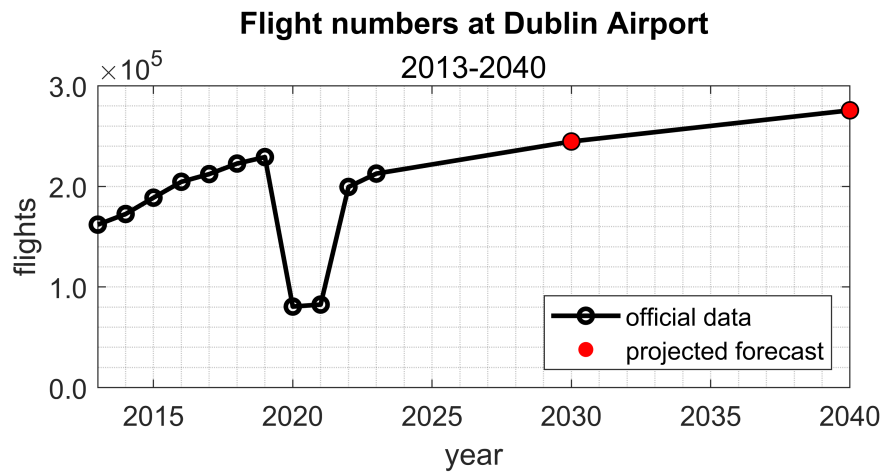


Figure 6.2: Flight numbers at Dublin Airport (2013 - 2040) from Central Statistics Office [87] with forecast data calculated with AAGR = 1.2 % according to Eurocontrol [3]

Scenario	Annual flight numbers								
	LA			BA			HA		
	AAGR	0.6 %		1.2 %			1.8 %		
Year	day	night	total	day	night	total	day	night	total
2030	202426	31643	234069	211564	33071	244635	221058	34555	255613
2040	214827	33581	248408	238280	37247	275527	264134	41289	305423
2050	228154	35664	263818	268567	41981	310548	315836	49370	365206

Table 6.4: Flight number forecast up to 2050 for different air traffic increase scenarios for Dublin Airport with AAGRs according to Eurocontrol [3]

Projected flight numbers through 2050 are presented in Table 6.4. With an AAGR = 1.2 %, flight numbers for the year 2030 are forecasted to reach 244 635 annually. Based on this extrapolation the average number of nighttime flights modeled for 2030 is 92 flights per night, which is less than the 95 flights discussed [171]. In the High Air Traffic Increase (HA) scenario for 2030, nighttime flights are projected to reach an average of 98 per night. For 2040, the Base Air Traffic Increase (BA) scenario anticipates 102 flights, increasing to 113 flights per night by 2050.

6.3.3 Dublin Airport Aircraft Technology Uptake

Aircraft generations are undergoing transformative change, driven by rapid technological advancements. The pace of technology uptake and fleet renewal is closely tied to the technology readiness level, which is influenced by factors such as research and development, production capabilities, and supply chain dynamics [3]. Airline orders for new aircraft depend on the broader economic climate and forecasts, which take into account factors like travel trends, cargo demand, and general air traffic patterns. Additionally, operational restrictions, such as bans on older or noisy aircraft, can significantly impact fleet composition and influence the overall rate of fleet renewal.

Aircraft fleet share are expected to undergo significant changes in the coming years. According to Eurocontrol [16] the share of the narrow body fleet will decrease as well as the share of regional jets and turboprop aircraft. At the same time, the wide body fleet will grow. Passenger air traffic increases at a lower rate than cargo air traffic [3, 16], in addition, passenger-to-freighter conversions drive the wide body fleet growth [185]. In the case of no to Low Technology Uptake (LTU) and little change between 2023 and 2030, the fleet share of 2023 is used as the LTU scenario in 2030. The fleet share of the base scenario for 2030 can be seen in Table 6.7. In addition Figure 6.1 visualizes the fleet and generation shares of the different technology uptake scenarios for year modeled year.

The OliverWyman report [185] is used to calculate the fleet shares for the 2030 Base Technology Uptake (BTU) and High Technology Uptake (HTU) scenarios, unless indicated otherwise. OliverWyman, a management consulting firm, produces aviation reports (covering fleet planning, maintenance, crew, and airport management), among other topics. This report presents western European fleet share numbers for 2023 and forecast for 2033. These numbers are in-

terpolated to 2030 and the growth rates for the individual fleets are calculated and projected onto the fleet numbers at Dublin Airport.

As 2030 is approaching the share of generation 0 is replaced with generation 1 and subsequently generation 2 aircraft. In the 2030 BTU scenario the regional jet and turboprop fleet individually makes up about 6 %, the wide body fleet follows with 15 %, and the narrow body fleet is assumed to make up 72 % of aircraft movements at Dublin Airport. Table 6.7 also shows the overall aircraft generation share according to the fleet type.

Figure 6.1 illustrates the relationship between the different forecast years and scenarios. In the 2030 BTU to 2040 LTU scenario, little to no technology uptake is assumed. The 2040 BTU fleet share, adapted from Eurocontrol [16], shows a decrease of approximately 5 % in the narrow body fleet share, while the wide body fleet share increases by a similar amount.

The 2050 LTU scenario is based on the 2040 BTU scenario, reflecting minimal technology uptake during this period. With a typical lifespan of around 25 years, most commercial generation 0 and generation 1 aircraft are expected to be replaced by newer aircraft generations. Generation 3 aircraft, representing new aircraft concepts, are not anticipated to enter service until after 2050. According to Eurocontrol [3], by 2050, generation 2 aircraft will make up 89 % of the fleet, while generation 1 (conventional) aircraft will account for 4 %, and revolutionary aircraft concepts will comprise 8 %. In the 2050 BTU scenario, this fleet composition is reflected by an increase to around 25 % wide body aircraft, including roughly 5 % generation 3 aircraft. The narrow body fleet is expected to continue decreasing, as short-distance flights may be increasingly replaced by improved train connections [3, 186].

Year Scenario	2030			2040			2050		
	LTU	BTU	HTU	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	25.99	18.88	14.27	18.47	11.21	3.30	7.71	0.00	0.00
generation 1 [%]	41.37	41.86	43.01	41.96	28.72	16.11	27.40	12.09	2.05
generation 2 [%]	32.53	39.00	42.71	39.53	60.08	80.59	64.89	82.96	87.75
generation 3 [%]	-	-	-	-	-	-	0.00	4.96	10.20

Table 6.5: Aircraft fleet generation share at Dublin Airport for Low Technology Uptake, Base Technology Uptake, and High Technology Uptake scenarios

For the year 2050, aircraft types and variations are grouped due to the lack of published specifications for different configurations. Generation 2 aircraft are implemented based on substitution tables [150, 151]. As generation 3 aircraft are still speculative at this stage of technology readiness, a single type (Blended Wing Body (BWB)) is used as a proxy.

2030

By 2030, flight numbers are projected to reach 244 635 annually, with an average of 92 nighttime flights per night, based on an AAGR of 1.2 % [171]. The air traffic operation for 2030, as shown in Table 6.6, is based on the percentage values from Table 6.1.

Operation	North Runway				South Runway			
	departure		arrival		departure		arrival	
time	day	night	day	night	day	night	day	night
movements	23558	4306	83812	1370	84937	9736	19253	17663
total	27864		85182		94674		36915	

Table 6.6: Air traffic operation at Dublin Airport for 2030 for the Base Air Traffic Increase (BA) scenario based on projections for 2025 from Dublin Airport [39]

This section provides an overview of the various scenarios regarding aircraft fleet shares and technology uptake at Dublin Airport.

Fleet Scenario	Narrow body			Wide body		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	22.13	14.83	10.21	1.22	1.82	2.19
generation 1 [%]	23.93	22.16	20.55	5.63	9.79	14.13
generation 2 [%]	29.64	34.53	36.59	2.20	3.83	5.52
total [%]	75.69	71.52	67.35	9.04	15.44	21.85

Fleet Scenario	Regional jet			Turboprop		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	2.06	1.80	1.56	0.59	0.43	0.31
generation 1 [%]	4.12	3.80	3.84	7.73	6.15	4.53
generation 2 [%]	0.69	0.64	0.60	0.00	0.00	0.00
total [%]	6.87	6.24	5.99	8.32	6.58	4.83

Table 6.7: 2030 Dublin Airport fleet share forecast for different technology uptake scenarios

The share of narrow body, regional jet, and turboprop aircraft is expected to decline, while the wide body fleet grows, driven by cargo traffic and passenger-to-freighter conversions [3, 16, 185]. For Low Technology Uptake (LTU), the 2023 fleet share is assumed unchanged for 2030. Fleet shares for Base Technology Uptake (BTU) and High Technology Uptake (HTU) scenarios are derived from OliverWyman forecasts [185], interpolated for 2030, and applied to Dublin Airport projections. For the HTU scenarios this is leaving the narrow body fleet at 67 %, wide body fleet share at 22 %, regional jets at 5 %, and the turboprop

fleet share at 5 %. The fleet shares for the Base Technology Uptake (BTU) scenario for 2030 are interpolated from the LTU and HTU scenarios.

In the BTU scenario the regional jet and turboprop fleet individually makes up about 6 %, the wide body fleet follows with 15 %, and the narrow body fleet is assumed to make up 72 % of aircraft movements at Dublin Airport.

2030 Narrow Body Fleet The most detailed forecast of the generation shift of aircraft in the narrow body fleet can be found in the OliverWyman report [185]. It presents the shift of generation 1 aircraft families (Boeing 737NG and A320ceo) to generation 2 aircraft (Boeing 737max and A320neo). The OliverWyman report [185] expects the share of Boeing 737NG aircraft (including -600, -700, -800, -900 variants [187]) to drop around 23 % from 2023 to 2033. The starting narrow body fleet percentage for Boeing 737NG aircraft is 34 % in the report. The overall share of Boeing 737NG at Dublin Airport of 33.6 % can be translated to 44 % of the overall narrow body fleet at Dublin Airport in 2023. Extrapolating the number of 737NGs at Dublin Airport, in 2030 the share of Boeing NGs will be around 20 % of the narrow body fleet as the LTU scenario. The HTU scenario uses the interpolation of the values in the OliverWyman report, which will lead to a share of 15 % of the narrow body fleet of Boeing 737NGs at Dublin Airport. The old Boeing aircraft will be replaced by the Boeing 737max, which is expected to grow from 6 % in 2023 to 27 % in 2033. Dublin Airport however starts at a high initial value of 11 % Boeing 737max in 2023. Interpolating the numbers from the OliverWyman report [185], the LTU scenario will have a share of 17 % Boeing 737max aircraft of the narrow body fleet at Dublin Airport. Using the 2023 share of 14 % Boeing 737max aircraft in the narrow body fleet at Dublin Airport and the growth rate suggested in OliverWyman [185], the HTU will have a share of 41 % Boeing 737max aircraft in the narrow body fleet at Dublin Airport.

A similar change will be presented with the A320ceo aircraft, which are replaced by the A320neo family. At Dublin Airport A320ceo (A319, A320, A321 [188]) has an overall share of 34 % (32 % of the narrow body fleet). The OliverWyman report [185] surmises a narrow body share of 36 %, which will drop down to 10 % in 2033. Interpolating these numbers to 2030 will result in 15 % of A320ceos in the narrow body fleet at Dublin Airport for the Low Technology Uptake (LTU) scenario. Using the OliverWyman stagnation rate on the 2023 share of A320ceos of the narrow body fleet, the HTU scenario applies to have 13 %.

The A320neo share of the narrow body fleet at Dublin Airport is 8 % in 2023. Similar to the increase of the Boeing 737max the interpolation of the growth scenario of OliverWyman is used for the LTU scenario, bringing it to 16 % of the narrow body fleet. The OliverWyman report [185] has a starting percentage of 15 % in 2023, increasing to 39 % of A320neo aircraft in the narrow body fleet. 29 % of A320neo of the narrow body fleet are modeled in the 2030 HTU scenario. This number is calculated from the 2023 A320neo share of the narrow body fleet and the growth rate of the OliverWyman report [185].

The Base Technology Uptake (BTU) percentages for these four aircraft types of the narrow body fleet are interpolated from the LTU and HTU scenario percentages.

For the Low Technology Uptake case of 2030, the other individual shares of each aircraft of 2023 were utilized (see Appendix A). In addition, the air traffic increase was taken into account. The 2023 aircraft share numbers were projected onto 2030 for the LTU scenario. The overall generation share of each fleet for the different technology uptake scenarios can be seen in Table 6.7.

For the narrow body fleet, the remaining generation 0 individual aircraft were reduced by 50 % in the overall fleet share for the base and by another 50 % for the HTU scenario. In addition, the generation 2 A220 aircraft increased from 4.7 % in the low to 5.6 % in the base and 6 % in the High Technology Uptake scenario.

2030 Wide Body Fleet The overall wide body fleet share increases from LTU to HTU scenario. Therefore, the wide body generation 0 fleet increases by 50 % and then another 20 % from the LTU to HTU scenario. At the same time generation 1 and 2 wide body aircraft shares increase by 74 % for the BTU and another 44 % for the HTU scenario.

2030 Regional Jet Fleet The regional jet fleet generation 0 individual aircraft shares were reduced by 13 % for the BTU scenario and another 13 % for the HTU scenario. As the overall share of regional jet aircraft at Dublin Airport decreases from 6.8 % to 6.2 % to 5.4 % for the different scenarios, the generation 1 regional jet fleet decreases to an overall share of 3.8 % for the BTU scenario. As more generation 0 aircraft are replaced for the HTU scenario, the total share of generation 1 regional jet aircraft remains 3.8 %. The overall share of the regional jet fleet decreases from the LTU to HTU scenario, which leads to an increase of generation 0 aircraft share within the regional jet fleet. Thus, the overall share of generation

2 regional jet aircraft decreases by 7 % for the BTU scenario and another 6 % for the High Technology Uptake scenario.

2030 Turboprop Aircraft Fleet Similar to the regional jet fleet, the turboprop fleet decreases throughout the different technology improvement scenarios. This leads to a decrease in all aircraft generations by 20 % to 27 % for the Base Technology Uptake scenario. There are no turboprop generation 2 aircraft, which leads to a slower intake of new aircraft. As the overall turboprop share decreases, the share of generation 0 aircraft decreases by 27 % and generation 1 turboprop aircraft by 20 % for the base scenario. For the High Technology Uptake (HTU) scenario the share of generation 0 turboprop aircraft is reduced by another 27 %, and the generation 1 aircraft share by another 26 %.

Table 6.5 shows how the overall generation 0 aircraft share in 2030 decreases towards the High Technology Uptake scenario. As generation 1 aircraft replace retired generation 0 aircraft, the share almost remains the same. This can be explained by the increase in the generation 2 aircraft share from LTU to HTU scenario.

2040

In the 2040 scenario aircraft movements are also modeled according to Table 6.1. In the base air traffic uptake scenario Dublin Airport is expected to operate 275 628 flights in 2040. With this increase in air traffic, the nighttime flight number is also expected to increase. Nighttime flights in 2040 in this study will average 104 flights per night. The air traffic operation for 2040, as shown in Table 6.8, is based on the percentage values from Table 6.1.

Operation	North Runway				South Runway			
	departure		arrival		departure		arrival	
time	day	night	day	night	day	night	day	night
movements	26533	4849	94396	1543	95663	10966	21684	19893
total	31383		95939		106629		41577	

Table 6.8: Air traffic operation at Dublin Airport for 2040 for the Base Air Traffic Increase (BA) scenario based on projections for 2025 from Dublin Airport [39]

Table 6.9 displays the fleet share at Dublin Airport for 2040. The Low Technology Uptake (LTU) shares are assumed to have the same fleet share as the 2030 BTU (see Figure 6.1, flowchart of the fleet share and technology uptake scenarios). The Base Technology Uptake

(BTU) fleet share is adapted from Eurocontrol [16]. In this forecast, the wide body fleet is expected to continuously increase until 2040. [16]

This results in 65.7 % narrow body, 20.2 % wide body, 9.1 % regional jets, and 5.1 % turboprop aircraft for the BTU in 2040. The growth rate for each fleet was calculated from LTU to BTU and utilized to calculate the fleet shares for the High Technology Uptake (HTU). The narrow body fleet is decreased to 59.7 %, and the turboprop fleet to 3.5 %, while wide body (25.1 %) and regional jet fleet (11.8 %) increase.

Fleet Scenario	Narrow body			Wide body		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	14.83	8.81	1.66	1.31	1.24	1.11
generation 1 [%]	22.16	13.17	7.42	9.62	4.27	0.67
generation 2 [%]	34.53	43.68	50.57	4.52	14.70	23.27
total [%]	71.52	65.66	59.65	15.44	20.20	25.05

Fleet Scenario	Regional jet			Turboprop		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	1.91	1.01	0.48	0.43	0.16	0.05
generation 1 [%]	4.03	6.39	4.58	6.15	4.89	3.44
generation 2 [%]	0.48	1.69	6.75	-	-	-
total [%]	6.42	9.09	11.81	6.58	5.05	3.49

Table 6.9: 2040 Dublin Airport fleet share forecast for different technology uptake scenarios

2040 Narrow Body Fleet The A321neo and Boeing 737max10 aircraft are expected to have a share of 40 % of all deliveries until 2040 [189]. This might result in an overall fleet share of 17.2 % LTU to 37.2 % of these two aircraft families. The narrow body generation 0 aircraft share within the narrow body fleet will decrease from 20.7 % LTU to 13.4 % BTU to 2.8 % HTU. As the production of generation 2 aircraft is stable, generation 1 aircraft shares within the narrow fleet are also decreasing. Starting with 31 % for LTU, decreasing to 20.1 % BTU, leaving HTU to 12.4 %. Generation 2 aircraft within the narrow body fleet is increasing up to 84.8 % in the HTU, starting from 48.3 % LTU increasing to 66.5 % BTU.

2040 Wide Body Fleet The wide body fleet is expanding with new generation 2 aircraft (A350G2 variations, A380neo variations, B777G2 variations, B787G2 variations, B78X) in 2040 [152]. This results in high generation 2 aircraft shares in the wide body fleet (Table 6.9). Within the wide body fleet, the generation 0 aircraft share decreases from 8 % to 4 %, while

the generation 2 aircraft share increases from 29 % to 93 % between the different technology uptake scenarios.

2040 Regional Jet Fleet The overall regional jet share increases from the LTU to the HTU scenario. In addition, three new generation 2 aircraft are expected to be on the market in 2035 [152]. This results in a significant growth of generation 2 aircraft in the regional jet fleet. However, these few new aircraft types cannot take over all generation 0 and 1 aircraft in this fleet, resulting in a slow decrease of generation 0 aircraft down to 0.5 %. While generation 1 and 2 are replacing retired generation 0 aircraft, generation 1 fleet share increases from 4 % LTU to 6.4 % BTU. In the High Technology Uptake, the production of generation 2 aircraft is increasing at a faster rate, and thus able to replace generation 0 and 1 aircraft faster, leading to a decrease to 4.6 % in generation 1 aircraft in 2040.

2040 Turboprop Aircraft Fleet There are no generation 2 aircraft in the turboprop fleet, resulting in the decrease of generation 0 aircraft, while generation 1 aircraft types are increasing as seen in Table 6.9.

Overall up to 2040 generation 0 and 1 aircraft are decreasing, while the share of generation 2 aircraft might reach 81 % in 2040 in the High Technology Uptake scenario (Table 6.5). In comparison to 2023 generation 0 aircraft might decrease by a maximum of 35 %, generation 1 by 24 %, and for generation 2 there will be a maximum increase of 61 %.

2050

In the 2050 BA scenario, a total of 310 548 aircraft operations are expected at Dublin Airport. The number of nighttime flights is projected to increase, with an average of 115 flights per night. The air traffic operation for 2050, as presented in Table 6.10, is based on the percentage values from Table 6.1.

Eurocontrol [3] predicts a share of 89 % generation 2 aircraft, 4 % conventional aircraft (generation 1) and 8 % revolutionary aircraft concepts in 2050. In addition, there is a high opportunity for short-distance flight replacements with rail, which would increase the percentage of long-distance flights. [186]

Operation	North Runway				South Runway			
	departure		arrival		departure		arrival	
time	day	night	day	night	day	night	day	night
movements	29906	5466	106394	1739	107822	12360	24440	22422
total	35371		108133		120182		46862	

Table 6.10: Air traffic operation at Dublin Airport for 2050 for the Base Air Traffic Increase (BA) scenario based on projections for 2025 from Dublin Airport [39]

The forecasted evolution of the aircraft fleet at Dublin Airport for 2050, presented in Table 6.11, outlines the anticipated distribution of different aircraft generations in 2050 with future aircraft concepts, such as the Blended Wing Body (BWB). Eurocontrol [3] anticipates that around 90 % of the aircraft fleet in 2050 will consist of generation 2 aircraft, with turboprop and regional aircraft types, experiencing a continuous decline in fleet shares [16]. In addition, only 4 % of aircraft are anticipated to be conventional aircraft (generation 0 and 1), while up to 8 % are anticipated to be future aircraft concepts [3, 186]. This forecast scenario is considered to be ambitious. In this study, a Base Air Traffic Increase (BA) Base Technology Uptake (BTU) scenario for 2050 is generated and it is assumed that Dublin Airport will operate a share of around 5 % future aircraft concepts.

The most intriguing aspect of this forecast is the introduction of a futuristic generation 3 aircraft, comprising 4.96 % of the fleet in 2050 with future aircraft concepts. This is particularly noteworthy, as it reflects the integration of innovative aircraft concepts, such as the BWB, showcasing a potential paradigm shift in aviation technology. Furthermore, it is anticipated that generation 0 aircraft will be phased out and not in service at Dublin Airport by the year 2050. The proportion of generation 1 aircraft is projected to decrease to 12.09 %, leaving the predominant share of the fleet composed of generation 2 aircraft at 82.96 %. This shift underscores the airport's trajectory towards a more technologically advanced and environmentally conscious fleet composition, aligning with industry trends and the adoption of innovative aviation technologies. The first future aircraft concepts, such as electric or hybrid electric aircraft are anticipated between 2035 and 2040, while large future aircraft concepts, such as the BWB concept are expected to start service between 2035 and 2045 [3]. While certification for very small electric aircraft is already underway [190], wide body aircraft like the BWB are still in the developmental stages. In this study, it is projected that BWB aircraft will not be operational until 2050.

Fleet Scenario	Narrow body			Wide body		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	5.31	0.00	0.00	1.24	0.00	0.00
generation 1 [%]	11.85	4.72	0.00	4.27	1.30	0.00
generation 2 [%]	48.49	57.92	60.02	14.70	17.84	15.45
generation 3 [%]	-	-	-	0.00	4.96	10.20
total [%]	65.66	62.63	60.02	20.20	24.09	25.65

Fleet Scenario	Regional jet			Turboprop		
	LTU	BTU	HTU	LTU	BTU	HTU
generation 0 [%]	1.01	0.00	0.00	0.16	0.00	0.00
generation 1 [%]	6.39	3.40	0.00	4.89	2.68	2.05
generation 2 [%]	1.69	7.20	12.28	0.00	0.00	0.00
total [%]	9.09	10.60	12.28	5.05	2.68	2.05

Table 6.11: 2050 Dublin Airport fleet share forecast for different technology uptake scenarios

2050 Narrow Body Fleet In the Base Technology Uptake (BTU) scenario, all generation 0 aircraft, such as the Boeing 737 variants, are replaced by generation 1 and 2 aircraft. At the same time, the generation 1 fleet is reduced to 4.7%. The overall decrease in narrow body aircraft across the different technology uptake scenarios in 2050 has slowed, with the difference in narrow body fleet share now under 3% between the different technology uptake scenarios. In the HTU scenario for 2050, all generation 0 and 1 aircraft are replaced by generation 2 aircraft (60%), with no generation 3 aircraft in the narrow body fleet. As a result, generation 2 aircraft, such as the A320neo and new variants of the 737max8, are expected to dominate the narrow body fleet.

2050 Wide Body Fleet In 2050, the wide body fleet at Dublin Airport is expected to make up between 20% to 26% of the overall fleet. In the BTU scenario, there are no generation 0 aircraft in the wide body category. The 1.3% share of generation 1 aircraft is primarily composed of A330, A350, A380, and B777 variants. In the HTU scenario, these generation 1 aircraft are replaced by newer generation 2 wide body aircraft of the same types, but with updated variations.

2050 Regional Jet Fleet From the LTU to the HTU scenario, the generation 1 regional jet fleet at Dublin Airport is expected to decrease from 6.39% to 0.00%. In the LTU scenario, the last generation 1 aircraft will be in operation. In contrast, the regional jet fleet is projected

to grow to 12.28 % in the HTU scenario, exclusively composed of generation 2 aircraft, such as newer variations of the Embraer E-jet family.

2050 Turboprop Aircraft Fleet The turboprop fleet at Dublin Airport cannot be represented by any generation 2 aircraft in any technology uptake scenario due to the lack of available aircraft noise and performance substitution data for this fleet type. By 2050, all generation 0 turboprop aircraft are expected to be retired. As a result, the turboprop fleet is represented solely by generation 1 aircraft in the BTU and HTU scenarios. In the LTU scenario, 0.16 % of the fleet is still composed of generation 0 aircraft. Overall, the turboprop fleet decreases from 5.05 % in the LTU scenario to 2.05 % in the HTU scenario.

Future Aircraft Concepts The BWB aircraft in this forecast is used to represent generation 3 aircraft. While the BWB concept serves as a proxy for the anticipated technological advancements of future aircraft, it is important to note that many other aircraft concepts are currently under development, which could significantly impact airport operations and the aviation industry as a whole (see Section 2.2.3). For example, aircraft with vertical takeoff capabilities or aircraft using alternative energy could change airport infrastructure requirements and operational dynamics [191]. Similarly, supersonic aircraft [192] or high aspect ratio designs [35] might impact travel times over long distances, but could also introduce new challenges such as noise or environmental impacts. These innovations could lead to substantial changes in airport operations, fleet composition, and the broader aviation ecosystem.

For this 2050 forecast, the BWB concept has been selected as a representation of generation 3 aircraft at Dublin Airport, as it reflects the potential for high efficiency and reduced environmental impact. Given the limited availability of data for future aircraft concepts, particularly acoustic data, the BWB aircraft was selected due to the availability of a complete noise emission profile from ONERA [155, 156, 163]). Therefore, for the purposes of this forecast, it is assumed that the BWB aircraft can represent all generation 3 aircraft. NPD data has been generated according to the methodology outlined in Section 4.1.2, providing the necessary noise and performance characteristics for these aircraft.

Figure 6.3 shows the departure noise contour lines of different wide body aircraft at $L_{Amax} = 55$ dBA available in the ANP database in comparison to the BWB aircraft. Depending on the departure profile, the L_{Amax} footprint can increase by around 30 % for these wide body aircraft. The generated BWB noise contour is around 55 % smaller than the

B777X and the B788 aircraft. Simultaneously, the BWB is projected to be approximately 25% lighter than the B777X, yet it maintains a range just over 10 000 km, which falls within a range of 3000 km to 6000 km lower than the compared wide body aircraft listed in Table 6.12. The anticipated generation 3 wide body aircraft is expected to accommodate 400 passengers, a capacity comparable to that of the B77W and B777X. The smaller departure footprint of the BWB aircraft shows, that future aircraft concepts have the capability to significantly impact overall airport noise.

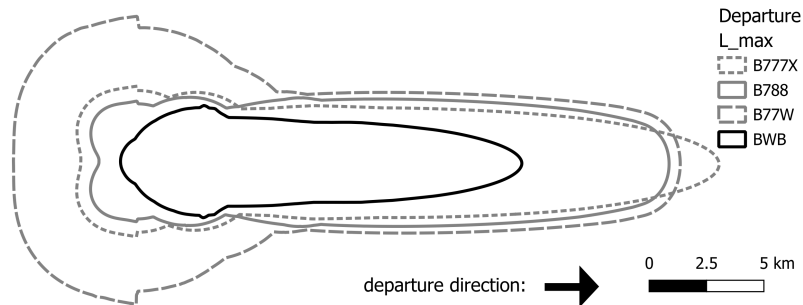


Figure 6.3: Aircraft departure noise footprint contour lines at $L_{max} = 55$ dBA for different wide body aircraft (generation 2 and generation 3)

Aircraft	Generation	MTOW [lb]	Passenger Capacity	Range [km]	Area [km^2] $L_{Amax} = 55$ dBA
B777X	2	660000	395	16190	126.40
B788	2	502500	248	13530	125.55
B77W	2	775000	392	13649	211.77
BWB	3	491630	400	10186	56.41

Table 6.12: Generation 2 and 3 wide body aircraft comparison (with Boeing aircraft [193] and BWB aircraft [155, 156, 163])

A stagnation in fleet shift from 2040 to 2050 is evident in Tables 6.8 and 6.10. Most opportunities for replacing narrow body flights with train travel or other alternative connections might have already been realized, or have reached a point where only minimal improvements are possible. As a result, fleet shares are not expected to change significantly by 2050. However, the introduction of generation 3 aircraft concepts could potentially alter this trend. Supersonic travel might become commercially viable, allowing for faster air travel over longer distances [191]. At the same time, new aircraft designs with electric propulsion, potentially

reducing overall carbon emissions and noise, might increase the overall travel time [194]. Given the speculative nature of these advancements, forecasting fleet share changes after 2050, particularly with the introduction of generation 3 aircraft, remains highly uncertain.

To assess the specific influence of the generation 3 aircraft on the 2050 forecast for Dublin Airport's aircraft fleet, an alternate scenario is examined by excluding any potential contributions from alternative future aircraft concepts. In this comparative analysis, the around 5 % representation of generation 3 aircraft within the wide body fleet is uniformly redistributed among the existing generation 2 wide body aircraft. Consequently, this redistribution elevates the overall share of generation 2 wide body aircraft to 22.8 %, while maintaining a consistent proportion within the wide body fleet as a whole. This approach allows for a clearer understanding of the distinct impact that generation 3 aircraft introduces to the 2050 fleet composition at Dublin Airport.

It's crucial to acknowledge that the assumptions and estimations made for the year 2050 are subject to potential changes over time. Factors such as economic fluctuations, advancements in aircraft technology, and shifts in traffic patterns could significantly impact the outcomes. Therefore, it's essential to recognize the inherent uncertainty associated with projecting future scenarios and to remain cognizant of the dynamic nature of these variables.

6.4 Results

Table 6.13 displays the modeled scenarios for each year. Due to the short timeline until 2030, only the Base Air Traffic Increase scenario were modeled for all three technology uptake scenarios. For 2040, all scenarios were modeled to analyze the influence of air traffic increase and technology uptake separately. The BA scenarios for 2040 are also compared to 2030. For 2050, the BA BTU scenario, which includes generation 3 aircraft, was modeled. This scenario is compared to a model where all generation 3 aircraft are substituted by generation 2 aircraft (BA BTU no BWB) to assess whether technology uptake makes a difference with an overall fleet share of only 5 %.

For 2040 the combination of the different scenarios results in 9 different possible predictions for Dublin Airport in 2040 (Table 6.14). The two extreme scenarios are Low Technology Uptake (LTU) combined with High Air Traffic Increase (HA) and High Technology Uptake

(HTU) combined with Low Air Traffic Increase (LA). LTU results in louder aircraft in the fleet and combined with a High Air Traffic Increase this scenario is expected to have the biggest noise contour line and thus the highest area and population exposure. On the other hand HTU can be associated with the newest and thus quietest technology. However, the wide body fleet also increases in this scenario, resulting in a bigger percentage of loud (wide body) aircraft. Combined with Low Air Traffic Increase this scenario is still expected to result in low noise exposure in comparison to the other scenarios.

Year	2030			2040			2050		
	LA	BA	HA	LA	BA	HA	LA	BA	HA
LTU		x		x	x	x			
BTU		x		x	x	x		x	
HTU		x		x	x	x			

Table 6.13: Modeled scenarios for 2030, 2040, and 2050 based on combinations of technology uptake and air traffic increase

Technology uptake → Air traffic increase ↓	low	base	high
low	LA LTU	LA BTU	LA HTU
base	BA LTU	BA BTU	BA HTU
high	HA LTU	HA BTU	HA HTU

Table 6.14: 2040 technology uptake (TU) and air traffic increase (A) matrix

The resulting contour lines will be color-coded as per the specifications in Table 6.14. In this section the contour lines for $L_{night} = 40$ dB(A) and $L_{den} = 45$ dB(A), recommended by the WHO [13] are discussed. Population and area exposure is calculated for $L_{night} = 40$ dB(A), $L_{den} = 45$ dB(A), $L_{night} = 50$ dB(A), and $L_{den} = 55$ dB(A). Contour lines for $L_{night} = 50$ dB(A) and $L_{den} = 55$ dB(A) are presented in Appendix B.

6.4.1 2030 Base Air Traffic Increase

In Figure 6.4, the 2030 noise exposure is displayed through a noise map, including noise contour lines. Corresponding area, houses, and population exposure are detailed in Table 6.15 and discussed for $L_{night} = 40$ dB(A) and $L_{den} = 45$ dB(A). It is evident that both L_{den} and L_{night} area and population exposure demonstrate an increase from scenarios with LTU

Scenario	LTU		BTU		HTU	
Exposure	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]
area [km^2]	237.18	212.63	243.44	217.32	256.65	237.71
houses	56286	64970	66158	57695	69329	60766
people	141193	163017	166073	144636	173978	152342

Scenario	LTU		BTU		HTU	
Exposure	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]
area [km^2]	47.31	40.52	48.53	41.42	51.19	43.31
houses	3600	1932	3933	2024	4713	2386
people	9501	4741	10253	4958	12175	5951

Table 6.15: 2030 area and population exposure at Dublin Airport divided into exposure and technology uptake scenario

to HTU. Specifically, in the transition from LTU to BTU scenarios, nighttime exposure area rises by approximately 2.6 %, accompanied by a population increase of 17.6 %. The L_{den} noise contour line expands by 2.6 %, and population exposure increases by 2.4 % when comparing LTU and BTU scenarios. In the High Technology Uptake (HTU) scenario, there is a notable growth in area, 9.4 % for L_{night} and an additional 5.4 % for L_{den} . Concurrently, population exposure in the HTU scenario sees a rise of 4.8 % for L_{night} and 5.3 % for L_{den} .

During nighttime, a shift in the contour lines can be observed in every scenario in comparison to the L_{den} contour line. This can be attributed to the airport's operational strategy of minimizing North Runway usage during nighttime hours. Resulting in a larger contour area around the South Runway and an expansion to the east.

Comparing the 2030 noise contours to 2023, a visible shift in day-evening-night and nighttime noise is visible to the north-west. Aircraft turning right and left after easterly departures have a significant impact, as they are flying over highly populated areas. As per the planned flight routes [39], the right turn from North Runway in westerly departure is shifted back, which causes the contour to move around 2 km to the west as in comparison to 2023. However, due to increasing flight numbers, the L_{den} and L_{night} contour lines in 2030 increase to the west and east. The easterly expansion of contour lines has no significant impact on population exposure, as it expands over the coastline of the Irish Sea. As a result of expanding contour lines, the area extends by another 36 to 80 km^2 in comparison to 2030, affecting an additional 57 900 to 62 500 people, depending on the technology uptake scenario.

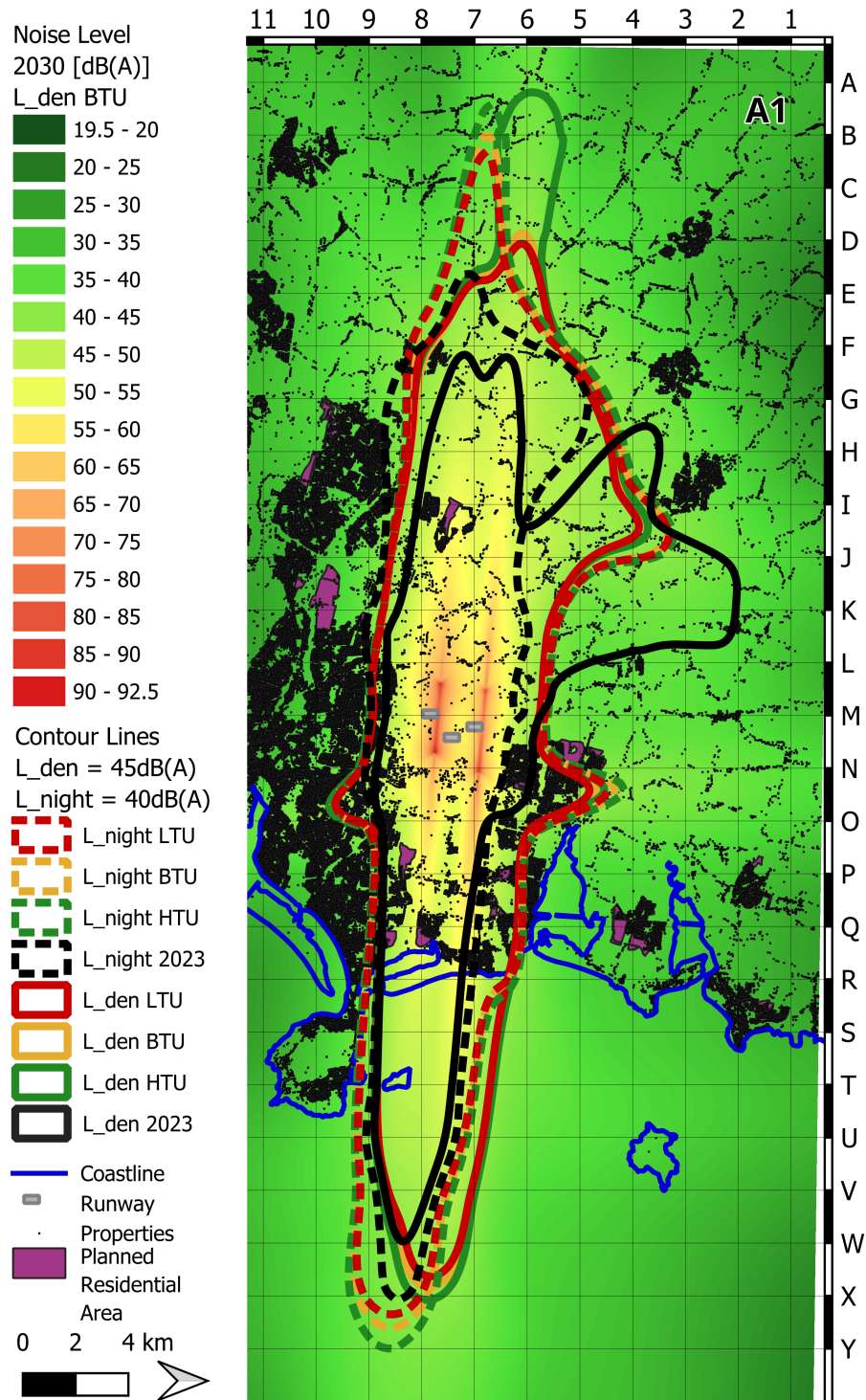


Figure 6.4: 2030 noise map for different technology uptake scenarios with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 40\text{ dB(A)}$ and $L_{den} = 45\text{ dB(A)}$)

6.4.2 2040 Base Air Traffic Increase

Figure 6.5 displays the contours of $L_{den} \geq 45$ dB(A) and $L_{night} \geq 40$ dB(A) for LTU, BTU, and High Technology Uptake (HTU). The corresponding details regarding area and population exposure are presented in Table 6.16. Compared to Base Technology Uptake (BTU), the LTU exhibits a 12.5 % larger area and 22.5 % higher population exposure for $L_{den} \geq 45$ dB(A). Meanwhile, the area exposure for HTU can be decreased by 3.3 %, and population exposure can be reduced by 7 % for the same time slice. The increased area and population exposure in the LTU scenario compared to the other 2040 scenarios shows how important the update and replacement of old aircraft is. The reduction of generation 1 aircraft and their replacement with generation 2 aircraft from the LTU to BTU in 2040 shows how technology uptake can reduce the noise footprint by 12.5 %.

Scenario	LTU		BTU		HTU	
Exposure	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]
area [km^2]	255.69	227.69	224.93	199.30	217.41	192.65
houses	69903	61260	56263	47390	52931	43987
people	175566	153643	141406	118948	133253	110659

Scenario	LTU		BTU		HTU	
Exposure	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]
area [km^2]	51.65	44.31	45.28	38.15	44.4	37.44
houses	4762	2504	3368	1796	3365	1751
people	12306	6230	8358	4317	8363	4228

Table 6.16: 2040 area and population exposure at Dublin Airport divided into exposure and technology uptake scenario

A noteworthy aspect lies in the comparison between the Base Technology Uptake (BTU) scenario in 2030 and the Low Technology Uptake (LTU) scenario in 2040. Despite the fleet shares remaining constant, there is an 11.2 % increase in flight numbers in 2040. The distribution of aircraft generations remains relatively unchanged, implying that the rise in flight numbers is the sole factor contributing to a 5 % increase in the $L_{den} \geq 45$ dB(A) and 4.8 % $L_{night} \geq 40$ dB(A) contour line.

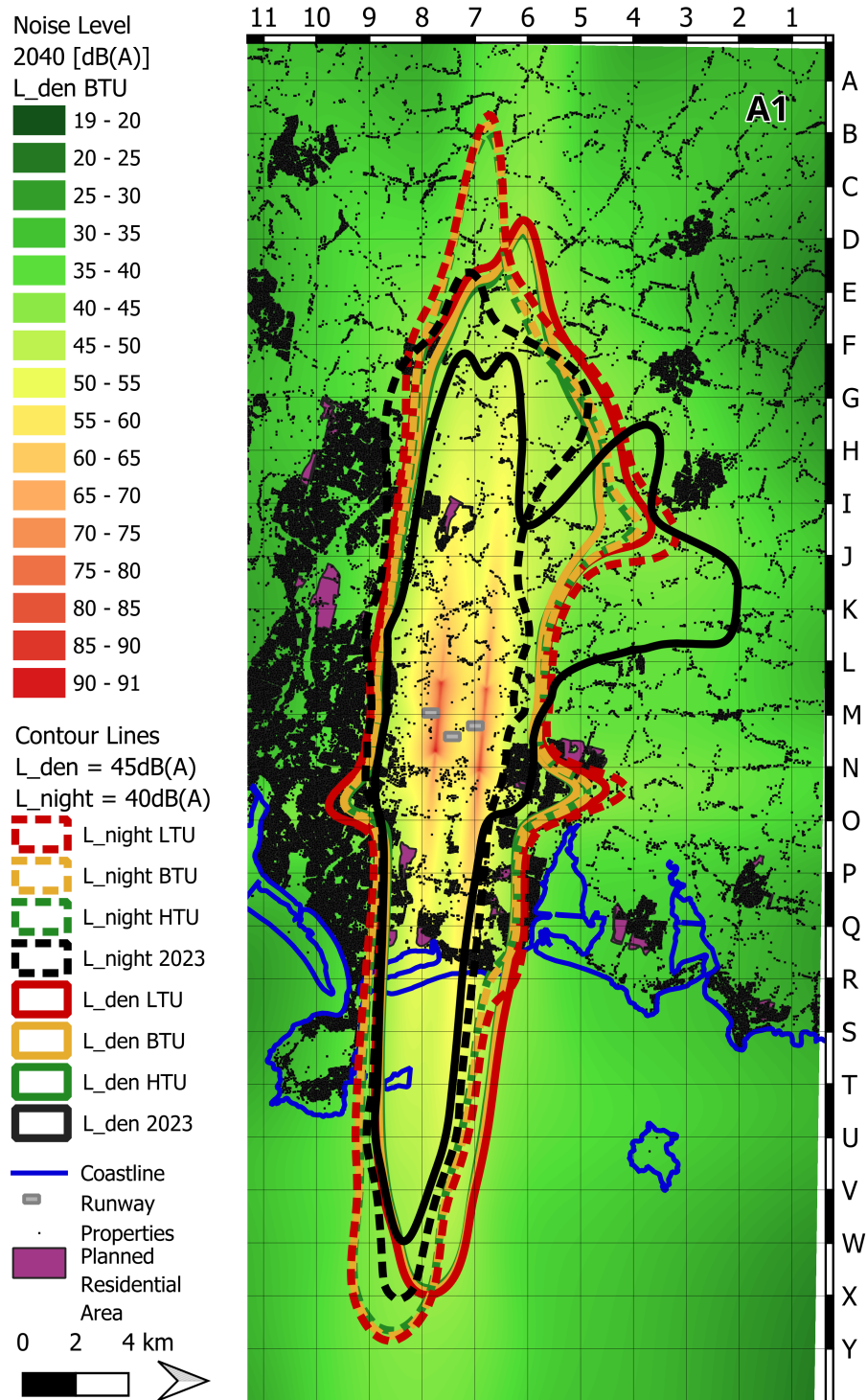


Figure 6.5: 2040 noise map for different technology uptake scenarios with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 40\text{ dB(A)}$ and $L_{den} = 45\text{ dB(A)}$)

The nighttime noise contour lines are significantly larger in 2040 compared to 2023 BTU. With an anticipated increase in the average number of nighttime flights, capped at 105 for this study, and a rise in the presence of wide body aircraft up to 25 %, the area exposure is projected to increase by 31 % to 54 % in 2040 for the HTU and LTU respectively. Notably, advancements in technology contribute to a reduction in the nighttime noise contour line in comparison to the BTU and HTU of 2030.

The 2040 projection indicates that despite a rise in air traffic, overall noise exposure is anticipated to decrease over time. This reduction is attributed to technological advancements and a generation 2 aircraft share ranging from 40 % to 81 % across various 2040 technology uptake scenarios, leading to a decrease in both area and population exposure compared to the levels observed in 2030. However, with an Average Annual Growth Rate (AAGR) = 1.2 %, the number of flights has increased by 30 %. Consequently, the 2040 noise footprint, encompassing both area and population exposure in all technology uptake scenarios, fails to return to the 2023 levels.

6.4.3 2040 all Scenarios

Figures 6.6 and 6.8 display the contour lines for L_{den} and L_{night} , respectively. The contour lines are color-coded as outlined in Table 6.14, noting that the black contour represents the BA BTU scenario. Results are reported for both L_{den} and L_{night} . The background noise map corresponds to the BA BTU scenario for the specified timeframe.

Air Traffic Increase	Exposure	Technology Uptake Scenario					
		LTU		BTU		HTU	
		L_{night}	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}
LA	area	238.62	213.10	210.14	187.47	199.92	178.64
	houses	64606	55571	51802	42956	47648	39245
	people	162134	139349	130206	107939	119867	98745
BA	area	255.69	227.69	224.93	199.30	217.41	192.65
	houses	69903	61260	56263	47390	52931	43987
	people	175566	153643	141406	118948	133253	110659
HA	area	274.27	243.16	241.26	212.28	232.62	204.80
	houses	75614	67330	61333	52134	57802	48514
	people	189959	168855	153982	130830	145382	121865

Table 6.17: 2040 area and population exposure at Dublin Airport for $L_{den} = 45$ dB(A) and $L_{night} = 40$ dB(A) depending on air traffic increase and technology uptake scenario

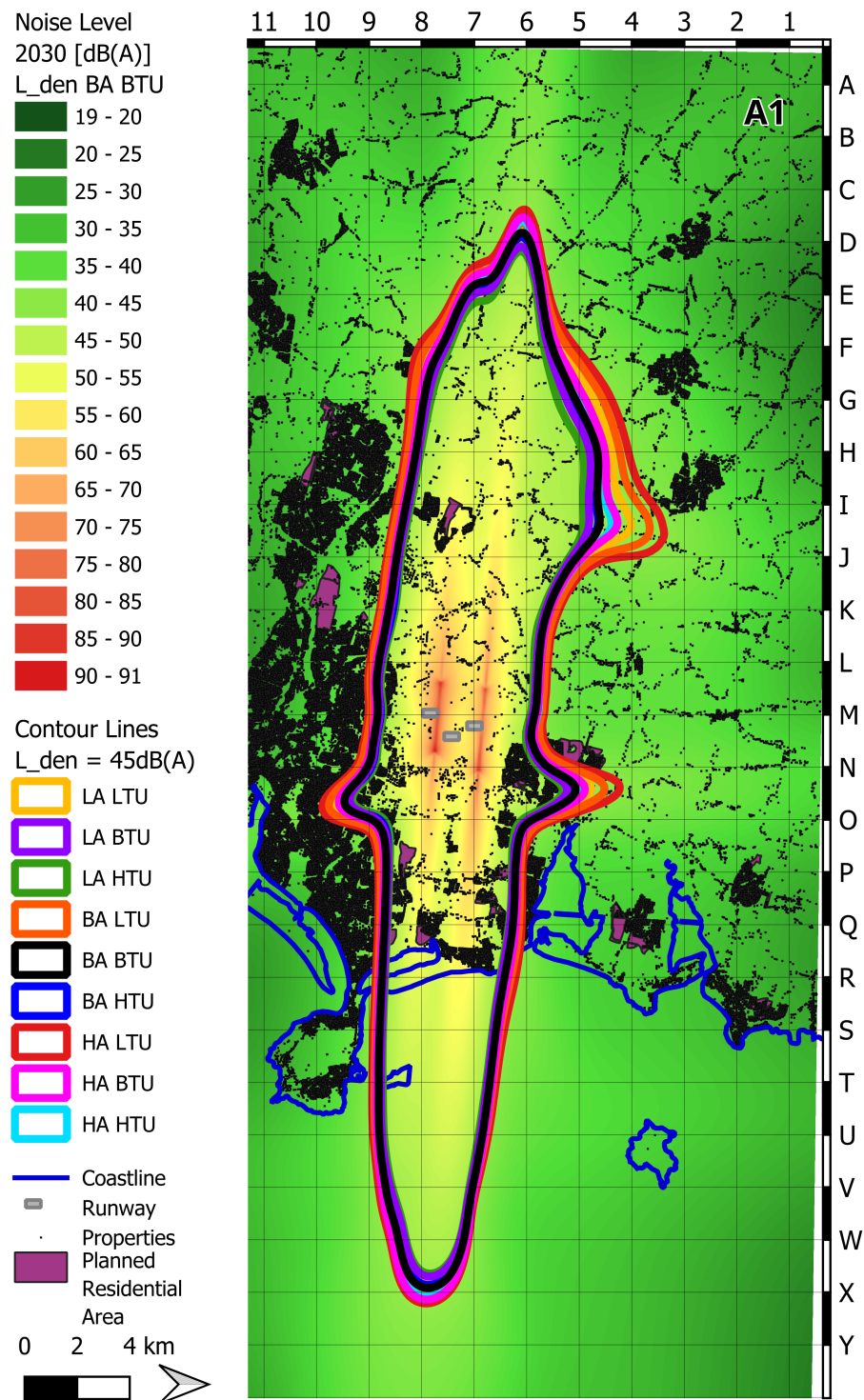


Figure 6.6: 2040 L_{den} contour lines for different technology uptake and air traffic increase combinations at Dublin Airport for $L_{den} = 45\text{ dB(A)}$ with L_{den} BA BTU noise footprint as background

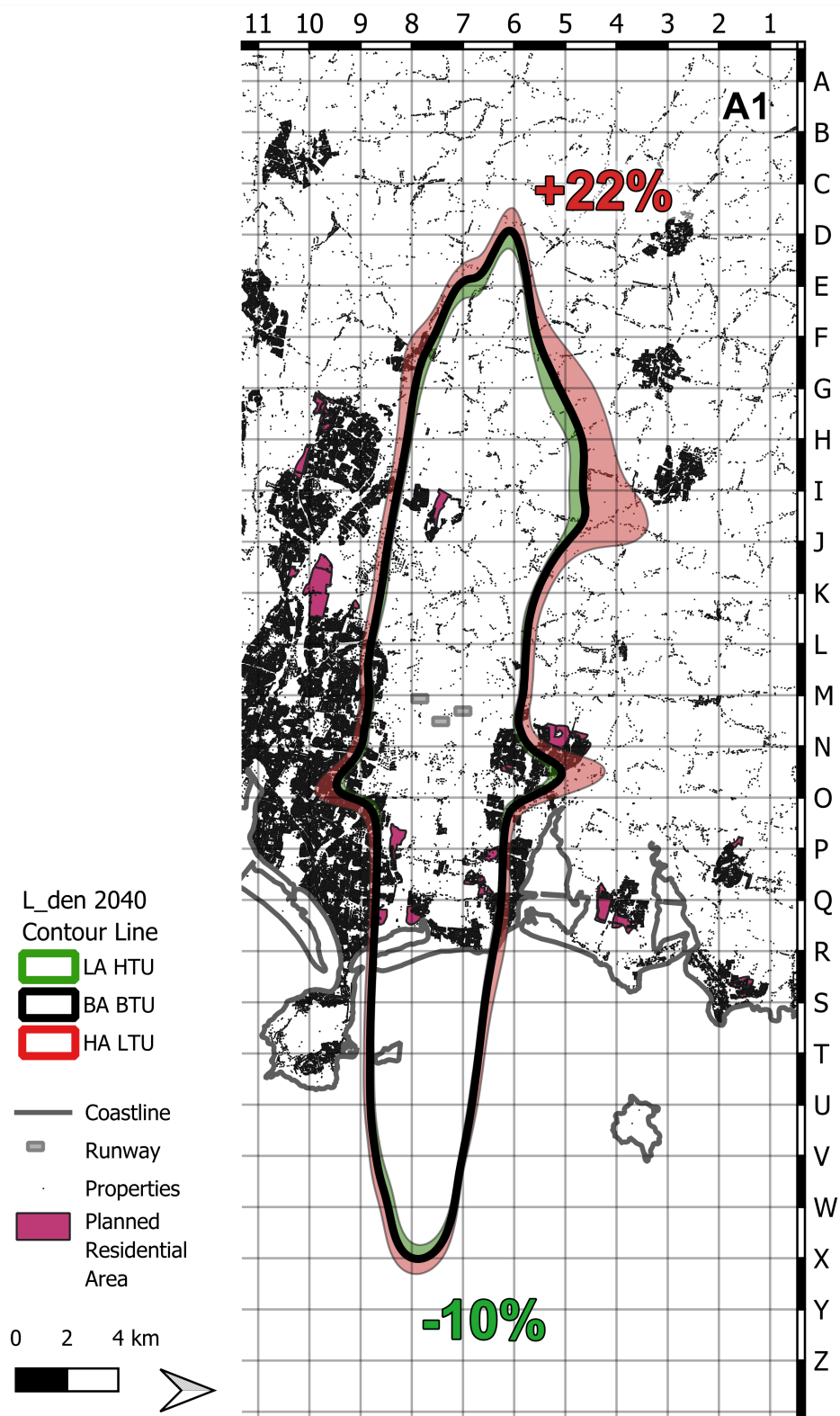


Figure 6.7: Differing impact of area exposure at $L_{den} = 45 \text{ dB(A)}$: comparison of the extreme (LA HTU and HA LTU) and the baseline (BA BTU) scenario contour lines for Dublin Airport for 2040

Table 6.17 presents the population and area exposure for all 2040 technology uptake and air traffic increase scenarios. Since population data was neither forecasted nor extrapolated to 2040, the analysis focuses on area exposure. The percentage change in area exposure is detailed in Tables 6.18 and 6.19.

Air Traffic Increase	Technology Uptake		
	LTU	BTU	HTU
LA	6.93	-5.93	-10.36
BA	14.24	0.00	-3.34
HA	22.01	6.51	2.76

Table 6.18: L_{den} area exposure change [%] compared to BA BTU forecast scenario for 2040

Air Traffic Increase	Technology Uptake		
	LTU	BTU	HTU
LA	6.09	-6.58	-11.12
BA	13.67	0.00	-3.35
HA	21.93	7.26	3.42

Table 6.19: L_{night} area exposure change [%] compared to BA BTU forecast scenario for 2040

Air Traffic Increase	Technology Uptake		
	LTU	BTU	HTU
LA	6.41	5.93	7.27
BA	0.00	0.00	0.00
HA	-6.80	-6.51	-6.31

Table 6.20: L_{den} area exposure change [%] based on the Base Air Traffic Increase (BA) scenarios for 2040 for Dublin Airport

Air Traffic Increase	Technology Uptake		
	LTU	BTU	HTU
LA	13.67	0.00	-4.71
BA	14.24	0.00	-3.34
HA	14.55	0.00	-3.52

Table 6.21: L_{den} area exposure change [%] based on the Base Technology Uptake (BTU) scenarios for 2040 for Dublin Airport

The area exposure for the BA BTU scenario is 199.30 km² for L_{den} and serves as a baseline in this analysis.

Examining the contour lines (Figures 6.6 and 6.8) reveals that the HA LTU scenario has the highest area exposure and the most pronounced contour lines, particularly after right and left turns when departing from the North and South Runways to the east (N4:6 and N9). The contour line for the right turn after departure from the North Runway to the west also extends the furthest in the HA LTU scenario (H3:I4). This is expected, as the HA LTU

scenario indicates the highest air traffic increase combined with the lowest technology uptake, featuring the noisiest aircraft. Consequently, this results in the largest contour line, with an area exposure of 243.15 km^2 for L_{den} , representing an increase of 22 % from the BA BTU scenario.

All scenarios investigated show significant changes in contour lines, with each scenario covering a different area. The contour line for LA BTU is situated between the LA HTU and BA HTU contour lines, while the BA BTU line is positioned between the BA HTU and HA HTU contour lines.

The HA BTU contour line lies between the LTU and HTU scenario contour lines. This shift of the BTU contour lines towards the HTU contour lines indicates that the gap between the LTU and BTU scenarios is larger than that between the BTU and HTU scenarios.

The LA HTU scenario, which combines the lowest air traffic increase with the highest technology uptake, is depicted in Figure 6.7. As expected, this scenario results in the smallest noise contour, being 10.4 % smaller than the baseline scenario. The LA HTU and HA LTU scenarios are anticipated to show extremes, as they represent opposite combinations of technology uptake and air traffic growth. In the worst-case scenario, HA LTU, the noise contour expands by 22 % compared to the baseline scenario.

Table 6.20 is separating air traffic increase from technology uptake and examining the area exposure change for the LTU scenario reveals that the change in area exposure from the BA LTU scenario is consistent in either direction. The difference in area exposure change from BA to LA is approximately 6.4 %, while the change from BA to HA is around 6.8 %. The changes from BA to LA and from BA to HA for the BTU and HTU scenarios also fall between 5.9 % to 7.3 %.

In contrast, the trend for changes in technology uptake is different, as seen in Table 6.21. For all air traffic increase scenarios, the change from BTU to LTU ranges from 13.7 % to 14.6 %, while the change from BTU to HTU ranges from 3.3 % to 4.7 %. This indicates that the change from LTU to BTU has a greater impact than the change from BTU to HTU.

The change of generation share from Table 6.9 between LTU and BTU, and BTU and HTU is approximately evenly distributed. This suggests that the change in area exposure does not result from an asymmetric shift in aircraft generation between the scenarios. In terms of fleet change, the distribution is also evenly divided among the scenarios, indicating that the combination of generation and fleet change could significantly influence area expo-

sure. Focusing on the narrow body fleet, the overall fleet share changes from 72 % (LTU) to 66 % (BTU) to 60 % (HTU). Simultaneously, the share of generations 0 and 1 decreases significantly, while the share of generation 2 increases from 35 % (LTU) to 44 % (BTU) to 51 % (HTU). Although the narrow body fleet diminishes towards the HTU scenario, the proportion of generation 2 aircraft rises substantially. The wide body fleet exhibits a similar increase in generation 2 share, with the overall share rising from 5 % (LTU) to 15 % (BTU) to 23 % (HTU). Notably, the total wide body fleet increases in increments of 5 %, from 15 % to 20 % to 25 %. The significant change in area exposure from LTU to BTU and the smaller change from BTU to HTU indicate a threshold beyond which technology uptake has diminishing returns on area exposure. The combination of overall quieter aircraft and a shift toward larger (wide body) and noisier aircraft [5] may contribute to the uneven distribution of noise contours.

Furthermore, technological advancements are expected to enhance the overall noise performance of the fleet. However, as demonstrated in these scenarios, such advancements often coincide with fleet changes. Consequently, the anticipated noise reductions may be less significant than expected, resulting in minimal overall improvement. This realization could diminish the motivation to transition to newer aircraft concepts.

Comparing the change in area exposure for the LA LTU and HA HTU scenarios to the baseline scenario reveals that the increase from BA BTU to LA LTU is 6.9 %, while the increase to HA HTU is 2.7 %. The inconsistency in change along the diagonal of the scenarios can be attributed to the previously discussed factors: the air traffic increase (or decrease in the case of the LA scenario) contributes roughly the same amount to the change towards LA or HA. However, the impact of technology uptake is significantly greater from LTU to BTU than from BTU to HTU, resulting in an uneven distribution of change in area exposure across the scenarios.

The nighttime area exposure and nighttime noise contour lines at $L_{night} = 40 \text{ dB}(A)$ exhibit a similar trend to those at L_{den} (Figure 6.8). During nighttime, the preferred usage of the South Runway is evident from the extent of the contour line along this runway (A6:E7 and S7:Y9). The pronounced right turn after departure from the North Runway to the west is also notable (G3:J4). While the contour lines for the nine different scenarios maintain the same shape, the extent of the contours along the flight paths varies.

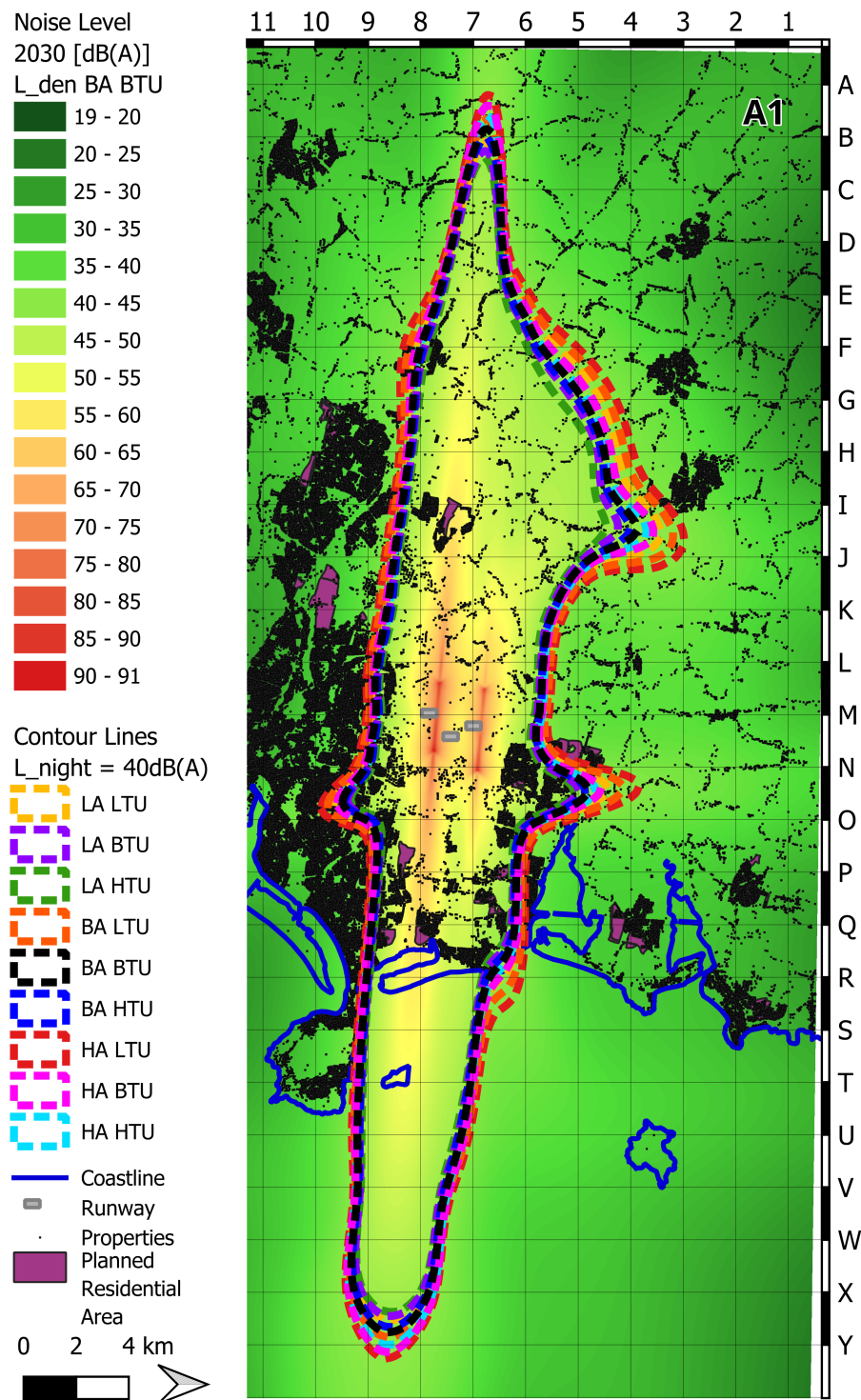


Figure 6.8: 2040 L_{night} contour lines for different technology uptake and air traffic increase combinations at Dublin Airport for $L_{night} = 40\text{dB(A)}$ with L_{night} BA BTU noise footprint as background

The relative change in area exposure remains nearly the same as for L_{den} . The significant difference between L_{den} and L_{night} lies in the noise distribution. Changes in runway usage are clearly reflected in the contour lines, which expose different areas to high levels of noise. It is important to note that nighttime noise exposure is also included in L_{den} , contributing to the total (8-hour nighttime period). However, the number of flights during nighttime is significantly reduced. Despite the low number of nighttime flights the $L_{night} = 40 \text{ dB}(A)$ contour line has a greater extent than $L_{den} = 45 \text{ dB}(A)$, reflecting the fact that nighttime noise exposure has a greater health impact [13]. The average area exposure is 12.7% higher during L_{night} compared to L_{den} .

The HA LTU and LA HTU scenarios represent the two extremes (Figure 6.7), outlining the inner and outer boundaries of the nine different scenarios. The HA LTU contour line presents a noise contour that is 74 km^2 larger than that of the HA LTU scenario, reflecting a difference of 37 %.

The area exposure for HA LTU increases by approximately 22 % in comparison to the BA BTU scenario for $L_{night} = 40 \text{ dB}(A)$ (Figure 6.7). Conversely, with the LA HTU scenario, the contour line can be decreased by 11 %. Since the relative fleet and generation distribution, as well as the relative flight numbers for day and night, remain unchanged between the scenarios, the changes in area exposure among technology uptake and air traffic increase show a similar trend to that observed for the daytime-evening-nighttime area exposure. Specifically, the technology uptake from LTU to BTU has a greater impact than the change from BTU to HTU, while the air traffic increase exhibits an even distribution.

Overall, the transition from LTU to BTU significantly impacts area exposure, while the change from BTU to HTU results in a smaller difference between the scenarios. The increase in air traffic uniformly affects all technology adoption scenarios, making its impact easier to predict. In contrast, technology uptake encompasses both fleet share and generation share, leading to a more complex calculation. This study demonstrates that technology uptake remains crucial until a certain threshold is reached, beyond which new aircraft concepts (generation 3) are necessary to effect substantial changes in the overall noise footprint.

Examining the general deviation from the baseline scenarios L_{den} and L_{night} , only three scenarios show a difference greater than 10 %: LA HTU, BA LTU, and HA LTU. Given the uneven distribution of influence of technology uptake, it is crucial to model extreme scenarios

alongside a baseline. This approach highlights the innermost and outermost contour lines, providing insight into the range of potential impacts and variations in noise exposure.

6.4.4 2050 Base Air Traffic Increase and Base Technology Uptake

This study primarily focuses on assessing area exposure of airport noise, recognizing that the complexity and uncertainty in predicting population exposure for 2040 and 2050 are linked to challenges in forecasting building data. Accurate predictions are highly dependent on factors such as changes in land use, urban development, and construction activities, which are subject to dynamic and evolving scenarios. Without comprehensive forecasts for building data, the assessment of population exposure becomes inherently uncertain. Consequently, it is expected that the challenges associated with predicting future population exposure will persist and that the absence of building data forecasts could lead to an underestimation of the true impact. In the absence of specific projections, it is reasonable to expect an increase in population exposure, given the historical correlation between urban development and heightened noise levels around airports.

The contour lines L_{night} and L_{den} for different years and 2050 scenarios are shown in Figure 6.9. Residential property data from 2023 [141] is combined with population data from 2022 [140].

Table 6.22 displays population and area exposure with and without future aircraft concepts in 2050, in addition to 2023 reference contour lines. In the particular scenario of Dublin Airport, the contour lines intersect with the Irish Sea, as depicted in Figure 6.9 (Q6:R10). This circumstance implies that up to 30 % of the noise contours are not pertinent to the surrounding population. However, this work presents findings based on the complete contour analysis.

Air traffic is assumed to increase by around 47 % from 2023 to 2050. At the same time, the $L_{den} = 45$ dB(A) contour line is projected to increase around 32 % to 2050 without Blended Wing Body (BWB) scenario. Comparing the 2050 with and without BWB aircraft contour lines reveals, that the $L_{den} = 45$ dB(A) contour line can be decreased by around 5.3 % and the $L_{night} = 40$ dB(A) contour line around 5.0 % when integrating the BWB aircraft at a share of around 4.9 % into the fleet.

This disproportionate rise can be attributed to the substantial growth in generation 2 aircraft. Additionally, the introduction of BWB aircraft in 2050 contributes to the upswing

Scenario	2023		2050		2050 no BWB	
Exposure	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]	L_{night} [40 dB(A)]	L_{den} [45 dB(A)]
area [km^2]	165.66	171.48	239.61	214.10	252.29	226.01
houses	38083	30334	53032	44016	55987	46520
people	93352	77377	133847	109885	140721	116759

Scenario	2023		2050		2050 no BWB	
Exposure	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]	L_{night} [50 dB(A)]	L_{den} [55 dB(A)]
area [km^2]	29.65	29.35	43.93	37.30	46.53	39.62
houses	2555	1296	3339	1800	4123	2151
people	6012	2771	9343	5303	10084	5218

Table 6.22: 2023 and 2050 BA BTU area and population exposure at Dublin Airport

in generation 3 aircraft. Moreover, the absence of generation 0 in the 2050 fleet share is anticipated, while the proportion of generation 1 is expected to decrease to below 15%. These trends highlight the evolving aircraft fleet composition and underscore the significance of future aircraft concepts in shaping the aviation landscape.

The increasing flight numbers in 2050 induce notable changes in the shape of the noise contours for both day and nighttime operations. Given the preference for the North Runway during western operations [124], which account for approximately 70 % [39] of aircraft movements, the L_{den} contour line for 2050 extends westward by approximately 6 km (A5:F8). Unlike in 2023, the right turn after departure from the North Runway to the west (F4:K6) is less pronounced in 2030, 2040, and 2050, due to adjusted flight routes designed to circumvent populated areas. This mitigation of the right turn is evident in both the night and daytime contour lines. While the L_{den} and L_{night} contour lines continue to expand eastward over the Irish Sea (R6:Z9) in 2050 due to increasing flight numbers, additional areas, and consequently populations, are expected to be exposed to aircraft noise to the northeast of Dublin Airport (N5:Q6). Changes in aircraft routes also result in additional peaks to the north (N5) and south (N9) of the airport due to early turns from both runways. During nighttime operations, the South Runway becomes the preferred runway [39], leading to an extension of the L_{night} contour line to the southwest of the 2050 L_{den} contour line. Comparing the $L_{night} \geq 50$ dB of 2023 and 2050, the area exposure increases around 48.2 % (with BWB) to 56.9 % (without BWB), attributed to the rise in nighttime flights from 65 to 115.

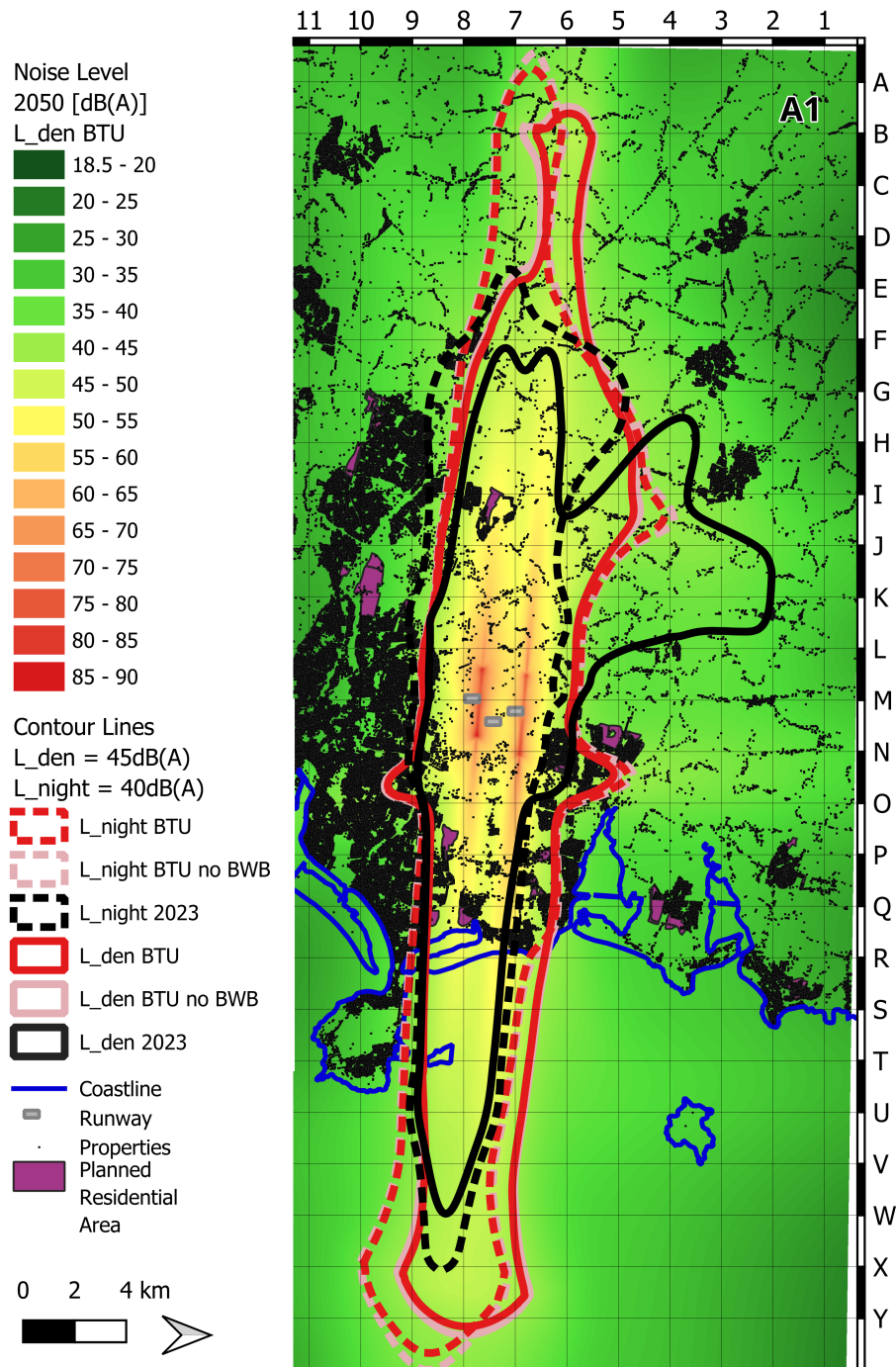


Figure 6.9: 2050 noise map for different technology uptake scenarios with and without future aircraft concepts with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 40 \text{ dB(A)}$ and $L_{den} = 45 \text{ dB(A)}$)

6.4.5 Comparison of Base Air Traffic Increase Base Technology Uptake Scenarios 2030 to 2050

The BA BTU scenarios for the years 2030, 2040, and 2050 provide a meaningful comparison, as all aircraft follow the same flight routes, and the same runway distribution is used across each scenario. As a result, the only variables that change between the years are air traffic and technology uptake. While air traffic is projected to increase by over 12.5% between the decades, the adoption of quieter technologies helps to mitigate the overall aircraft noise generated by Dublin Airport. A comparison of the noise contours across different years is shown in Figure 6.10.

Over the course of the scenarios, the share of narrow body aircraft at Dublin Airport decreases from 72 % in 2030 to 63 % in 2050. In contrast, the share of wide body aircraft increases from 15 % to 24 % during the same period. The regional jet fleet is expected to grow from 6 % in 2030 to 11 % by 2050, while the turboprop fleet share declines from 6 % to 3 % over the same timeframe. In terms of aircraft generation, 19 % of generation 0 aircraft are expected to operate at Dublin Airport across all fleets in 2030. These older aircraft will be gradually replaced by newer, more efficient models, with the share of generation 0 aircraft dropping to 6 % by 2040 and reaching zero by 2050. At the same time, the share of generation 1 aircraft decreases from 42 % in 2030 to 12 % in 2050. Generation 2 aircraft, which replace the older generations, will see a significant increase, rising from 39 % in 2030 to 83 % by 2050. Generation 3 aircraft, which are expected to enter service by 2050, will make up approximately 5 % of the fleet in the BTU scenario.

Table 6.23 compares the area and population exposure to different noise levels under the BA BTU scenarios for 2030, 2040, and 2050.

Figure 6.10 displays the BA BTU scenarios for 2030, 2040, and 2050, in addition to the 2023 contour lines for $L_{den} = 45 \text{ dB(A)}$ and $L_{night} = 40 \text{ dB(A)}$. It is evident that the 2023 noise contour shape significantly differs from the predicted noise contour lines. This can be explained by the fact, that the planned routes for 2025 were used for airport noise prediction for Dublin Airport, while the 2023 noise contour lines deviated from the planned ones. In addition, the 2030 noise contour lines cover a significantly larger area than the ones for 2023. In 2040 a slight decrease in noise level can be observed, which is only slightly visible on the maps. The 2050 contour line experiences another slight increase from 2040, indicating a small

Year	2030		2040		2050	
Movements	244635		275527		310548	
Exposure	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}
	[40 dB(A)]	[45 dB(A)]	[40 dB(A)]	[45 dB(A)]	[40 dB(A)]	[45 dB(A)]
area [km^2]	243.44	217.32	224.93	199.30	239.61	214.10
houses	66158	57695	56263	47390	53032	44016
people	166073	144636	141406	118948	133847	109885
Exposure	L_{night}	L_{den}	L_{night}	L_{den}	L_{night}	L_{den}
	[50 dB(A)]	[55 dB(A)]	[50 dB(A)]	[55 dB(A)]	[50 dB(A)]	[55 dB(A)]
area [km^2]	48.53	41.42	45.28	38.15	43.93	37.30
houses	3933	2024	3368	1796	3339	1800
people	10253	4958	8358	4317	9343	5303

Table 6.23: Area and population exposure comparison for BA BTU scenarios for 2030, 2040, and 2050 at Dublin Airport

change in aircraft generation, while managing the same relative air traffic increase as from 2030 to 2040.

Figure 6.10 illustrates the BA BTU scenarios for 2030, 2040, and 2050, alongside the 2023 contour lines for $L_{den} = 45$ dB(A) and $L_{night} = 40$ dB(A). A clear discrepancy is observed between the 2023 and predicted noise contours, which can be attributed to the fact that the 2025 planned flight routes were used for noise predictions at Dublin Airport, while the 2023 noise contours were based on actual radar tracks, which partially deviated from those planned routes. Moreover, the 2030 noise contours encompass a significantly larger area compared to 2023, reflecting projected increases in air traffic and aircraft operations. In 2040, a slight reduction in noise levels is noted, although this change is only marginally visible in the maps. The 2050 contours show a small increase from the 2040 contours, driven by gradual technological advancements and small changes in aircraft generation while maintaining a similar relative increase in air traffic as from 2030 to 2040. This demonstrates the ongoing impact of technology uptake on noise mitigation and aircraft performance over time.

From 2030 to 2040, the area exposed to noise decreases on average by around 7.6 % for each displayed noise contour in Table 6.23. At the same time, the population exposure is significantly reduced. For example, population exposure at $L_{den} = 45$ dB(A) was reduced by 17.8 %, while it only decreased by 12.9 % at $L_{den} = 55$ dB(A). This almost 5 % difference highlights the importance of considering different noise levels in exposure assessments. The noise level of $L_{den} = 45$ dB(A) is the threshold recommended by the WHO for assessing

the population exposed to harmful levels of noise [13]. Although this practice is not yet widespread, it is essential as it captures individuals who are exposed to potentially harmful noise levels. Simultaneously, the 12.6 % increase in air traffic, coupled with the adoption of quieter aircraft through technology uptake until 2040, underscores the effectiveness of noise mitigation strategies enabled by new, quieter technologies.

From 2040 to 2050, an increase in the contour lines for $L_{den} = 45$ dB(A) and $L_{night} = 40$ dB(A) can be observed. This indicates that, despite advancements in technology, the rise in air traffic has a significant impact on noise levels. By 2050, no generation 0 aircraft are projected to operate under the BA BTU scenario, compared to approximately 11 % in 2040. At the same time, the share of generation 2 aircraft in the fleet is expected to grow from 60 % in 2040 to approximately 83 % in 2050 for baseline scenarios. While this generational shift is substantial, the addition of 5 % generation 3 aircraft, represented by the BWB, also contributes to a smaller overall 2050 noise footprint, particularly for the expanding wide body fleet. When comparing the 2050 BA BTU scenario with the BA BTU no BWB scenario, the data clearly demonstrates that even a 5 % shift in fleet composition toward newer aircraft generations can lead to a noticeable reduction in noise exposure.

Figure 6.10 illustrates the planned residential areas around Dublin Airport in relation to the projected noise contours. Some of the proposed residential zones, such as G9, H10, J:K9, J10, and Q3:4, fall outside the noise contour of $L_{den} = 45$ dB(A). However, there are also several residential areas planned within this contour, including I7, N6, O8, P6, and Q7:9. Additionally, a residential area is planned near the edge of the predicted noise contour for the 2030 to 2050 period, specifically in the M4:5 area.

While the development of new residential areas is crucial in addressing the ongoing housing crisis in Dublin [195], the decision to plan residential zones within airport noise contours [142] is questionable, given the potential impact of noise on residents. It may be more appropriate to designate these areas for industrial development rather than for residential use.

Based on the noise map in Figure 6.10, there appear to be several communities outside the (predicted) noise contours that could be expanded. Specifically, areas such as Dunshaughlin (C2:D3), Ratoath (F2:3), and Ashbourne (H2:I3) could provide opportunities for growth. These towns are located to the northwest of Dublin Airport, meaning they may have limited direct connectivity to Dublin City Centre. On the south side of the airport, communities

such as Blanchardstown (G8:J10) could also further expand the planned residential zones in J:K9.

However, this analysis is based solely on the noise map and does not account for factors such as local infrastructure, zoning regulations, or other land-use considerations, all of which are essential when evaluating the feasibility of expanding a community.

Noise is expected to continue increasing until 2030. However, in the Base Air Traffic Increase scenario for 2040, it is possible to mitigate the overall noise footprint even as air traffic numbers rise. Comparisons between the planned scenario and the 2023 scenario are complicated, as aircraft in 2023 have deviated from the planned flight paths, resulting in significant differences in both population exposure and the shape of the noise contours. This is especially noticeable after the right turn from the North Runway in the westerly direction.

The increasing number of flights until 2050 complicates efforts to reduce noise, as the rising traffic volume exacerbates the overall impact. On a positive note, the current deviations from the planned flight paths provide an opportunity to improve the noise situation from 2040 onward. However, returning to the noise levels observed in 2023 will be very challenging. While mitigation measures can help reduce the noise footprint, achieving a reversal of these changes will require substantial adjustments to both flight paths and operational strategies.

From 2023 to 2030, the $L_{\text{den}} = 45 \text{ dB(A)}$ contour line is projected to expand by approximately 27 %, compared to an increase of around 16 % from 2023 to 2040 for the same contour line. At Dublin Airport, the 2050 contour line is expected to expand by approximately 15 % relative to 2023. In contrast, the nighttime area exposure at $L_{\text{night}} = 40 \text{ dB(A)}$ is projected to increase significantly, by around 47 % by 2030, 37 % by 2040, and approximately 30 % by 2050. The significant increase in nighttime area exposure, reaching nearly 50 % by 2030, can be attributed to the rise in nighttime flights. In this study, the number of nighttime flights is projected to grow to 115 by 2050, resulting in elevated nighttime noise exposure with current aircraft types. While the adoption of newer aircraft generations can mitigate the overall nighttime noise impact, non-acoustic effects continue to rise. This underscores the need for stricter nighttime flight restrictions to protect residential areas surrounding the airport.

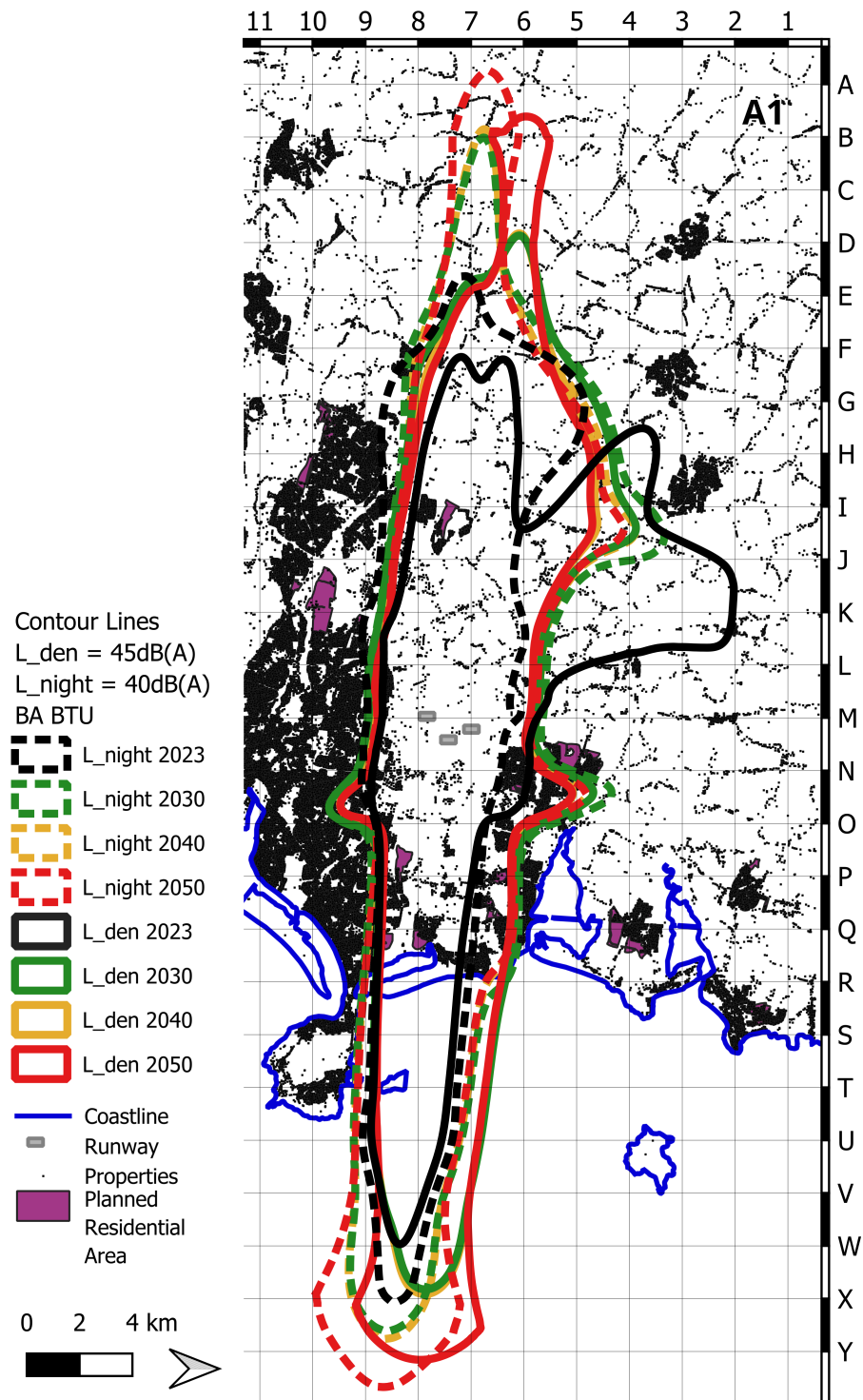


Figure 6.10: Noise contours for BA BTU for 2023, 2030, 2040, and 2050 at Dublin Airport (for $L_{night} = 40\text{ dBA}$ and $L_{den} = 45\text{ dBA}$)

6.5 Discussion

The interaction between airports, airlines, manufacturers, and legislators plays a crucial role in managing aviation noise and advancing technology. Each stakeholder faces unique challenges and incentives, with the common goal of balancing operational efficiency, economic growth, and environmental impact. Legislative measures are key to accelerating the adoption of quieter, next-generation aircraft, ensuring sustainable progress in the industry.

Airports impose noise charges per aircraft movement, depending on the noise category of the aircraft. Louder aircraft incur higher noise charges, and airports have the authority to ban certain aircraft. For example, Dublin Airport has banned ICAO category 2 aircraft, a noise categorization determined during the noise certification process [39]. Aircraft in ICAO category 2 would primarily fall under generation 0. The goal for airports is to minimize the overall noise contour and stay within set limits. Louder aircraft contribute disproportionately to the noise footprint. By operating quieter aircraft, more flights can be accommodated without exceeding noise limits. However, generation 3 aircraft may require modifications to runways and gates due to potential changes in airframe dimensions. Alternatively, these aircraft could park remotely, leading to increased use of passenger transport buses and additional infrastructure changes.

Airlines aim to minimize operating costs. Newer, quieter aircraft also have lower fuel consumption due to advancements in materials and technology [5]. As a result, these aircraft incur lower noise charges per movement, contributing to cost-efficient operations. However, airlines must first invest in purchasing these expensive new aircraft, which poses a significant upfront cost.

Manufacturers benefit only if airlines purchase aircraft. With rising air traffic, the demand for more aircraft exists, though not necessarily for newly developed models. Research and development is expensive and time-consuming, and will only benefit manufacturers if the technological improvements justify the high costs. There may be a preference for minor changes, such as aircraft variations or configurations, rather than the development of a new model.

Residents benefit primarily from reduced noise contour lines, as their health is directly impacted by living in close proximity to airports [13]. They advocate for quieter aircraft, fewer or limited aircraft movements, operational restrictions, and noise mitigation measures.

However, their influence on decisions regarding the implementation of new aircraft is limited, with little direct input in shaping aviation policies.

To drive technological advancement in the aircraft industry, external pressure from legislation is necessary. Legislators must balance protecting residents near airports with promoting economic growth. This requires setting noise limits while encouraging increased flight numbers. The integration of quieter aircraft into airline fleets is essential.

From 2023 to 2030, BA BTU area exposure is expected to increase by approximately 27% for $L_{\text{den}} \geq 45 \text{ dB(A)}$. This indicates that, even with moderate technology uptake and air traffic increase, Dublin Airport will impact a larger area in terms of noise exposure in the coming years. A decrease in contour lines and thus area and population exposure is expected from the 2030 LTU to HTU driven by technology improvements leading to noise reduction. However, a contrasting trend is evident in Table 6.15, where there is a clear increase in both aspects. This can be explained by looking at fleet shares for the different technology uptake scenarios for 2030. While narrow body, regional jet, and turboprop fleet shares decrease in the overall fleet at Dublin Airport, there is a notable increase in the wide body fleet share from 9% to 22%. As indicated in Figure 2.5, wide body aircraft can exhibit a significantly larger noise footprint compared to smaller aircraft types. This fleet share shift results in higher noise contribution from wide body aircraft and thus, increases noise footprints with quicker technology uptake. This development shows that rapid technology uptake does not necessarily result in a smaller overall noise contour. From 2030 to 2040, area exposure is expected to decrease by approximately 8.3% for $L_{\text{den}} \geq 45 \text{ dB(A)}$ in the BA BTU scenarios. This reduction highlights the positive impact of technology uptake, even as the number of flights continues to rise. It suggests that advancements in aircraft technology, such as quieter engines, can mitigate the effects of increased air traffic, providing a more sustainable noise environment despite growth in airport operations.

An interesting observation arises when comparing the 2030 BA BTU scenario with the 2040 BA LTU scenario. The only difference between these scenarios is the number of flights, as fleet shares remain unchanged, indicating no technology uptake. Despite an approximate 11.2% increase in the number of flights, area exposure only increased by around 5%. This suggests that while more flights result in greater noise exposure, the increase in area impacted is not directly proportional to the rise in air traffic. The lack of technology uptake in the 2040 BA LTU scenario means that any potential noise reduction from quieter aircraft is not

realized, yet the overall noise footprint still grows at a slower rate than the increase in flights. This highlights the complexity of balancing air traffic growth with noise exposure, suggesting that factors beyond the number of flights, such as flight paths or operational adjustments, may also play a role in mitigating noise impacts.

Between the extreme scenarios Low Air Traffic Increase HTU and HA LTU in 2040, changes of approximately -22% and 10.4% , respectively, were observed relative to the 2040 BA BTU baseline for $L_{\text{den}} = 45 \text{ dB(A)}$. Because all combinations of air traffic increase and technology uptake were modeled for 2040, the individual impacts of these two factors could be assessed independently. The analysis revealed that air traffic increase has a relatively balanced effect on area exposure. The change in area exposure from the LA or HA scenarios to the BA scenario was approximately equal, regardless of the level of technology uptake. In contrast, the influence of technology uptake was not evenly distributed. Moving from BTU to LTU resulted in an average increase in area exposure of around 14.15% , while the reduction from BTU to HTU was only around 3.86% across all air traffic increase levels. This highlights the complex and asymmetrical role of technology uptake. In this study, technology uptake refers to both the aircraft generation and the associated fleet share. While newer aircraft generations tend to be quieter, the proportion of wide body aircraft, typically the loudest, also increases within the technology uptake scenarios. This can dampen the positive effect of quieter aircraft, leading to less pronounced reductions in noise exposure. These findings underscore the importance of carefully managing fleet composition alongside technological improvements. Simply adopting newer aircraft is not sufficient if the mix of aircraft types includes a greater share of high-impact noise sources. Therefore, future planning and noise mitigation strategies should consider not only the adoption of quieter technologies but also the structure of the fleet, particularly the share of wide body aircraft. The finding that the overall impact of technology uptake may be smaller than expected could be discouraging. However, it emphasizes the need for realistic expectations and a more comprehensive approach to noise mitigation that includes operational strategies, regulatory frameworks, and careful fleet planning alongside technological advancements.

For $L_{\text{den}} = 45 \text{ dB(A)}$, area exposure is projected to increase by approximately 25% from 2023 to 2050 when assuming the introduction of generation 3 aircraft (BWB). Without BWB, this increase reaches around 32% . The change from the 2040 BA BTU scenario to 2050 is particularly noteworthy. Despite continued technology uptake, area exposure still increases by

approximately 13.4 % without BWB, and by about 7.4 % even with the inclusion of generation 3 aircraft. This can be attributed to the increase in air traffic and the shift toward a greater share of wide body aircraft, which is a component of the overall technology uptake.

The 5 % reduction in area exposure when introducing generation 3 aircraft to the 2050 fleet, compared to the 2050 scenario without BWB, demonstrates the positive impact that quieter generation 3 aircraft can have on noise levels. However, it is important to note that despite this improvement, area exposure still increases relative to both the 2040 and especially the 2023 scenarios.

These findings suggest that while advanced aircraft technologies, such as BWB, can help mitigate noise to some extent, they are insufficient on their own to fully offset the impacts of rising air traffic and changes in fleet composition. Therefore, it is crucial to integrate a variety of strategies, including optimizing flight procedures, implementing effective land use planning, and managing traffic volumes, to achieve long-term noise reduction around airports.

As demonstrated by this analysis, the noise reduction benefits of generation 2 aircraft are substantial up until 2040. However, from 2040 to 2050, further gains become minimal, as the fleet will predominantly consist of generation 2 aircraft, leaving limited opportunities for additional technological improvements. To overcome this, legislation will be crucial in expediting the adoption of generation 3 aircraft. Furthermore, comprehensive long-term planning is vital to ensure the efficient operation of airports, assist airlines in their procurement decisions, and provide local communities with the information they need for informed urban development, particularly in areas impacted by noise.

6.6 Summary

Aircraft noise at Dublin Airport was predicted for the years 2030, 2040, and 2050 under different air traffic growth and technology uptake scenarios. The forecast indicates an increase in air traffic until 2030, a possible reduction to 2040, and another increase until 2050, with an average annual growth rate (AAGR) of 1.2 % in the Base Air Traffic Increase scenario. This growth is accompanied by a trend towards a smaller narrow body fleet. At the same time, the share of generation 2 aircraft is increasing as they replace older aircraft generations. However, significant noise mitigation measures will be required to manage the rising noise impact from air traffic. It is unlikely that the airport's noise footprint will decrease until

after 2040, when the adoption of more generation 2 aircraft, as well as new aircraft concepts like generation 3, begins to take effect. For 2050, generation 3 aircraft were represented by the Blended Wing Body (BWB) aircraft concept, which promises improvements in efficiency and potential noise reduction.

The overall impact of generation 3 aircraft on noise remains uncertain. If these aircraft are louder than their predecessors, it will be impossible to reduce the airport's noise footprint. Conversely, if they are quieter, there will be an opportunity to mitigate noise, but this will require substantial investment and development into quieter aircraft technologies.

Overall, the rapid transition to generation 2 and possible generation 3 aircraft is essential for reducing noise at Dublin Airport. This transition must be driven by policymakers, as the industry alone may lack the incentive or capacity to implement such changes without external pressure.

Chapter 7

Discussion

7.1 Comparison to recent Literature

In this section, a comparison is made between the findings of this thesis and recent literature on aircraft fleet distribution, noise exposure, and future projections. The aim is to highlight how the results of this research align with or differ from previous studies and to identify gaps in current forecasting methodologies. This section will also address the importance of incorporating scenario forecasting, particularly for long-term projections. Additionally, the section emphasizes the need for considering extreme forecasting scenarios to better inform policymakers and the public about the full range of potential outcomes. By examining these studies, this section places the study's assumptions and methodologies within the broader context of existing research, while also highlighting areas where further analysis or updated data would be beneficial.

Reports such as Mott MacDonald Global Aviation [32] provide projections of fleet distribution by generation share but do not offer detailed information on fleet share up to 2040. Additionally, these reports do not predict the overall noise footprint or flight routes for future scenarios.

Noise contour maps depicting future aircraft noise exposure for 2030 at Heathrow Airport were published by Environmental Research and Consultancy Department Civil Aviation Authority [196]. This report not only included surrogate models for future aircraft types but also considered different airport operational modes. It presented fleet shares for typical summer day operations at the airport and provided estimates of both area and population exposure to noise. Furthermore, the Environmental Research and Consultancy Department Civil Aviation Authority [196] also generated a noise footprint for Heathrow for the years 2040 and 2050, including a range of airport operation scenarios. However, the fleet mix used in these forecasts was not published. Therefore, it remains uncertain whether the forecast provides sufficient detail or if it simply represents an extrapolation of current noise contour lines without adequately accounting for future developments and uncertainties.

In April 2024, proposed aircraft movements, including aircraft type and runway usage, were published for forecast scenarios for Dublin Airport for 2025 and 2035. The report also included noise modification assumptions for new aircraft configurations [197]. However, the full report [198] only presents noise contour lines in the form of very small, low-quality maps. The report considers just 25 different aircraft types, which are clustered into broader categories of configurations, and labels small aircraft movement shares as *others*. While this

approach simplifies the prediction process, it also limits the granularity of the aircraft fleet distribution at Dublin Airport. Overall, very high annual movement numbers are predicted, particularly during nighttime operations. Table 7.1 shows the permitted and proposed flight numbers for 2025 and 2035 in comparison to the 2030 BA BTU scenario. It is evident that the total flight numbers for the 92-day summer period scaled up to a full year for 2025 and 2035 are significantly higher than those calculated in this work. In this study, the AAGR from Eurocontrol [16], with an AAGR of 1.2 % for the Base Air Traffic Increase scenario, was applied. The flight numbers for 2030 were then calculated based on tracked flight data for 2023, as official data from Central Statistics Office [87] was not yet available. This may have resulted in a slight underestimation of the overall flight numbers for 2030.

Year	Scenario	Annual aircraft movements			
		day	night	per night	total
2025	permitted	209 094	18 922	52	228 016
	proposed	203 873	35 921	98	239 794
2035	permitted	209 068	18 919	52	227 987
	proposed	203 871	35 922	98	239 793
2030	BA BTU	211 096	32 998	90	244 094

Table 7.1: Proposed and permitted annual aircraft movement numbers at Dublin Airport from Dublin Airport Authority [197] in comparison to the 2030 BA BTU scenario

Calculating the AAGR from the official 2023 flight numbers (229 756 [87]) to the proposed 2025 aircraft movements from Dublin Airport Authority [197], the resulting $AAGR = 2.17\%$. This growth rate is higher than those forecasted in some scenarios but still remains within a plausible range. The report also includes data for summer movements. By extrapolating the 92-day summer period to estimate the annual totals, a total of 287 181 flights is permitted for 2025. Of these, 59 166 are expected during the nighttime, which corresponds to an average of 162 flights per night. While this number may not be realistic for the entire year, the summer scenario represents the maximum extent of air traffic. Consequently, this would lead to higher noise exposure and a significant number of aircraft movements, which could result in disturbances and negative health effects.

For both permitted scenarios in 2025 and 2035, no increase in air traffic is allowed. This is due to the passenger cap and the nighttime movement limits associated with the North Runway [128]. However, the proposed air traffic numbers for 2035 suggest an AAGR of 0.35 %

from 2023, which is lower than the Low Air Traffic Increase (LA) projected by Eurocontrol [16].

To compare the permitted and proposed scenarios with the generated projections in this work, the flight numbers for 2025 and 2035 were interpolated to 2030, as shown in Table 7.2. To facilitate a more meaningful comparison, all aircraft in the 2030 BA BTU scenario were categorized according to the classification in the report.

Scenario Aircraft Type	2030					
	permitted		proposed		BA BTU	
	movements	[%]	movements	[%]	movements	[%]
Airbus A306	946	0.41	1103	0.46	35	0.01
Airbus A319	1262	0.55	1261	0.53	8792	3.60
Airbus A320	29014	12.72	29620	12.35	23095	9.46
Airbus A320neo	35950	15.77	35292	14.72	14303	5.86
Airbus A321	1892	0.83	1891	0.79	8792	3.60
Airbus A321neo	10407	4.56	9139	3.81	14303	5.86
Airbus A330	6938	3.04	6775	2.83	621	0.25
Airbus A330neo	3784	1.66	3466	1.45	18292	7.49
Airbus A350	316	0.14	315	0.13	1082	0.44
ATR 42	0	0.00	0	0.00	19	0.01
ATR 72	12614	5.53	16071	6.70	39	0.02
BAe 146/Avro RJ	0	0.00	0	0.00	409	0.17
Boeing 737-400	2523	1.11	4412	1.84	251	0.10
Boeing 737-700	0	0.00	0	0.00	8502	3.48
Boeing 737-800	28069	12.31	30723	12.81	8502	3.48
Boeing 737 MAX	63070	27.66	65699	27.40	55676	22.81
Boeing 757	1576	0.69	1576	0.66	1488	0.61
Boeing 767	1262	0.55	1891	0.79	12007	4.92
Boeing 777	631	0.28	630	0.26	1276	0.52
Boeing 777X	1578	0.69	1575	0.66	3583	1.47
Boeing 787	9145	4.01	10714	4.47	9363	3.84
Bombardier CS300	2838	1.24	2836	1.18	22758	9.32
Bombardier Dash 8	631	0.28	630	0.26	496	0.20
Embraer E190/195	4573	2.01	4254	1.77	7548	3.09
Embraer E190-E2	5203	2.28	4884	2.04	1161	0.48
Other	3784	1.66	5041	2.10	21701	8.89
Total	228002	100	239794	100	244059	100

Table 7.2: Proposed and permitted annual aircraft movement numbers for 2030 interpolated from 2025 and 2035 at Dublin Airport from Dublin Airport Authority [197] in comparison to the 2030 BA BTU scenario

Table 7.3 presents the fleet shares of all these 2030 scenarios alongside the 2023 baseline data. In the proposed scenario, the narrow body fleet is expected to decrease at a faster rate, suggesting a quicker shift towards newer aircraft. This shift is even more pronounced in the 2030 BA BTU scenario, where the narrow body fleet is projected to decrease more rapidly, while the wide body fleet is expected to grow. This trend indicates a shift toward long-haul flights over the next decade. In contrast, the narrow body fleet in the permitted scenario is expected to show only a slight increase between 2023 and 2030, while the wide body fleet is also projected to grow, albeit at a slower pace than other reports suggest, such as Eurocontrol [3] and Prentice et al. [185]. At the same time, both the regional jet and turboprop fleets are expected to decrease in the permitted and proposed scenarios, while they remain stable in the 2030 BA BTU scenario.

Aircraft Fleet	2023	Share [%]		
		2030		
		permitted	proposed	BA BTU
narrow body	75.7	77.45	76.08	71.52
wide body	9.1	10.79	11.04	15.44
regional jet	6.9	4.29	3.81	6.24
turboprop	8.3	5.81	6.96	6.58
other	-	1.66	2.10	-
total	100	100.00	100.00	100

Table 7.3: Aircraft fleet shares for 2023 and 2030 at Dublin Airport interpolated for the permitted and proposed scenario from 2025 to 2035 from Dublin Airport Authority [197] and the 2030 BA BTU scenario in comparison to 2023 data

In terms of aircraft generation shares (Table 7.4), generation 0 aircraft are expected to be replaced more quickly in the permitted and proposed scenarios than in the 2030 BA BTU scenario. However, rather than being replaced by generation 1 aircraft, the generation 2 fleet share is anticipated to increase significantly, reaching almost 60 % by 2030. This shift towards newer-generation aircraft can be seen as an ambitious projection. The 2030 BA BTU scenario, on the other hand, takes a more conservative approach, with generation 1 and 2 aircraft making up around 40 % each. This may be a more realistic scenario, as air traffic continues to grow and not all generation 1 aircraft will be retired by 2030, given that many are still within their typical 25-year lifespan [32].

Aircraft Generation	2023	Share [%]		
		2030		BA BTU
		permitted	proposed	
not defined	1.62	1.66	2.10	-
generation 0	38.54	3.18	4.14	18.88
generation 1	40.91	37.28	38.04	41.90
generation 2	18.93	57.88	55.72	39.00
total	100	100	100	100

Table 7.4: Aircraft generation shares 2030 at Dublin Airport interpolated for the permitted and proposed scenario from 2025 to 2035 from Dublin Airport Authority [197] and the 2030 BA BTU scenario in comparison to 2023 data

While the Dublin Airport Authority [197] forecast for 2025 and 2035 suggests lower flight numbers and a quicker replacement of aircraft generations with newer, more efficient models, this scenario may not be entirely realistic. A forecast assuming zero growth in aircraft movements is particularly questionable, as Dublin Airport plays a crucial role in Ireland’s economy [39], and air traffic is generally expected to rise as global connectivity increases. Furthermore, new movement limits at Dublin Airport are currently under discussion, which could lead to an increase in nighttime flights. The proposed average of 162 flights per night during the summer, however, could pose significant health risks to the residents living in the vicinity of the airport. Given the potential impacts, this proposal warrants careful reconsideration.

While the rapid adoption of new aircraft technology is a key element of the forecast, the projection that generation 2 aircraft will comprise 60 % of the fleet by 2030 seems overly ambitious. This would represent a steep increase from less than 20 % in 2023, suggesting an acceleration in fleet turnover that may be difficult to achieve within this time frame.

Although the flight number and fleet share projections from Dublin Airport Authority [197] provide valuable insights, it is essential to incorporate scenario forecasting, especially for long-term planning over the next decade. For a more comprehensive assessment, at least two extreme scenarios should be considered: the Low Air Traffic Increase and High Air Traffic Increase scenarios in combination with High Technology Uptake and Low Technology Uptake, respectively. This forecast fails to explore such scenarios, leaving a significant gap in our understanding of the potential extent of airport noise exposure in 2035. It is critical that future projections address these uncertainties and better inform both policymakers and the public about the range of possible outcomes.

Airport noise forecasts, while valuable for short-term planning, are often too short-sighted, with projections typically extending only to 2035, just over a decade into the future. This limited time frame presents challenges for long-term decision-making, particularly for stakeholders involved in significant investments such as purchasing property, building infrastructure, or developing long-term policies. For instance, residents near Dublin Airport, as well as developers and policymakers, may find it difficult to plan for future noise exposure and changes in air traffic, as these forecasts do not provide a clear view of trends beyond 2035. Furthermore, the assumption of little to no growth in aircraft movements, coupled with overly ambitious projections regarding the rapid adoption of new aircraft technologies, raises concerns about the realism and adequacy of these forecasts. To address these issues, more comprehensive and long-term scenario planning, spanning several decades, should be incorporated into future projections. This would not only help to better inform stakeholders but also ensure more effective and sustainable planning for the future.

7.2 Discussion

Dublin Airport is required to produce annual noise maps every five years in accordance with European environmental regulations set by the Environmental Protection Agency (EPA). As of August 2022, Dublin Airport operates with a parallel runway system, typically functioning in mixed mode, with preferential runway usage for departing and arriving aircraft. In 2023, approximately 70 % of operations were conducted in a westerly direction, with 30 % in an easterly direction. Annual noise contours, area, and population exposure were calculated for common noise levels, including $L_{den} = 55$ dB(A) and $L_{night} = 50$ dB(A), as well as for the levels recommended by the WHO, namely $L_{den} = 45$ dB(A) and $L_{night} = 45$ dB(A). All contour lines for these levels exceeded the HSIP and RNIS insulation schemes currently in place. Furthermore, the modeling of aircraft noise at Dublin Airport for 2023 revealed a significant discrepancy between the planned flight routes, as outlined in the North Runway Report [39] during the planning of the North Runway, and the actual flight paths. This divergence resulted in unexpected noise disturbance in communities that were not initially expected to be impacted by aircraft noise from the airport.

As part of this study, monthly noise contour maps for Dublin Airport were generated for 2023 and compared to the annual maps. The analysis revealed significant seasonal and

monthly fluctuations in noise exposure, influenced by flight numbers and variations in runway operations. These fluctuations were particularly evident in the contours, where monthly variations in noise exposure exceeded the area covered by the annual noise maps. To quantify this, the *maximum change in area exposure* was introduced, highlighting the difference between the minimum and maximum area exposures within a predefined grid resolution of 1 km².

Overall, the extent of the noise contour lines for 2023, whether monthly or annual, clearly underscores the urgent need for improved airport noise mitigation strategies. While nighttime operation restrictions are in place at Dublin Airport, the limit of 65 flights per night is, on average, exceeded by an additional 7 flights each night. Noise Preferential Routes are also implemented, which direct aircraft along specific flight paths to reduce population exposure to excessive aircraft noise. Furthermore, Noise Monitoring Terminal (NMT) are placed around Dublin Airport by Dublin City Council and Dublin Airport, although the data for these measures is only partially accessible for analysis.

For communities surrounding the airport, a clear and transparent communication strategy regarding current and future flight routes, expected increases in air traffic, and airport operations is essential. Publishing both short-term and long-term plans, along with detailed information about potential changes in aircraft noise levels, can help communities better understand and prepare for periods of high noise exposure, particularly during months with increased flight numbers or when wind direction influences airport operations. All information related to airport noise and its potential health impacts should be easily accessible through a central platform, such as a dedicated website. Furthermore, it is important to provide the public with clear expectations regarding future flight numbers, along with detailed explanations of how these changes will affect the surrounding population. Airport policies, including operational schedules, flight routes, and operation restrictions, should be developed with long-term goals in mind, minimizing the need for frequent adjustments that could negatively impact local communities. A consistent and forward-looking approach will assist residents in their long-term planning and help them better cope with the challenges of living in proximity to an airport.

For long-term planning, airport noise predictions were conducted for 2030, 2040, and 2050, considering different air traffic growth and technology uptake scenarios. Technology uptake was modeled through a combination of fleet share and aircraft generation share. As the years

progress, older aircraft generations, such as generation 0 and generation 1, are expected to be replaced by more advanced aircraft, such as generation 2. The first future aircraft concepts, known as generation 3 aircraft, are anticipated to begin operations by 2050. In this study, all generation 3 aircraft are assumed to be represented by the Blended Wing Body (BWB) concept. Noise-Power-Distance (NPD) data for the BWB was integrated into the aircraft database, with fixed-point departure and arrival profiles. Contour lines were generated for the following noise levels: $L_{den} = 55$ dB(A) and $L_{night} = 50$ dB(A), as well as $L_{den} = 45$ dB(A) and $L_{night} = 45$ dB(A). Noise contour maps and area exposure revealed a continued increase in aircraft noise until at least 2030. Despite an increase in flight numbers, with an AAGR of 1.2 % in the Base Air Traffic Increase (BA) scenario, airport noise can still be mitigated. The replacement of older aircraft and the shift toward generation 2 aircraft show the potential to reduce the overall noise footprint. In particular, noise contour lines for $L_{den} = 45$ dB(A) in the BA BTU scenario are projected to decrease by around 18 % from 2030 to 2040. By 2050, generation 1 aircraft are likely to be fully replaced by newer aircraft generations, with the introduction of generation 3 aircraft potentially providing further reductions in noise. Newer aircraft are expected to be more efficient in terms of both carbon emissions and noise. Future aircraft concepts could significantly transform airport operations, travel times, and ground procedures, and even shift the fleet composition. While the exact impact of generation 3 aircraft remains speculative, since they have not yet reached a sufficient technology readiness level for precise projections, it is plausible that their introduction could lead to a substantial reduction in airport noise.

Airport noise prediction, particularly when considering technology uptake, is a highly complex process. As a result, only annual noise maps were generated for this study. However, generating extreme scenarios to capture potential monthly fluctuations would provide additional insight, as demonstrated by the monthly contour lines from 2023. In this work, population exposure data was not forecasted but instead utilized from 2022 and 2023. This approach makes it challenging to directly compare population exposure across years, especially since new communities are expected to emerge around Dublin Airport over the next decades. Instead, the scenarios were compared through area exposure, which offers a more generalized view of the noise impact. These forecast scenarios are specific to Dublin Airport, based on the 2023 aircraft fleet currently operating at the airport. The growth scenarios considered are tailored to the Republic of Ireland and the broader western Europe region.

The analysis reveals that airport noise will continue to increase until at least 2030, with a gradual reduction of increase anticipated by 2050. This highlights the urgent need for a rapid shift towards newer, quieter aircraft types. To achieve this, collaboration between airports, airlines, manufacturers, and legislators is essential. It is particularly crucial that the legislation encourages technological advancement within the aviation industry, as aircraft noise directly impacts residents' health and well-being. The legislation must set stringent noise limits and incentivize the integration of state-of-the-art, quieter aircraft into airport fleets. Such measures will not only help protect citizens but also enable airports to accommodate growing flight numbers, thereby supporting the economic growth of the country.

The annual noise maps currently used for airport noise assessments are insufficient, as they fail to capture the extreme monthly fluctuations in noise levels. While these maps depict annual averages, they do not accurately reflect the variations that can have a significant impact on residents' well-being. Therefore, using annual noise maps to determine insulation scheme areas is not advisable. Instead, monthly extreme noise maps should be the basis for such decisions, as they better account for periods of high noise exposure that are more likely to cause harm. Given that airport noise modeling is complex and time-consuming, it would be more practical to focus on modeling the most extreme monthly scenarios rather than attempting to represent the entire year. Additionally, when planning new residential areas, priority should be given to ensuring that they are located outside of the airport's noise zones to protect residents from the detrimental effects of excessive noise exposure.

Chapter 8

Conclusions

8.1 Introduction

This thesis has examined the current state of aircraft noise at Dublin Airport, with a particular focus on its impact on surrounding communities, existing mitigation strategies, and the future trajectory of noise exposure given the expected air traffic increase and technological uptake. The analysis highlighted significant discrepancies between the planned flight routes and actual operational patterns, leading to unintended noise disturbances in previously unaffected areas. Moreover, the study reveals that the reliance on annual noise maps for policy-making is insufficient, as they fail to capture the substantial monthly and seasonal variations in noise exposure that can have a more direct impact on residents' health and quality of life.

Through modeling noise contours for 2023 and projections for the years 2030, 2040, and 2050, this research underscores the pressing need for more responsive noise mitigation measures, transparent communication strategies, and a greater emphasis on technological innovation within the aviation sector. The findings demonstrate that while noise levels are expected to increase in the short term, significant reductions could be achieved through the adoption of quieter, more efficient aircraft technologies by mid-century.

In the following conclusion, the key takeaways from this research will be summarized, with recommendations for future noise management practices, policy development, and long-term planning for Dublin Airport. These recommendations aim to ensure that noise exposure is effectively mitigated and that communities can better adapt to the evolving dynamics of airport operations and air traffic growth.

8.2 Key Findings and Implications

- **Limitations of Existing Forecasts:** While air traffic and airport noise forecasts for Dublin Airport exist [32, 198] and provide important insight, they are lacking detail in aircraft fleet distribution and high-quality noise maps. In particular, they do not offer detailed fleet share data or account for the overall noise footprint for long-term future scenarios. This makes it difficult for policymakers and residents to make long-term plans. The current forecasts are short-term (typically until 2035), which makes long-term decision-making difficult for policymakers, airport authorities, and local stakeholders. Longer-term projections, over several decades, are needed to better

assess the potential impacts of air traffic and noise exposure beyond 2035. At the same time, different reports project different fleet mixes and technology uptake. The Dublin Airport Authority [198] forecast, for example, suggests a quicker replacement of older aircraft (including generation 2 aircraft making up nearly 60 % of the fleet by 2030), which seems overly ambitious considering current trends in fleet turnover. In addition, the proposed scenario considers up to 162 flights per night (in summer months), which could pose as a health risk to nearby residents. While this number might represent an extreme scenario, it highlights the need for a more careful assessment of potential noise exposure. The 2030 BA BTU scenario presents a more conservative view, with generation 1 and 2 aircraft comprising about 40 % each, which might be more realistic given aircraft lifespans.

- **2023 Noise Exposure:** Despite existing operational restrictions (such as nighttime flight limits and preferential runway use), noise exposure continues to be significant. Even on average, Dublin Airport exceeds the nighttime flight limits, exacerbating noise disturbances for surrounding communities. This indicates a gap in enforcement or a need for more stringent noise control measures. In addition, there is a significant difference between the planned flight routes from the North Runway Report [39] and the actual flown routes in 2023. Aircraft are turning too early to the right after a westerly departure from the North Runway, which results in unanticipated noise disturbances.
- **Limitations of Annual Noise Maps:** Monthly and seasonal variations in aircraft noise were found to be substantial, suggesting that annual noise maps, which are commonly used for noise impact assessments, do not accurately reflect periods of high exposure that could significantly affect residents' health and well-being. It was also shown that the area affected by noise exposure can fluctuate significantly throughout the year, depending on flight numbers, weather, and runway usage patterns. As a result, surrounding communities are exposed to variations of noise exposure. Annual noise maps can only display the average noise exposure, neglecting monthly variations. Insulation schemes are often based on annual noise contour lines, which leaves out extreme scenarios due to high air traffic months and seasonal variations.
- **Future Airport Noise:** Predictions for the future (2030, 2040, and 2050) show that airport noise may increase until at least 2030, but the shift toward quieter, more ef-

ficient aircraft (e.g., generation 2 and 3 aircraft, including the BWB concept) could significantly reduce noise exposure by 2040 and beyond. Overall the narrow body fleet will probably decrease, due to a better ground transportation network, while the wide body fleet will slightly increase. At the same time, there will be an aircraft generation shift, replacing older aircraft with new generation 2 aircraft, which are generally quieter. Dublin Airport is assumed to see a Base Air Traffic Increase of $AAGR = 1.2\%$. Even in combination with technology uptake the trend of growing noise contour lines cannot be stopped until 2040, meaning an increasing amount of people will be affected by aircraft noise.

- **Future Aircraft Concepts:** Future aircraft concepts (generation 3) are not expected to be on the market before 2050. In the study for 2050, they were represented by the Blended Wing Body (BWB) aircraft for which NPD data was generated and implemented into the local ANP database. Generation 3 aircraft have the ability to change the course of airport noise, by introducing quieter, ground-breaking technology to the market and help to reduce the overall noise footprint. However, the introduction of future aircraft concepts is speculative and depends on technological advancements. This underscores the importance of fostering innovation and regulatory support for quieter aircraft to help reduce noise in the long term.

8.3 Recommendations

- **Future Scenario Planning:** For a more robust and informed approach to airport and noise exposure planning, future airport noise forecasts should account for a wider range of potential growth scenarios (LA HTU and HA LTU) and address uncertainties in fleet air traffic increase and technology uptake. Forecasts should also include realistic estimates for nighttime flights, reflecting both regulatory limits and the potential for operational deviations. Moreover, future planning should model extreme scenarios that account for monthly and seasonal fluctuations in noise exposure, which are often overlooked in annual noise maps. To ensure comprehensive noise mitigation, it is essential to map monthly or extreme noise contours that capture the full range of potential impacts from airport operations. This way, planners can more accurately identify areas affected by high noise levels during peak periods. This would allow for better-targeted

mitigation measures and ensure that communities are protected during times of elevated exposure. By extending scenario forecasting beyond the 2035 timeframe, airport authorities, policymakers, and stakeholders can better prepare for long-term noise impacts, facilitating more effective policy development, infrastructure planning, and noise mitigation strategies that reflect the evolving dynamics of aviation and its impact on surrounding communities.

- **Transparent Communication Strategy:** A comprehensive communication strategy is vital for ensuring that local communities are well-informed about current and future noise exposure levels. This strategy should clearly communicate any changes in flight routes, increasing traffic volumes, and seasonal variations in noise, allowing residents to anticipate periods of higher exposure. To facilitate understanding, all information should be presented in an easily accessible, user-friendly format, with a central online platform where residents can easily access all relevant data without the need for extensive web searches. This platform should include clear explanations of the potential health impacts of noise exposure, as well as detailed information about noise insulation schemes, eligibility criteria, and how to apply.

To enhance transparency, historic and current data from Noise Monitoring Terminals should be accessible for download in a user-friendly format, such as CSV or PDF. This ensures that residents can easily analyze and compare noise levels over time. Furthermore, the platform should provide information about anticipated changes, not only those related to flight routes but also any potential increases in noise due to maintenance work, runway closures, or other operational changes at the airport. For example, when one runway is closed for maintenance, the use of alternative runways may lead to higher noise levels in certain areas. Information about expected flight numbers, particularly in comparison to typical or average flight volumes, should also be included, giving residents a clear understanding of how short-term or long-term changes in airport operations could impact noise exposure. By offering this comprehensive and easily digestible information, residents can better anticipate and understand the noise levels in their environment, fostering a sense of control and helping them make informed decisions about how to mitigate the effects of noise exposure on their health and quality of life. This strategy should also emphasize the importance of proactive communication about both scheduled and unscheduled disruptions to air traffic. Residents should be

regularly updated not only on immediate changes, such as emergency flight rerouting, but also on longer-term adjustments to air traffic management, ensuring that they are always aware of the factors influencing noise exposure. In doing so, the strategy will promote transparency, reduce uncertainty, and support the health and well-being of affected communities. By providing transparent and accessible information, airport authorities can help residents better manage the impacts of living near the airport and foster a sense of trust and cooperation between the airport and the surrounding community.

- **Policy Recommendations:** Effective long-term land-use planning is essential to minimizing the impact of airport noise on surrounding communities. Policymakers should ensure that new residential areas are developed outside of high-noise zones, with noise contours projected decades in advance to guide urban planning decisions. By proactively designating areas for growth that are less exposed to aircraft noise, local governments can safeguard residents' quality of life while accommodating future development. At the same time, stronger regulations and incentives should be introduced to prioritize the adoption of quieter, more efficient aircraft technologies. Supporting the transition to newer aircraft through regulatory measures and incentives will be crucial in reducing noise levels over time. Additionally, noise mitigation strategies should focus on extreme noise exposure scenarios, rather than relying on annual averages, to better reflect the actual lived experiences of residents. To effectively address the growing noise issue, collaboration among airports, airlines, manufacturers, and regulators is vital, ensuring that noise management is a shared responsibility and that public health is adequately protected.

8.4 Limitations to the Study

This study has several limitations that should be considered when interpreting the findings. Firstly, the projections for technology uptake and air traffic increase are speculative. These estimates are based on current trends and available forecasts, but they represent only projections and not definitive figures. Therefore, future noise exposure scenarios, especially those involving quieter aircraft technologies and air traffic growth, should be viewed with caution

as they are subject to uncertainty and potential changes in both technological advancements and aviation patterns.

The study also assumes static airport policies, particularly regarding movement caps and noise restrictions, which were not modeled in detail. Changes in these policies could significantly affect noise exposure, but this study does not incorporate potential future policy adjustments, making it difficult to predict their impact on noise levels.

In terms of aircraft technology, the study uses the Blended Wing Body aircraft as an assumed proxy for all future generation 3 aircraft. This approach limits the analysis by assuming a single aircraft concept for a broad range of future technologies, which may not accurately capture the diversity of potential aircraft designs and their varying noise profiles. Additionally, no extreme noise scenarios were modeled for the year 2050. The study relied on a general forecast that assumes moderate conditions but did not account for high-traffic, worst-case scenarios that might result in significantly higher noise exposure.

The noise predictions for 2030, 2040, and 2050 were based on annual noise maps, which aggregate data over the year. This approach overlooks monthly or seasonal variations in noise exposure and does not capture periods of peak traffic or extreme noise events that may have a more significant impact on residents' well-being. As such, the study does not fully reflect the dynamic nature of airport noise exposure throughout the year.

Finally, the population exposure analysis was based solely on 2022 and 2023 data, without extrapolation to account for potential future population changes or shifts in the geographic distribution of affected communities. As such, the exposure estimates are limited to the current demographic and spatial patterns, which may not hold true over the long term.

8.5 Future Work

For the forecast scenarios presented in this study, monthly fluctuations in noise exposure, and the resulting extreme scenarios driven by seasonal variations, were not considered. These fluctuations, such as increases in air traffic during peak travel seasons or changes in weather patterns and climate change that affect flight paths, can have a significant impact on the actual noise levels experienced by surrounding communities. Future work should include these monthly and seasonal variations to provide a more accurate and realistic representation of noise exposure. Incorporating these extremes into future models would better capture the

full range of noise impacts, ensuring that mitigation strategies are responsive to the real-world conditions experienced by residents.

Another important area for future research is exploring how to incorporate non-acoustic effects into common noise metrics. These effects, such as sleep disturbance, stress, or cardiovascular health impacts, are often overlooked in traditional noise assessments but are crucial for a complete understanding of the health impacts of airport noise. Developing methodologies to include these factors within established noise metrics could lead to more comprehensive and effective noise management strategies.

Additionally, combining air pollution factors, such as carbon emissions and noise emissions, into a comprehensive environmental assessment would provide a more holistic view of the overall impact of airport operations. By integrating these two major environmental pollutants, future studies could better understand the synergistic effects of both noise and air pollution on nearby communities and the environment.

Lastly, future work could look into combining airport noise and carbon pollution maps to create integrated environmental impact models. Such combined maps would enable policymakers and airport authorities to assess both noise and carbon pollution together, facilitating more informed decision-making and more comprehensive mitigation strategies for the long-term sustainability of airport operations and their surrounding communities.

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Appendix A

Aircraft Type Shares at Dublin Airport

A.1 Aircraft Type Shares at Dublin Airport 2023

narrow body fleet		turboprop fleet		continue previous column	
aircraft	share [%]	aircraft	share [%]	aircraft	share [%]
B733	0.0056	BE20	0.1241	TBM7	0.0056
B734	0.3046	BE40	0.0113	AT45	0.0451
B737	0.1467	C25C	0.0395	E135	0.1128
B738	31.9664	DH8D	0.2820	E170	0.0113
B752	0.7784	P180	0.0056	E190	3.1532
B764	0.9082	PC12	0.1297	E195	0.4118
BCS1	0.2820	AT76	7.7617	E50P	0.0169
BCS3	0.4287	total	8.3540	E55P	0.2426
A319	1.4553	regional jet fleet		E75L	0.0846
A320	21.4745	aircraft	share [%]	EA50	0.0113
A321	1.0379	C25A	0.0395	FA7X	0.0846
B739	0.0620	C25B	0.0338	G280	0.0113
A20N	3.2096	C510	0.0790	GL5T	0.0113
A21N	2.8486	C525	0.0226	LJ35	0.0226
B38M	10.7852	C550	0.0282	LJ40	0.1185
total	75.6938	C560	0.0113	E290	0.0338
wide body fleet		C56X	0.3497	E295	0.2256
aircraft	share [%]	C650	0.0113	total	6.8705
A310	0.0113	C680	0.2820		
A35K	0.0338	CL30	0.0113		
B350	0.0169	CL60	0.1805		
B762	0.0338	CRJ2	0.0564		
B763	1.0718	CRJ9	0.0677		
B767	0.0282	E545	0.2708		
B772	0.2369	F100	0.0113		
A332	0.1241	F2TH	0.1072		
A333	3.4465	F900	0.0451		
A343	0.0113	GLEX	0.3667		
A359	0.1805	GLF4	0.0508		
B77W	0.6995	GLF5	0.0620		
B788	1.2015	H25B	0.0056		
B789	0.5359	LJ45	0.1636		
B78X	0.0903	LJ60	0.0113		
total	7.7222	continue next column			

Table A.1: Aircraft shares (03/2023) at Dublin Airport separated by fleet type with data from Steve Beaney [170]

A.2 Proposed and Permitted Annual Aircraft Movements interpolated to 2030 for a 92-Day Summer Period

Scenario Aircraft Type	2030			
	permitted movements	[%]	proposed movements	[%]
Airbus A306	1125	0.39	1237	0.42
Airbus A319	1618	0.56	1617	0.54
Airbus A320	36599	12.74	36491	12.26
Airbus A320neo	45409	15.81	43993	14.79
Airbus A321	2383	0.83	2292	0.77
Airbus A321neo	13039	4.54	11235	3.78
Airbus A330	8678	3.02	8381	2.82
Airbus A330neo	4810	1.68	4403	1.48
Airbus A350	405	0.14	360	0.12
ATR 42	0	0.00	0	0.00
ATR 72	16184	5.64	20086	6.75
BAe 146/Avro RJ	0	0.00	0	0.00
Boeing 737-400	3058	1.06	4946	1.66
Boeing 737-700	0	0.00	0	0.00
Boeing 737-800	35297	12.29	38531	12.95
Boeing 737 MAX	79222	27.59	82209	27.63
Boeing 757	1934	0.67	1933	0.65
Boeing 767	1529	0.53	2114	0.71
Boeing 777	720	0.25	675	0.23
Boeing 777X	1934	0.67	1933	0.65
Boeing 787	11465	3.99	12989	4.37
Bombardier CS300	3641	1.27	3639	1.22
Bombardier Dash 8	809	0.28	808	0.27
Embraer E190/195	5822	2.03	5370	1.80
Embraer E190-E2	6631	2.31	6178	2.08
Other	4855	1.69	6113	2.05
Total	287164	100	297529	100

Table A.2: Proposed and permitted annual aircraft movement numbers for a 92-day summer period interpolated to 2030 from 2025 and 2035 at Dublin Airport from Dublin Airport Authority [197]

A.3 Aircraft Type Shares Prediction for Dublin Airport 2030

Table A.3: Predicted fleet shares for different technology uptake scenarios for 2030 at Dublin Airport

Aircraft Type	Generation	Fleet Type	2030 Fleet Share [%]		
			LTU	BTU	HTU
B733	0	narrow body	0.0058	0.0031	0.0017
B734	0	narrow body	0.3131	0.0995	0.0705
B735	0	narrow body	0.2899	0.2204	0.1734
B737	0	narrow body	10.3595	6.9506	4.7416
B738	0	narrow body	10.3595	6.9506	4.7416
B753	0	narrow body	0.8002	0.6081	0.4784
A319	1	narrow body	5.0302	3.5940	2.6445
A320	1	narrow body	5.0302	3.5940	2.6445
A321	1	narrow body	5.0302	3.5940	2.6445
B739	1	narrow body	8.8379	11.3794	12.6187
A19N	2	narrow body	5.3533	5.8467	5.9977
A20N	2	narrow body	5.3533	5.8467	5.9977
A21N	2	narrow body	5.3533	5.8467	5.9977
B38M	2	narrow body	8.8379	11.3794	12.6187
BCS3	2	narrow body	4.7396	5.6072	5.9757
A310	0	wide body	0.0095	0.0143	0.0171
A35K	0	wide body	0.0285	0.0428	0.0514
B762	0	wide body	0.9323	1.3970	1.6806
B767	0	wide body	0.0238	0.0356	0.0429
B772	0	wide body	0.1998	0.2994	0.3601
B77L	0	wide body	0.0084	0.0126	0.0152
A332	1	wide body	4.4161	7.6868	11.0908
A340	1	wide body	0.0120	0.0209	0.0302
A343	1	wide body	0.0136	0.0236	0.0341
A359	1	wide body	0.2172	0.3780	0.5454
A380	1	wide body	0.0060	0.0105	0.0151
B777	1	wide body	0.1203	0.2094	0.3022
B77W	1	wide body	0.8415	1.4648	2.1134
B788	2	wide body	1.4455	2.5161	3.6303
B789	2	wide body	0.6447	1.1222	1.6192
B78X	2	wide body	0.1086	0.1890	0.2727
BWB	3	wide body	0.0000	0.0000	0.0000
BE40	0	turboprop	0.1342	0.0973	0.0706
DH8D	0	turboprop	0.2796	0.2028	0.1470
AT43	1	turboprop	0.0099	0.0079	0.0058

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Table A.3 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
AT75	1	turboprop	7.6935	6.1202	4.5030
ATR72	1	turboprop	0.0198	0.0158	0.0116
DHC8	1	turboprop	0.0099	0.0079	0.0058
C25A	0	regional jet	0.1404	0.1256	0.1120
C510	0	regional jet	0.0717	0.0624	0.0541
C550	0	regional jet	0.0256	0.0223	0.0193
C560	0	regional jet	0.0102	0.0089	0.0077
C56X	0	regional jet	0.3174	0.2765	0.2395
C650	0	regional jet	0.0102	0.0089	0.0077
C680	0	regional jet	0.2560	0.2230	0.1931
CL30	0	regional jet	0.0102	0.0089	0.0077
CL60	0	regional jet	0.1638	0.1427	0.1236
CRJ2	0	regional jet	0.0512	0.0446	0.0386
CRJ9	0	regional jet	0.0614	0.0535	0.0464
E545	0	regional jet	0.2457	0.2140	0.1854
F100	0	regional jet	0.0102	0.0089	0.0077
F2TH	0	regional jet	0.0973	0.0847	0.0734
F900	0	regional jet	0.0410	0.0357	0.0309
GIV	0	regional jet	0.0461	0.0401	0.0348
GLEX	0	regional jet	0.3327	0.2899	0.2511
GV	0	regional jet	0.0563	0.0491	0.0425
H25B	0	regional jet	0.0051	0.0045	0.0039
LJ45	0	regional jet	0.2560	0.2284	0.2122
LJ60	0	regional jet	0.0102	0.0089	0.0077
PA42	0	regional jet	0.1393	0.1018	0.0744
AT45	1	regional jet	0.0410	0.0377	0.0382
BAE146	1	regional jet	0.1815	0.1673	0.1691
E135	1	regional jet	0.1024	0.0944	0.0954
E190	1	regional jet	2.8616	2.6373	2.6667
E50P	1	regional jet	0.0154	0.0142	0.0143
E55P	1	regional jet	0.2201	0.2029	0.2051
E75L	1	regional jet	0.0768	0.0708	0.0716
EA50	1	regional jet	0.0102	0.0094	0.0095
EMB170	1	regional jet	0.0102	0.0094	0.0095
EMB195	1	regional jet	0.3737	0.3444	0.3482
FA7X	1	regional jet	0.0768	0.0708	0.0716
G280	1	regional jet	0.0102	0.0094	0.0095
GL5T	1	regional jet	0.0102	0.0094	0.0095
LEAR35	1	regional jet	0.0205	0.0189	0.0191

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Table A.3 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
E175-E2G2	2	regional jet	0.0908	0.0848	0.0789
E190-E2G2	2	regional jet	0.0908	0.0848	0.0789
E195G2	2	regional jet	0.0908	0.0848	0.0789
E290	2	regional jet	0.0307	0.0287	0.0267
E295	2	regional jet	0.2048	0.1914	0.1780
SU95	2	regional jet	0.1815	0.1696	0.1578

A.4 Aircraft Type Shares Prediction for Dublin Airport 2040

Table A.4: Predicted fleet shares for different technology uptake scenarios for 2040 at Dublin Airport

Aircraft Type	Generation	Fleet Type	2030 Fleet Share [%]		
			LTU	BTU	HTU
B733	0	narrow body	0.0031	0.0006	0.0001
B734	0	narrow body	0.0995	0.0179	0.0034
B735	0	narrow body	0.2204	0.0396	0.0075
B737	0	narrow body	6.9506	1.2490	0.2357
B738	0	narrow body	6.9506	4.3741	0.8255
B753	0	narrow body	0.6081	3.1252	0.5898
A319	1	narrow body	3.5940	1.6145	0.6094
A320	1	narrow body	3.5940	4.8263	1.8216
A321	1	narrow body	3.5940	1.6145	3.0548
B739	1	narrow body	11.3794	5.1120	1.9294
A19N	2	narrow body	5.8467	9.5327	5.9964
A20N	2	narrow body	5.8467	9.5327	5.9964
A21N	2	narrow body	5.8467	6.3036	13.4751
B38M	2	narrow body	11.3794	12.2687	10.4346
B737max8G2	2	narrow body	0.0000	0.0000	5.4342
B737max9G2	2	narrow body	0.0000	0.0000	5.4342
BCS3	2	narrow body	5.6072	6.0454	3.8028
A310	0	wide body	0.0102	0.0097	0.0087
A35K	0	wide body	0.0306	0.0290	0.0260
B762	0	wide body	1.0001	0.9464	0.8507
B767	0	wide body	0.0255	0.0241	0.0217
B772	0	wide body	0.2143	0.2028	0.1823

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Table A.4 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
B77L	0	wide body	0.0090	0.0086	0.0077
A332	1	wide body	5.5030	2.2318	0.2866
A340	1	wide body	0.0150	0.0061	0.0008
A343	1	wide body	0.0169	0.0069	0.0009
A359	1	wide body	0.2706	0.4756	0.1221
A380	1	wide body	0.0075	0.0030	0.0004
B777	1	wide body	0.1499	0.0608	0.0156
B77W	1	wide body	1.0486	0.4253	0.1092
A330-900neo	2	wide body	0.9046	7.4595	12.4608
A350-900G2	2	wide body	0.9046	1.9441	3.1070
A380-800neo	2	wide body	0.0000	0.0000	0.0000
B777-9xG2	2	wide body	0.9046	1.2229	1.5703
B777X	2	wide body	0.9046	1.6291	2.9874
B787-8G2	2	wide body	0.9046	2.4458	3.1405
B788	2	wide body	1.8013	0.7305	0.0938
B789	2	wide body	0.8034	0.3258	0.0418
BE40	0	turboprop	0.0973	0.0361	0.0119
DH8D	0	turboprop	0.2028	0.0753	0.0247
AT43	1	turboprop	0.0079	0.0063	0.0044
AT75	1	turboprop	6.1202	4.8674	3.4215
ATR72	1	turboprop	0.0158	0.0125	0.0088
DHC8	1	turboprop	0.0079	0.0063	0.0044
C25A	0	regional jet	0.1243	0.0676	0.0368
C510	0	regional jet	0.0664	0.0350	0.0167
C550	0	regional jet	0.0237	0.0125	0.0060
C560	0	regional jet	0.0095	0.0050	0.0024
C56X	0	regional jet	0.2939	0.1552	0.0742
C650	0	regional jet	0.0095	0.0050	0.0024
C680	0	regional jet	0.2370	0.1251	0.0598
CL30	0	regional jet	0.0095	0.0050	0.0024
CL60	0	regional jet	0.1517	0.0801	0.0383
CRJ2	0	regional jet	0.0474	0.0250	0.0120
CRJ9	0	regional jet	0.0569	0.0300	0.0144
E545	0	regional jet	0.2275	0.1201	0.0574
F100	0	regional jet	0.0095	0.0050	0.0024
F2TH	0	regional jet	0.0901	0.0476	0.0227
F900	0	regional jet	0.0379	0.0200	0.0096
GIV	0	regional jet	0.0427	0.0225	0.0108
GLEX	0	regional jet	0.3081	0.1627	0.0778

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Table A.4 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
GV	0	regional jet	0.0521	0.0275	0.0132
H25B	0	regional jet	0.0047	0.0025	0.0012
LJ45	0	regional jet	0.2428	0.2394	0.1543
LJ60	0	regional jet	0.0095	0.0050	0.0024
PA42	0	regional jet	0.0973	0.0361	0.0119
AT45	1	regional jet	0.0401	0.0636	0.0456
BAE146	1	regional jet	0.1778	0.2817	0.2019
E135	1	regional jet	0.1003	0.1589	0.1139
E190	1	regional jet	2.8033	4.4406	3.1837
E50P	1	regional jet	0.0150	0.0238	0.0171
E55P	1	regional jet	0.2156	0.3416	0.2449
E75L	1	regional jet	0.0752	0.1192	0.0854
EA50	1	regional jet	0.0100	0.0159	0.0114
EMB170	1	regional jet	0.0100	0.0159	0.0114
EMB195	1	regional jet	0.3661	0.5799	0.4158
FA7X	1	regional jet	0.0752	0.1192	0.0854
G280	1	regional jet	0.0100	0.0159	0.0114
GL5T	1	regional jet	0.0100	0.0159	0.0114
LEAR35	1	regional jet	0.0201	0.0318	0.0228
E175-E2G2	2	regional jet	0.0902	0.3174	1.2641
E190-E2G2	2	regional jet	0.0902	0.3174	1.2641
E195G2	2	regional jet	0.0902	0.3174	1.2641
E290	2	regional jet	0.0305	0.1074	0.4278
SU95	2	regional jet	0.1803	0.6347	2.5282

A.5 Aircraft Type Shares Prediction for Dublin Airport 2050

Table A.5: Predicted fleet shares for different technology uptake scenarios for 2050 at Dublin Airport

Aircraft Type	Generation	Fleet Type	2030 Fleet Share [%]		
			LTU	BTU	HTU
B733	0	narrow body	0.0003	0.0000	0.0000
B734	0	narrow body	0.0108	0.0000	0.0000
B735	0	narrow body	0.0239	0.0000	0.0000
B737	0	narrow body	0.7533	0.0000	0.0000
B738	0	narrow body	2.6384	0.0000	0.0000
B753	0	narrow body	1.8850	0.0000	0.0000
A319	1	narrow body	0.9739	0.3877	0.0000
A320	1	narrow body	2.9111	1.1589	0.0000
A321	1	narrow body	4.8819	1.9435	0.0000
B739	1	narrow body	3.0834	1.2275	0.0000
A19N	2	narrow body	5.7499	6.8670	7.1163
A20N	2	narrow body	5.7499	6.8670	7.1163
A21N	2	narrow body	12.9211	15.4315	15.9916
B38M	2	narrow body	10.0056	11.9495	12.3833
B737max8G2	2	narrow body	5.2108	6.2232	6.4491
B737max9G2	2	narrow body	5.2108	6.2232	6.4491
BCS3	2	narrow body	3.6464	4.3549	4.5130
A310	0	wide body	0.0097	0.0000	0.0000
A35K	0	wide body	0.0290	0.0000	0.0000
B762	0	wide body	0.9464	0.0000	0.0000
B767	0	wide body	0.0241	0.0000	0.0000
B772	0	wide body	0.2028	0.0000	0.0000
B77L	0	wide body	0.0086	0.0000	0.0000
A332	1	wide body	2.2318	0.6785	0.0000
A340	1	wide body	0.0061	0.0018	0.0000
A343	1	wide body	0.0069	0.0021	0.0000
A359	1	wide body	0.4756	0.1446	0.0000
A380	1	wide body	0.0030	0.0009	0.0000
B777	1	wide body	0.0608	0.0185	0.0000
B77W	1	wide body	0.4253	0.1293	0.0000
A330-900neo	2	wide body	7.4595	2.9929	2.5926
A350-900G2	2	wide body	1.9441	2.4500	2.1223
A380-800neo	2	wide body	0.0000	3.7180	3.2207
B777-9xG2	2	wide body	1.2229	1.8590	1.6103
B777X	2	wide body	1.6291	2.3543	2.0394

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Table A.5 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
B787-8G2	2	wide body	2.4458	2.6026	2.2545
B788	2	wide body	0.7305	0.2221	0.0000
B789	2	wide body	0.3258	0.0991	0.0000
B78X	2	wide body	0.0000	1.8590	1.6103
BWB	3	wide body	0.0000	4.9573	10.1988
BE40	0	turboprop	0.0361	0.0000	0.0000
DH8D	0	turboprop	0.0753	0.0000	0.0000
AT43	1	turboprop	0.0063	0.0000	0.0000
AT75	1	turboprop	4.8674	0.8922	0.6840
ATR72	1	turboprop	0.0125	0.8922	0.6840
DHC8	1	turboprop	0.0063	0.8922	0.6840
C25A	0	regional jet	0.0676	0.0000	0.0000
C510	0	regional jet	0.0350	0.0000	0.0000
C550	0	regional jet	0.0125	0.0000	0.0000
C560	0	regional jet	0.0050	0.0000	0.0000
C56X	0	regional jet	0.1552	0.0000	0.0000
C650	0	regional jet	0.0050	0.0000	0.0000
C680	0	regional jet	0.1251	0.0000	0.0000
CL30	0	regional jet	0.0050	0.0000	0.0000
CL60	0	regional jet	0.0801	0.0000	0.0000
CRJ2	0	regional jet	0.0250	0.0000	0.0000
CRJ9	0	regional jet	0.0300	0.0000	0.0000
E545	0	regional jet	0.1201	0.0000	0.0000
F100	0	regional jet	0.0050	0.0000	0.0000
F2TH	0	regional jet	0.0476	0.0000	0.0000
F900	0	regional jet	0.0200	0.0000	0.0000
GIV	0	regional jet	0.0225	0.0000	0.0000
GLEX	0	regional jet	0.1627	0.0000	0.0000
GV	0	regional jet	0.0275	0.0000	0.0000
H25B	0	regional jet	0.0025	0.0000	0.0000
LJ45	0	regional jet	0.2394	0.0887	0.0000
LJ60	0	regional jet	0.0050	0.0000	0.0000
PA42	0	regional jet	0.0361	0.0000	0.0000
AT45	1	regional jet	0.0636	0.0338	0.0000
BAE146	1	regional jet	0.2817	0.1497	0.0000
E135	1	regional jet	0.1589	0.0844	0.0000
E190	1	regional jet	4.4406	2.3600	0.0000
E50P	1	regional jet	0.0238	0.0127	0.0000
E55P	1	regional jet	0.3416	0.1815	0.0000

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Table A.5 – continued from previous page

Aircraft Type	Generation	Fleet Type	Fleet Share [%]		
			LTU	BTU	HTU
E75L	1	regional jet	0.1192	0.0633	0.0000
EA50	1	regional jet	0.0159	0.0084	0.0000
EMB170	1	regional jet	0.0159	0.0084	0.0000
EMB195	1	regional jet	0.5799	0.3082	0.0000
FA7X	1	regional jet	0.1192	0.0633	0.0000
G280	1	regional jet	0.0159	0.0084	0.0000
GL5T	1	regional jet	0.0159	0.0084	0.0000
LEAR35	1	regional jet	0.0318	0.0169	0.0000
E175-E2G2	2	regional jet	0.3174	1.3493	2.3004
E190-E2G2	2	regional jet	0.3174	1.3493	2.3004
E195G2	2	regional jet	0.3174	1.3493	2.3004
E290	2	regional jet	0.1074	0.4567	0.7786
E295	2	regional jet	0.0000	0.0000	0.0000
SU95	2	regional jet	0.6347	2.6987	4.6008

A.6 Aircraft Substitutions for new Aircraft Configurations and Generations

Proxy	Aircraft Modernized	Expected Noise Level Correction [dB]	
		Arrival	Departure
737700	BCS3	-3.4	-4.3
A321	A21N	-2.4	-5.4
A330-300	A330-900neo	-1.1	-4.8
A330-300	A350-900G2	-3	-7.5
B777-300	B777X	-0.8	-3.8
E190	E190-E2G2	-1.9	-6.2
E175-E2	E175-E2G2	-1.4	-0.3
E190-E2	E190-E2G2	-1.4	-0.3
E195-E2	E195G2	-1.4	-0.3
A19N	A19NG2	-0.7	-0.2
A20N	A20NG2	-0.7	-0.2
B737-8 MAX	B737max8G2	-0.6	-0.1
B737-9 MAX	B737max9G2	-0.6	-0.1
A350-900	A350-900G2	-2.1	-0.4
A380	A380-800neo	-1	0
B787-8	B787-8G2	-1.9	-0.4

Table A.6: Aircraft noise level correction for new aircraft configurations and generations, which are not included in the ANP substitution table [151] from Civil Aviation Authority [152] and Bickerdike Allen Partners [153]

Appendix B

Additional Noise Maps for Dublin Airport

$L_{den} = 55 \text{ dB(A)}$ and $L_{night} = 50 \text{ dB(A)}$

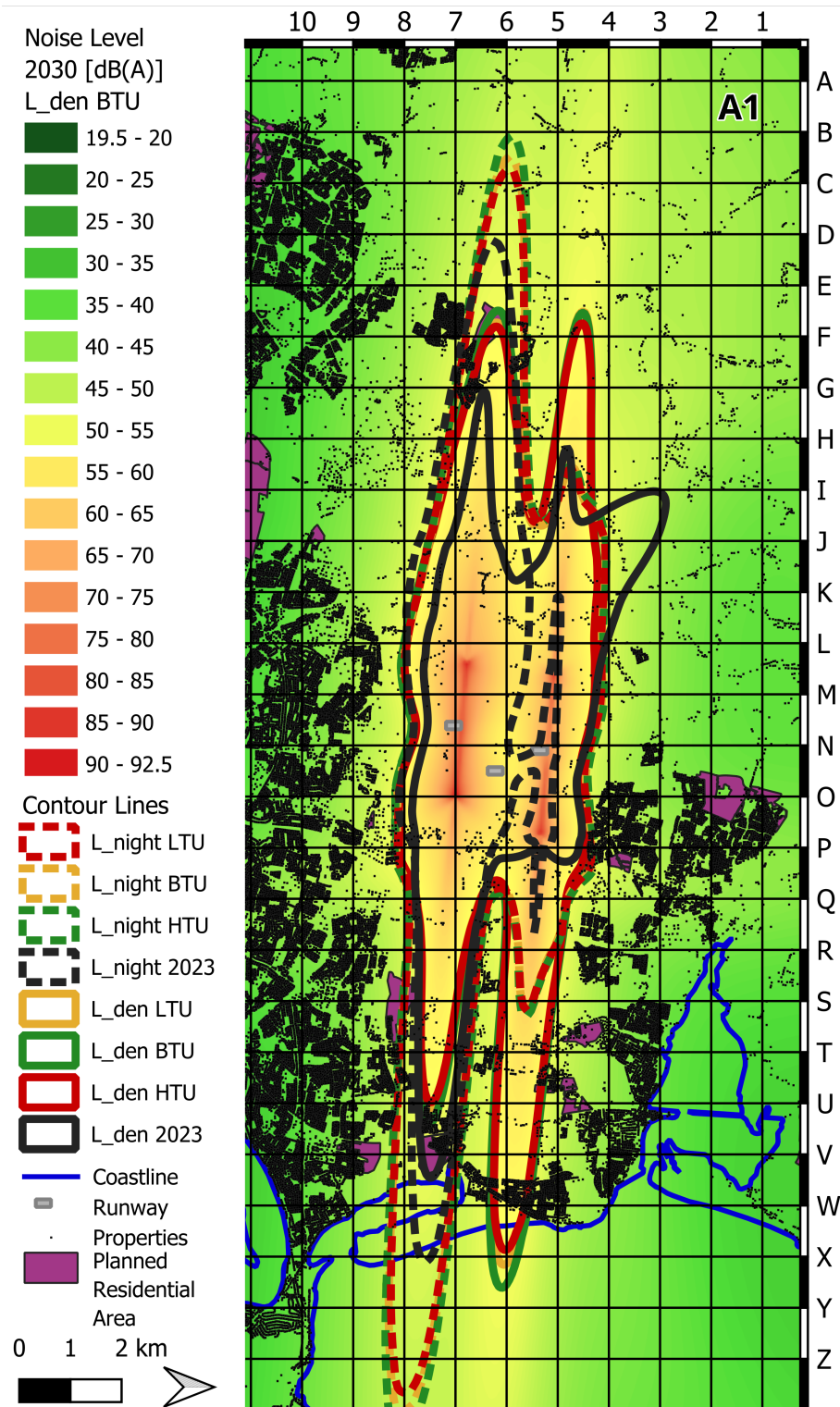


Figure B.1: 2030 noise map for different technology uptake scenarios with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 50$ dB(A) and $L_{den} = 55$ dB(A))

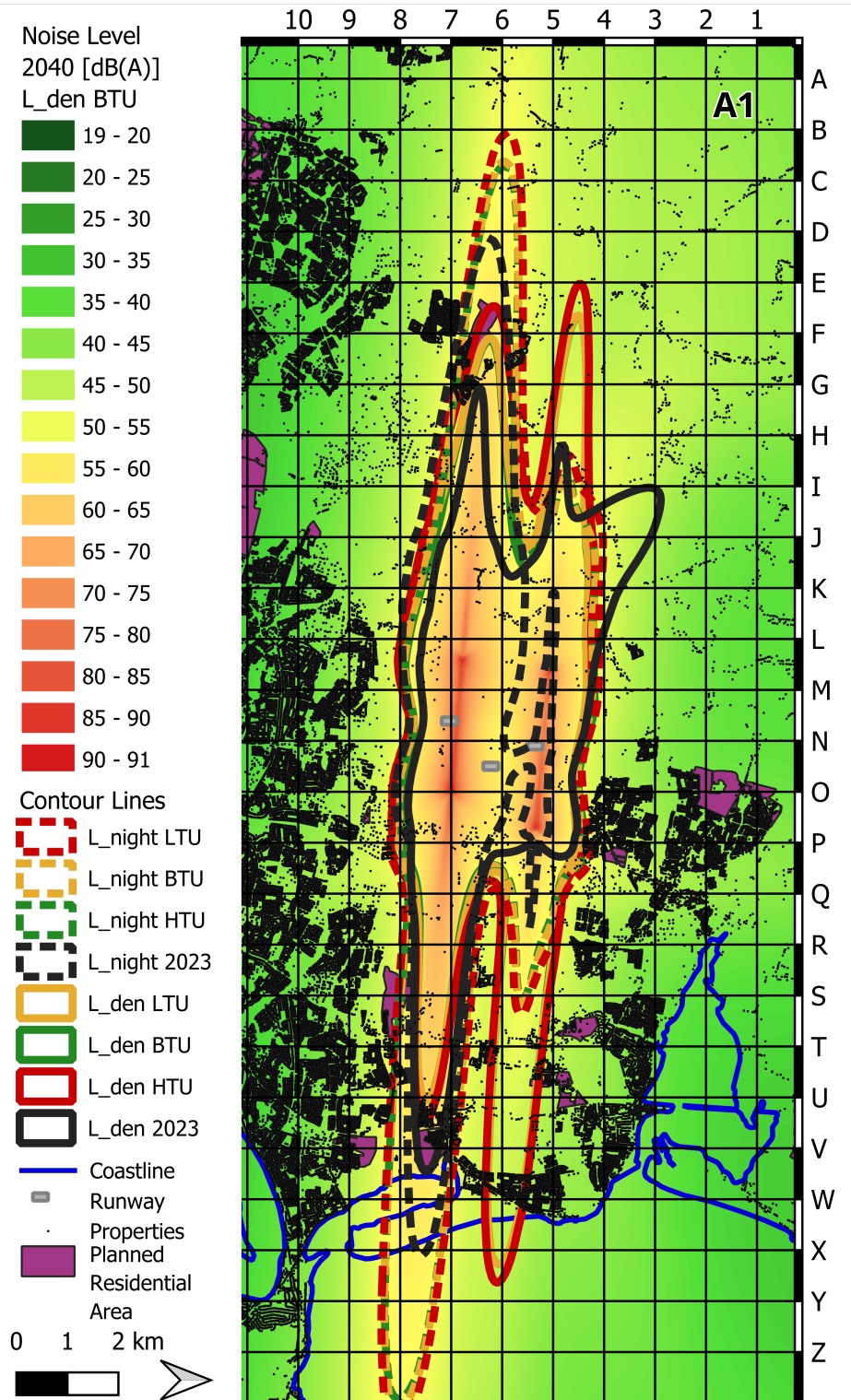


Figure B.2: 2040 noise map for different technology uptake scenarios with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 50$ dB(A) and $L_{den} = 55$ dB(A))

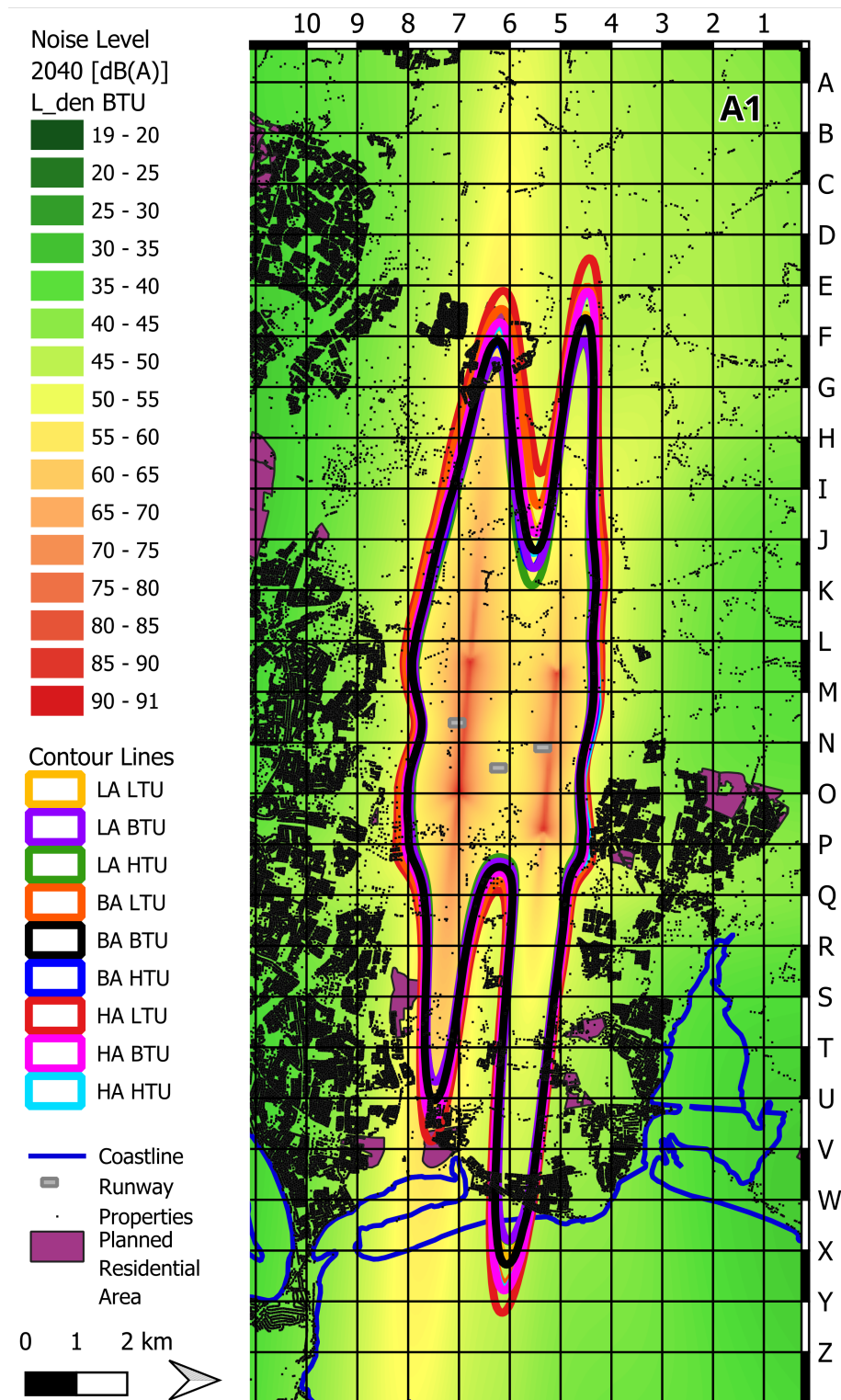


Figure B.3: 2040 L_{den} contour lines for different technology uptake and air traffic increase combinations at Dublin Airport for $L_{den} = 55$ dB(A) with L_{den} BA BTU noise footprint as background

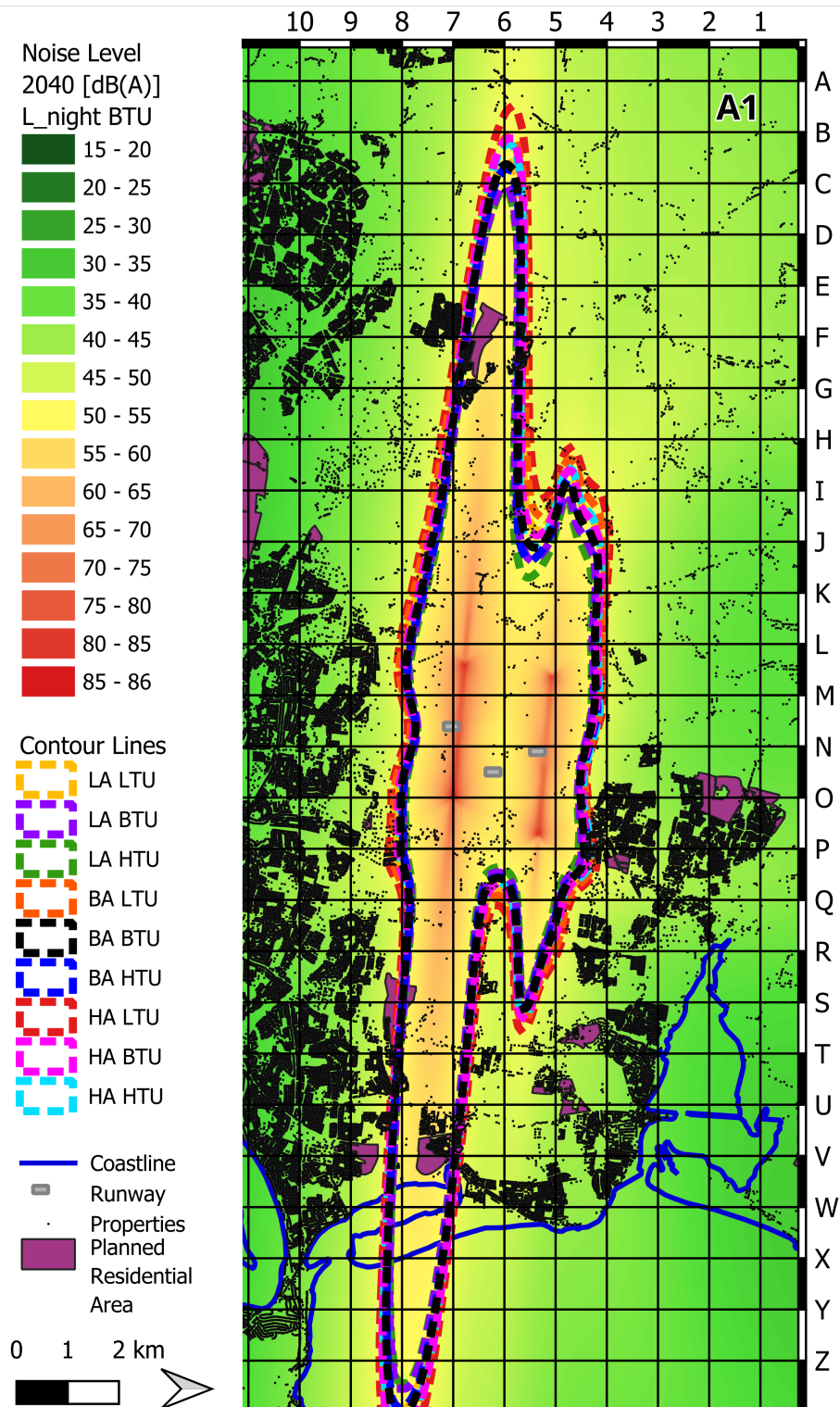


Figure B.4: 2040 L_{night} contour lines for different technology uptake and air traffic increase combinations at Dublin Airport for $L_{night} = 50$ dB(A) with L_{den} BA BTU noise footprint as background

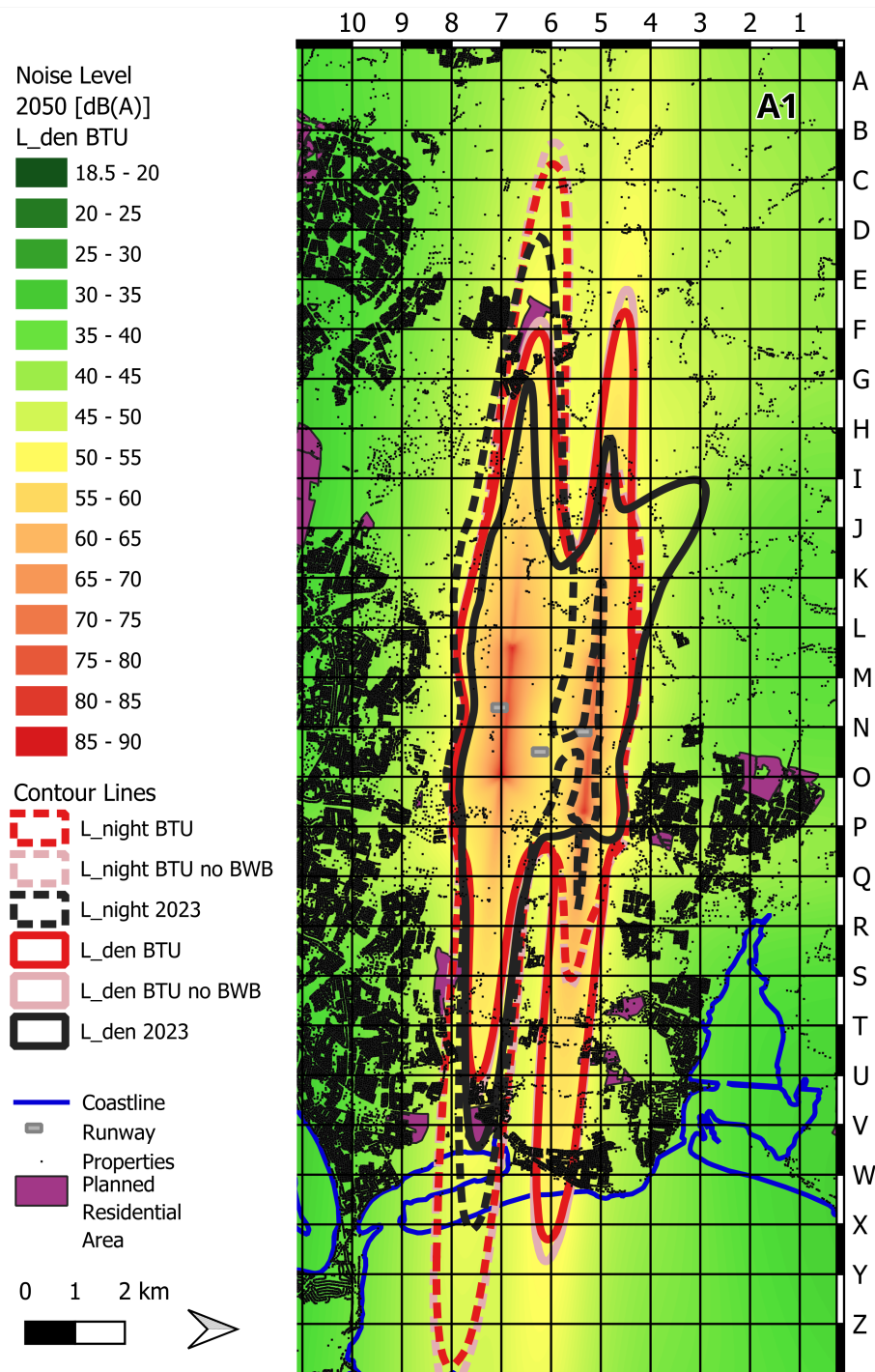


Figure B.5: 2050 noise map for different technology uptake scenarios with and without future aircraft concepts with Base Air Traffic Increase at Dublin Airport with L_{den} BTU noise footprint as background ($L_{night} = 50$ dB(A) and $L_{den} = 55$ dB(A))

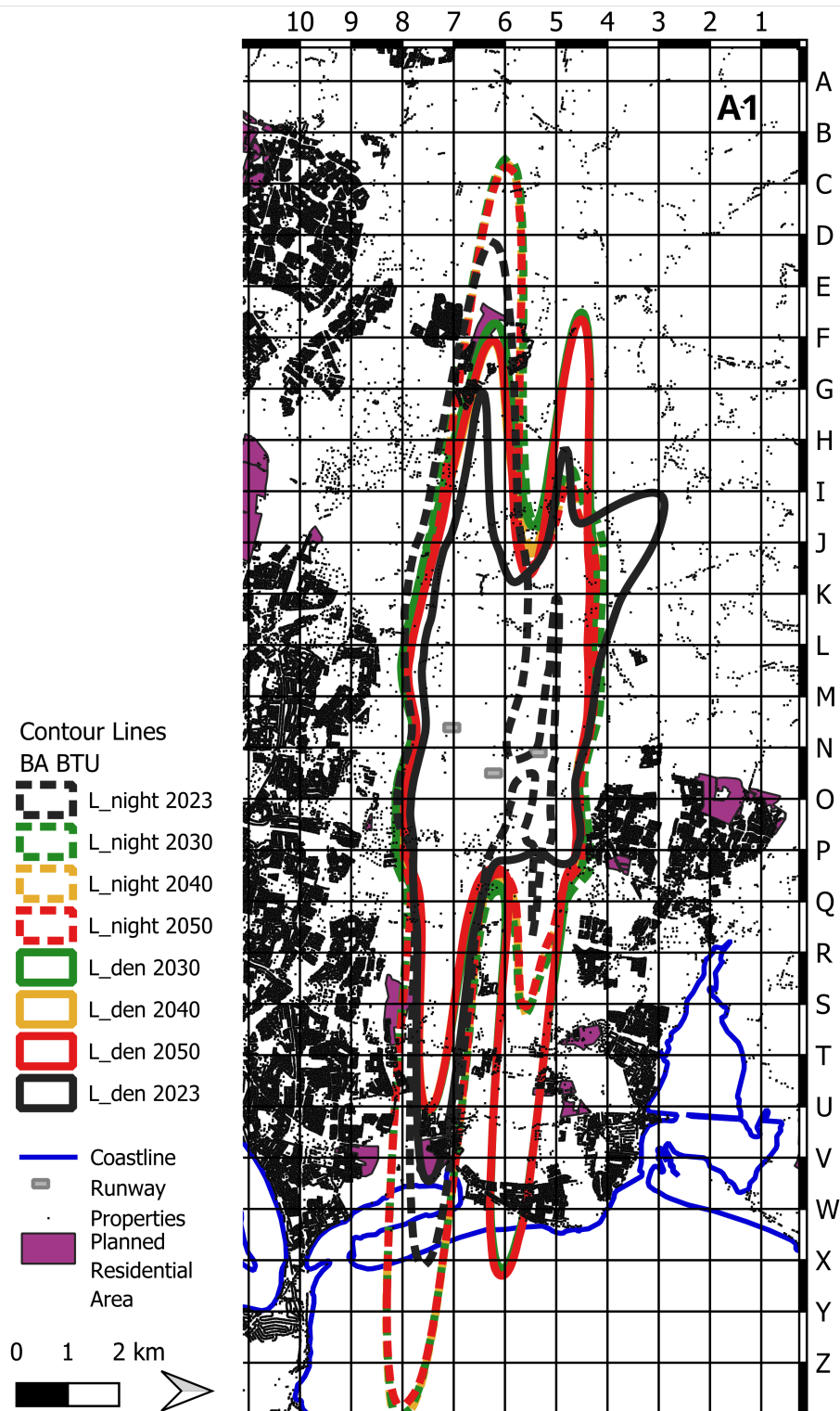


Figure B.6: Noise contours for BA BTU for 2023, 2030, 2040, and 2050 at Dublin Airport (for $L_{night} = 50 \text{ dB(A)}$ and $L_{den} = 55 \text{ dB(A)}$)