HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

SZENT ISTVAN CAMPUS

BSc ENVIRONMENTAL ENGINEERING

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MEASRUREMENT AND ASSESMENT OF NOISE POLLUTION LEVELS ACROSS KEY AREAS OF THE GÖDÖLLŐ CAMPUS

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1. Introduction

Noise pollution also known as environmental noise affects our health and lifestyle in ways most of us are not aware, the threat represented by environmental noise keeps increasing particularly in urban and suburban settings, such as residential areas and universities campuses, and like many other pollutants in the environment, the detrimental effects of exposure are only noticed when health issues arise. It represents an issue to the world's population since continuous exposure to environmental noise has considerable impacts on human health and academic productivity. It disrupts the cognitive functions of the body and increases stress, inducing several health hazards such as heart and vascular diseases, sleep distortion, and its visual impact health issue is the subsequent hear loss according to the World Health Organization (2011), noise is an essential environmental threat to the health of millions of people.

While potentially harmful noise sources can vary depending on the area, understanding the dynamics of how different materials interact at the source points is crucial for categorizing noise in different types such as traffic, railway and aircraft noise, such categorization is important to determine what methods of noise control can be used in attempts for governments to mitigate the adverse effects of noise on people's health and safeguarded by the different frameworks provided by internation bodies like the World Health Organization (WHO), the U.S Environmental Protection Agency (EPA) and the European Union (EU) such strategies align with the guidelines developed by these institutions based on scientific investigations.

My thesis work focuses on the assessment of noise pollution in specific areas within the Gödöllő University Campus environment, using small manual measurements it aims to identify the critical zones of noise pollution within the campus and understand its sources intensity impact on the environment and can be used to understand how the day-to-day sources like traffic or construction works.

Through the assessment done by both, manual and continuous remote measurements, my aim is to provide an overview on what are the prevailing values of noise pollution in the Gödöllő campus and how they vary across different areas understanding what are the sources that have higher risk to emit high noise levels while focusing in whether they remain under the recommended threshold values or not and therefore, might represent a thread for the people residing in the vicinity.

2. Literature review

2.1 Noise as a physical property

To better understand what noise is and how the exposure to high levels of noise affects human health, the field of acoustics must be reviewed, Lawrence et all (1982) explain that this specific field encompasses the 3 different stages of vibrational energy waves in matter, which origins with the generation, transmission and subsequent reception of these waves. Lawrence et all (1982) provide a scientific background regarding these stages, in which the molecules are arranged in what's denoted as "normal configuration" by nature, nevertheless, when displacement of these takes place, a force that intends to tie them back to the original arrangement arises, which is known as elastic restoring force.

From an alternative viewpoint, we can consult to the text "Acoustic and noise control", R.J Peters et all (2013) define noise as essentially any kind of sound which is often regarded as disruptive or unwanted, from the standpoint of the acoustics field, noise is produced whenever there is an energy transfer though the medium in the form of vibrational waves as a result of any modification or disruption in the physical configuration of the medium, whether it is solid, gas or liquid.

2.1.1 Types of sound waves

As explained by Jacobsen et al (2011) based on their distribution pattern, sound waves can be categorized into plane and spherical sound waves. When plane sound waves travel through the medium, they are characterized for the homogeneity of any acoustic variable across any plane which is located perpendicular to the wave's travel path. Plane sound waves are frequently described with two main characteristics such as having perfectly flat fronts that travel in a straight trajectory without any deviation, although this is an idealized idea, it perfectly illustrates how soundwaves behave under controlled conditions inside of isolated environments. Jacobsen et al (2011) use the propagation through a duct as an example of this, since it is a confined medium with rigid walls, it allows the isolation of soundwaves and contributes to propagation of these in a particular direction, while maintaining the characteristic flat fronts by preventing the waves from spreading out laterally across the duct.

Whereas spherical sound waves, as explained by Jacobsen et al (2011) are characterized by having spherical-shaped wavefronts, assimilating to expanding spheres (similar to the expanding waves on surface water after dropping a rock in it) therefore, the sound coming from this type of waves follow a distribution patter in each direction within the medium, forming invisible and expanding spheres. Both type of waves move away move from their source, as they do so continuously decrease the sound's intensity as each wave spread across the space.

In brief, the authors explain that spherical sound waves are the most accurate representation of sound waves found on the real world, specially at low frequencies, since typically point sources such as loudspeakers or any type of sound emitter creates spherical waves, traveling in all directions uniformly as long as no barriers are found in their way, although, for confined environments where sound wave behavior is monitored at high frequencies, such characteristics might deviate from spherical to directional like it is found in plane waves.

2.1.2 What is noise?

With the basics of acoustics and how waves propagate being explained, the concept of noise can be analyzed, in their handbook about acoustics Alton Everest and Pohlmann (2009) analyze the concept of sound within the framework of acoustics in relation to how it is perceived and affects humans, and for this, they provide two different approaches; the first one from the physiological perspective describing it as a sensation that excites of the internal ear mechanism leading to the interpretation of sound by the brain, whereas the scientific perspective focuses on sound as a wave motion moving though air.

2.1.3 Factors affecting the distribution of noise

Noise in the environment is not only shaped by its source, but across its distribution path is shaped by atmospheric conditions. As Bullen and Frickle (2003) explain Meteorological factors such as temperature, wind and precipitation rate play an important role the reach and intensity of noise in the medium, therefore understanding the dynamics of these variables becomes important prior to the noise assessment.

2.1.3.1 Temperature

During the morning or evening, temperature variations cause the air to separate in layers with different densities, and sound waves travel differently trough these layers. At normal weather conditions, the noise travels directly outwards, but during a temperature inversion, what happens is that warm air overlays cooler air, allowing waves to travel longer distances because the warm air layer bends the sound waves back to the ground. It's due to this that during the morning and evening period, the odds of noise levels increasing for many residents living far away on the highway are higher. (Larsson & Israelsson, 2003)

2.1.3.2 Wind

Factors like the direction and speed of wind become an important part of environmental risk assessments since the speed and direction of the wind refract the sound waves making it travel longer distances and times, Bullen and Frickle (2003) explain that as the sound moves with the wind, it get bended towards the ground, resulting in more intense sound (loudness). Additionally, when the sound travels against the wind direction the waves are refracted away from the surface, therefore the sound disperses in the environment.

2.1.3.3 Precipitation

When rainfall, and other forms of precipitation such as snow, absorb and scatter sound waves, it reduces sounds in the atmosphere. On one side, raindrop create refraction and absorption points that reduce the sound intensity. Whereas snow provides an insulating layer and damps sound propagation, since it also has a soft, porous structure and can contain air, thus precipitation can act as a natural block to noise. For this reason, precipitation is an essential factor in noise modeling since the levels of noise are reduced during heavy rains. (Larsson & Israelsson, 2003)

2.2 Effects of noise on human health

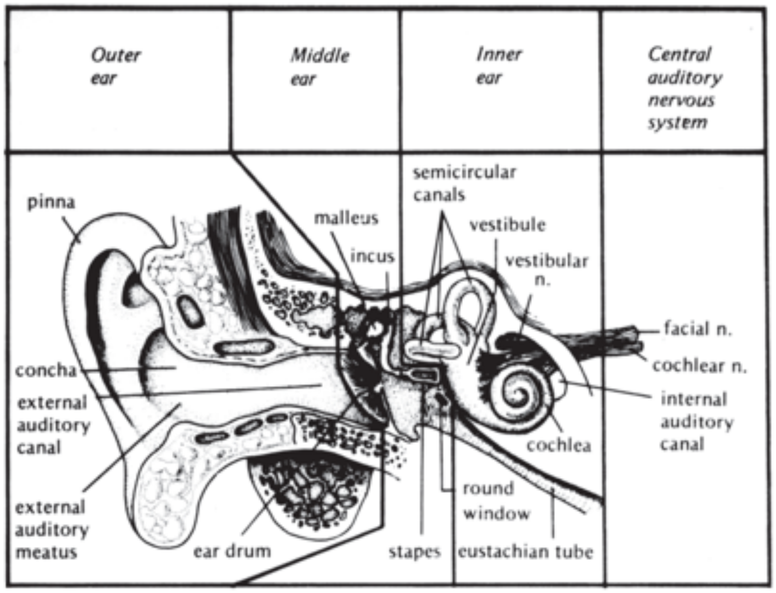
The fast expansion and establishment of urban centers across the world plays an important role in the frequency at which humans get exposed to dangerous sound levels, and while unwanted noise can be originated from multiple sources, the most vulnerable populations can be found inside of major urban centers due to the intensification of the noise pollution levels. Therefore, the regular activities of daily urban life are linked to the exposure of high frequency sounds to residents, which is why it has been identified as a serious threat to public health on a global scale, which as explained by the World Health Organization (2018) is directly linked to a wide range of health issues such as stress, sleep disturbances, cardiovascular issues and the most direct one being hearing loss.

Two main routes in which noise impacts health can be separated into direct exposure, which causes hearing issues and loss, while the indirect exposure causes disruption in daily tasks and rest schedule, while this disruption has not been linked, in first instance, to any physical effects, it triggers stress responses, impacting both the nervous and hormonal systems leading to second staged responses, due to stress levels increasing bring common health risks like high blood pressure and changed blood fat levels worsen. In a long term, all these combined can lead to heart-related illnesses like high blood pressure and ischemic heart disease (IHD), explains the World Health Organization (WHO, 2009)

2.2.1 Hearing loss.

The ear is a complex structure but also sensitive, it is responsible for keeping our balance while standing but also by collecting acoustic waves and transforming them into electrical pulses so that they can be decoded by our brain. In first instance, this process takes place in the outermost section where the sound waves reach the pinna and are directed to the eardrum through the ear canal. Then in the inner section of the ear bones like the malleus and incus help the sounds pass from the air medium to the fluid medium, so that they reach the cochlea. At this point the sound is transformed into electrical pulses by the inner hair cells which act as messengers, while the outer cells can biomechanically adjust their size based on the frequency of the incoming waves to sharpen the sounds our brains read, making the cochlea sensible to a wide range of sound frequencies. (Dobie & Hemel, 2005) – the mechanism and its components are shown in the Figure 1.

Figure 1: Internal structure of the ear system with its components. Source (Dobie & Hemel, 2005)



It's important to highlight the ability of the brain to determine the location of sound sources in the environment, which plays an important role in daily life tasks, Dobie and Hemel (2005) explain that when we try to figure out where a sound is coming from, the brain uses clues to make sense of this and, sound waves, despite not having have actual spatial dimensions, it can be determined if the origin point is located in front, above, or far away.

2.2.1.1 Causes of hearing loss

Generally speaking, the loss in earing functions can be categorized in two main groups, genetic (hereditary) and non-genetic, in one hand, the first category refers to mutations in the genetic that is passed down through generations and manifests at birth or develop later during the growing stages, whereas the non-genetic refers to such disorders or malfunctions caused by environmental or obtained causes, the term encompasses presbycusis (which is the natural hearing loss caused by aging), exposure to environmental noise, diseases caused by infections and traumas associated to accidents. Dobie and Hemel (2005) categorize the hearing loss into the following ranges based on the loudness as follows:

- Slight (16-25 dB hearing loss)
- Mild (26-40 dB hearing loss)
- Moderate (41-55 dB hearing loss)
- Moderately severe (56-70 dB hearing loss)
- Severe (71-90 dB hearing loss)

- Profound (greater than 90 dB hearing loss)

With the growing of urban centers the necessity of properly managing environmental noise becomes clearer, Muzet (2007) on one hand, emphasizes how noise can harm individuals' sleeping cycle which plays an important part in physical and mental recover and when it get compromised in any way can lead to chronic sleep problems, decrease individual's quality of life due to constant feeling of exhaustion and even long-term health risks such as cardiovascular problems from time to time.

2.2.2 Sleep cycle disturbances

2.2.2.1 Sleeping cycle and its importance

The human body along with the brain need to have rest periods, and the sleep cycle is the only time in which both can be achieved, this is why a healthy sleep cycle is crucial, since it allows us to recharge, process the day's experiences and consolidate memories and knowledge gathered in the memory. An overview of the sleeping cycle is provided by Fuller et al (2006), listing the main two mechanisms that drive the sleep cycle: circadian rhythms and homeostatic sleep drive. Circadian rhythms are in summary the body's internal biological clock, which under the control of the suprachiasmatic nucleus in the brain help synchronize the sleep-wake cycle within the 24-hour day, ensuring that awake and sleep happen at the proper times of the day due to its susceptibility to external environmental stimuli, in special light and noise sources.

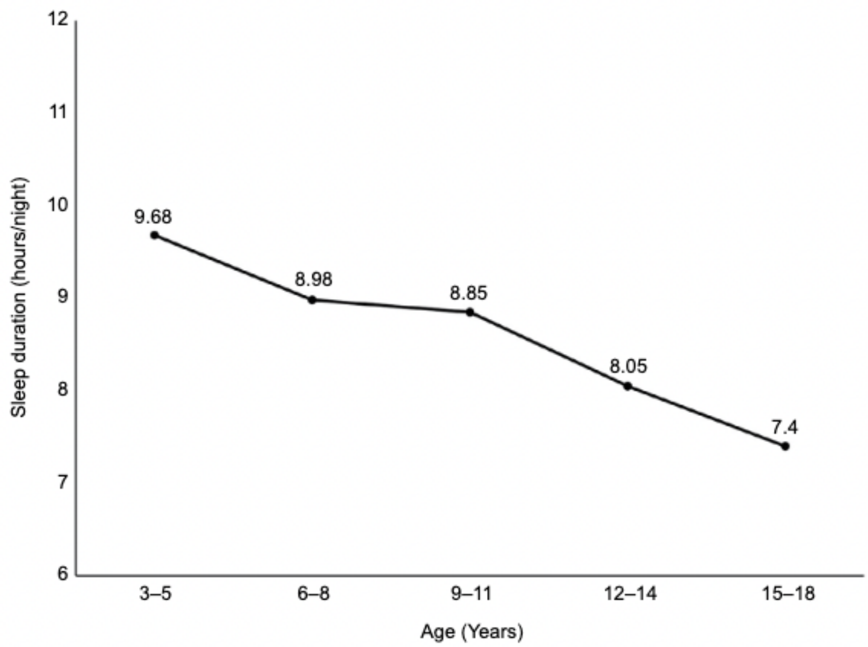
Maintaining a healthy and constant sleep-wake cycle depends essentially on the interaction between these two, and whenever high levels of environment noise interrupt sleep, they alter the balance between the circadian and homeostatic systems. This leads to what Fuller et al (2006) define as "sleep fragmentation", where spontaneous transitions between sleep stages are not complete, reducing the quality of sleep and disrupting the REM sleep stage, which are both critical for physical recovery, memory consolidation, and emotional regulation.

2.2.2.2 REM and non-REM phases and their importance

The REM (Rapid Eye Movement) phase of the sleep cycle is where most dreaming happens due to the active state of the brain and high neural activity, showing patterns almost similar as to when we're fully awake, although, the body is under a full relaxation phase where only breathing and eye movement muscles are used, as explained by Fuller et al (2006). REM phase plays a big role in processing emotions and consolidating memories, this is why while we're in REM sleep, our brains are busy with the separation and organization of the learning and experience gathered throughout the day.

Any fragmentation caused by disrupting the REM phase stops the brain from performing the relevant tasks, which causes individuals to face challenges while processing emotions and to have clear thinking and long-term memory formation during the REM phase. Since the human brain possess a “toggle mechanisms" to naturally facilitate the changes between being in deep sleep phase and being awake, the authors explain that frequent interruptions, like environment noise can interfere with this toggle mechanism leading to sleep patterns and leaving us feeling mentally and emotionally exhausted. (Chaput et al, 2018)

Figure 2: Normal actigraphy-determined sleep duration values in children aged 3–18 years. Source (Chaput et al, 2018)



To better understand the importance of a healthy sleep cycle Chaput et al (2018) explain its connection to an overall well-being condition and how sleep cycle duration changes through humans’ life spawn. Their actigraphy study demonstrated that babies typically sleep for 12. 7 hours each day in average whereas toddlers and preschoolers get around 11. 9 hours of sleep daily and elementary school children aged between 6 to 12 years old usually get an average of 9. 2 hours of sleep per day. Additionally, their study explains that sleep schedules tend to drop-in sleep hours from approximately 10 hours among 3- to 5-year-olds to just about 7 and a half hours for youths aged 15 to 18 years old, as it is shown in in Figure 2.

The discussion about the effects can be described around two focus points: physical and cognitive health. In one hand, Chaput et al (2018) explain that individuals with poor sleeping quality present cognitive abilities disruption such as memory, attention and emotional regulation. Whereas, in terms of physical health, sleep disruptions in a chronic level can be directly connected with the increased risk of developing physical conditions such as hypertension, cardiovascular diseases and diabetes due to the fragmentation patterns in the sleeping cycle that alter the hormonal and metabolic processes responsible for regulating hunger and energy, leading to overeating and gaining weight.

2.2.3 Hormonal effects

Due to daily basis exposure, noise pollution has become an accepted environmental problematic and stressor among inhabitants in metropolitan centers, and one of the biggest concern arise in the relation it has with sleep disturbances and interruption in the circadian cycle, an essential, internally regulated process that affects multiple physiological processes such as hormonal balance and metabolic activities, which leads to metabolic disorders, cardiovascular diseases and several cancer types. (WHO, 2009)

Melatonin also known as the "darkness hormone" which is secreted by the pineal gland to the bloodstream during nighttime is responsible for controlling the sleeping cycle and preventing cancer due to the capacity it has to influence a few immunological functions in the body that are important in cancer metastasis. The issue lies when the generation of melatonin is affected by sleep fragmentation which causes unbalance and increases the vulnerability to a number of endocrinological disorders, as Blask explains (2008), therefore, understanding this relation is important in the development of public health policies that seek the individual well-being.

2.2.3.1 Melatonin and its importance in the body

Melatonin has multiple action mechanisms that prevent the development of cancer, these mechanisms can be explained from different perspectives; for instance, during cancer metastasis, cells lose their cohesion ability, which allows them to break down from the primary tumor and spread out in the organism, this is where melatonin comes into play, since it boosts the production of molecules that help maintaining the adhesive properties of cells through their cell walls. Additionally, melatonin helps in the inhibition of matrix metalloproteinases (MMPs) enzymes, which are uptake by cancer cells and utilized to degrade the extracellular matrix and spread freely into human tissues, as it is explained by Chi Su et al (Su, et al., 2016).

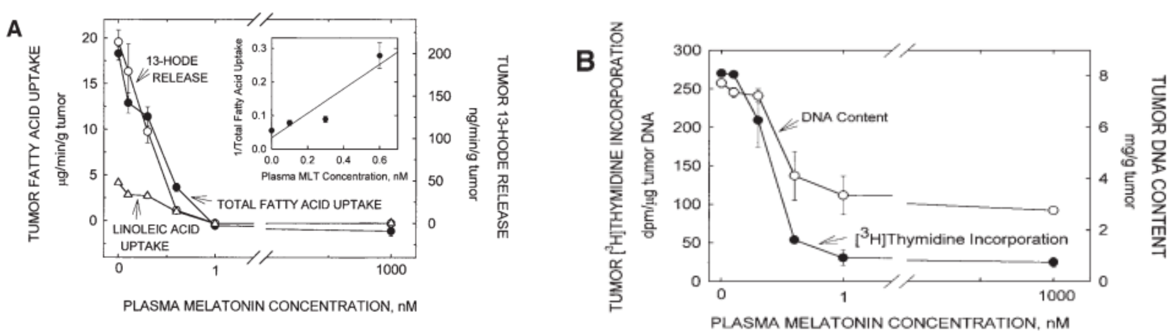
Parallelly, Chi Su et al (Su, et al., 2016) explain that, melatonin prevents the formation of new blood vessels which tumors use as a mean to grow and spread, also known as angiogenesis, therefore, they are crucial in cutting the tumor's blood supply which drives its growth and chances to metastasize.

On the other hand, high concentrations of melatonin were linked to the suppression of linoleic acid absorption, which is an acid used by tumors to boost their growth takes after going a metabolization process that turns this acid into 13-hydroxyoctadecadienoic acid (13-HODE), which drives the tumor growth rate, as it was found by Blask et al (Blask et al, 2005) in their experiment about tumor growth inhibition properties of melatonin through in vivo and in vitro models.

Firstly, the in vitro model sought to illustrate how melatonin impacts the metabolism and growth of MCF-7 cancer cells, a cancer cell line used to study breast cancer due to its ability to grow when exposed to estrogen. Blask's study (Blask et al, 2005) concluded that melatonin's ability to cease the growth of the cancer cells remained the most effective at the concentration which is closer to the one naturally produced by the pineal gland during the circadian cycle at night- The figure 2 displays how the release of 13-HODE along with the absorption of acid and the total linoleic acid uptake decrease as melatonin levels increase, indicating that melatonin delays these processes based on the dose amount.

On the other hand, the in vivo model sought to support the theory that melatonin affects the growth of cancer cells in living animals, by using "tissue isolated" hepatomas in Buffalo rat specimens. The liver tumors and breast cancer cell tumors (MCF-7) inside of the specimens got different concentrations along with different conditions to alter the day-night cycles, some specimens had their pineal gland removed to remove the production of melatonin and others were given supplements boost the melatonin concentration even more. As expected, the results concluded that individuals with normal concentration presented a slow tumor growth speed (especially during at night during the arcadian cycle) and the melatonin supplementation though diet had even a stronger effect, whereas the individuals with no pineal gland saw an accelerated growth rhythm - Figure 3 displays how the growth inhibition increases as the concentration increases by lowering the tumors mass (shown as decreased DNA content) and the rate of DNA replication (shown as decreased thymidine incorporation).

Figure 3: Growth inhibition increases as the concentration increases by lowering the tumors mass and the rate of DNA replication in the case study. Source (Blask et al, 2005)

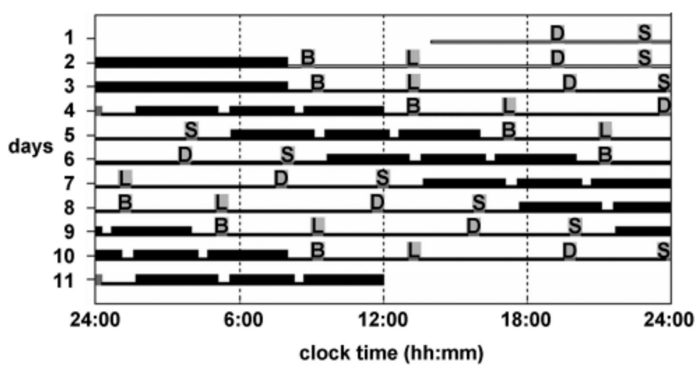


2.2.3.2 Role of melatonin in hormonal processes

Since Melatonin's secretion levels are higher during the evening, concerns arise around people with working schedules during the nighttime, and the effect of such misalignment is explained by Scheera et al (2009), where approximately 9 million people working night shifts in the US leads to distorted circadian and eating schedules, which is directly linked to and increased risk of obesity or type 2 diabetes.

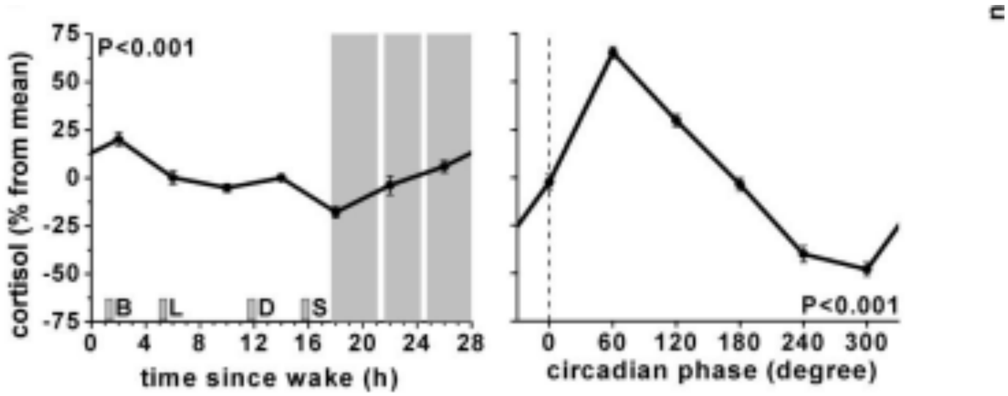
The study conducted by Scheera et al (2009) explains more into details the 3 implications of schedule changes, in certain occasions the individuals were allowed to sleep during the day and were awake at night. Thick black bars show when they slept, and gray bars show when they were given meals (B for breakfast, L for lunch, D for dinner, and S for snack). Whereas their wake times are shown as thin lines, and after Day 2, they were in dim light to confuse their body clocks – as shown in the Figure 4.

Figure 4: Methodology of the sleep case study. Source (Scheer, Hilton, Mantzoros, & Shea, 2009)



- Cortisol rhythm disruption: Cortisol is segregated by the adrenal glands as a response to stress, but also regulates physiological processes such as metabolism, immune response and blood pressure, it also regulates how the organism consumes carbohydrates, fats and proteins as explained by Scheer et al (2009). In this sense, the normal secretion rate of cortisol follows high levels in the morning right after waking up, gradually decreasing throughout the day, reaching the lowest point at night, and this process is directly driven by the circadian clock that is naturally integrated in the body – as shown in the Figure 5.
  The study found that the alteration in cortisol levels at the end of a day cycle, and the sleep cycle starts, contributes to insulin resistance, interfering with its task to regulate the blood sugar levels, leading to the development of insulin resistance and higher blood sugar levels which are both cause type 2 diabetes.

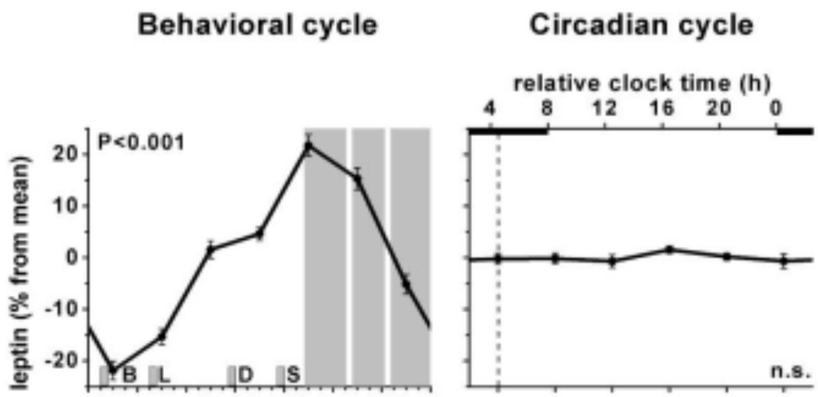
Figure 5: Cortisol's secretion natural rhythm during the day after each meal, the right side shows the path of cortisol driven by the circadian rhythm with the peak in the morning. The decrease follows the natural body's clock regulated by daylight. Source (Scheer



- Leptin suppression: In the human body, Leptin is produced by fat cells, and is an important part in the regulation of food intake and energy balance, its action mechanism is based on letting our brain know how much fat is stored in the body, it kind of keeps energy stuff in check, therefore, when the fat storage is high, leptin secretion increases, which tends to cut down on hunger and makes the body burn more calories. Whereas if the fat storage is scarce then leptin diminishes, and hunger ramps up while less energy is used. Conditions like irregular circadian cycles and non-aligned eating schedule affect this balance and suppress the secretion of Leptin in the organism.

  After their study, Scheer et al (2009) concluded that any misalignment in the sleeping cycle results in significantly diminished leptin concentrations. Additionally, lower levels of increase appetite cravings while decreasing caloric usage which brings added weight and possibly insulin sensitivity issues that open the doors to type 2 diabetes- Figure 6 shows how leptin levels are low before breakfast (B), after breakfast, lunch and meal (B, L, M) leptin levels raise and during sleep (S) the levels decrease being that the body enters a fasting stage, and the right side shows that leptin levels remain stable during the circadian cycle.

Figure 6; leptin levels before breakfast (B), after breakfast, lunch and meal (B, L, M) leptin levels raise and during sleep (S) the levels decrease due to fasting stage. Whereas the right-side shows - Source (Scheer, Hilton, Mantzoros, & Shea, 2009)



The previous findings around sleep schedule disturbances demonstrated the effects of environmental noise and contrast them with the importance of maintaining a healthy sleeping cycle to preserve the constant secretion of hormones like melatonin and preserve its protective functions, and this is why, public health policies around urban centers must aim to address environmental noise and the long term consequences it has along with ensuring the welfare of populations against cancer and other metabolic diseases caused by hormonal disturbances.

2.2.4 Stress indicators, cognitive and emotional response effects

The discussion about the cognitive and emotional effects of noise disturbance in humans requires to understand that the constant exposure to environmental noise makes the auditory system, and thus, the brain to be at constant active mode, receiving and analyzing acoustic stimuli from the surroundings, to have a clearer perspective on this Spreng (Spreng, 2000) explains the neurophysiological processes that occur internally whenever living creatures are exposed to different noise levels. Specially in the Amygdala, which processes emotions - stress and fear responses to different stimuli included, in this sense, the acute environmental noise exposure affects its functionality, resulting in a quick release of stress hormones like cortisol.

On the other hand, a longer-term exposure to relatively high environmental noise leads to what Spreng (Spreng, 2000) defines as neuroplasticity in the amygdala, which in simple words increases its sensitivity to sounds, triggering difficulties in the brain's abilities to respond to experiences – basically the brain gets modified to generate a fear response in noisy environments.

The World Health Organization (WHO, 2011) describes the cognitive abilities as the capabilities of children to read and comprehend, while using their brain functions to memorize and remain focused, which are all important in the academic environment. All these abilities become vulnerable when exposed to noise pollution for a long period of time.

Reading deficits and memory loss are caused because of the exposure to noise pollution. But it may be possible to reverse the effects of deficit if the exposure is removed from the environment, this was demonstrated through a study conducted in Munich airport child exposed to environmental noise like traffic or aircraft for a prolonged time may also be exposed to cognitive deficits like memory and problem in reading. But, when the airport was resituated, the impact on their memory and reading abilities of the children improved within a short time of two years. (Hyge, Evans, & BUllinger, 2000)

On the other hand, The RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) study was performed with the aim to deep dive into the effects of aircraft noise, and in this way, identify the impact of noise pollution on children's cognition and health. The research was conducted in schools near the major European airports in the UK, the Netherlands, and Spain, involving nearly 3,000 children from 90 schools. Based on the results, a clear relationship between aircraft noise and lower reading scores was stablished - In the RANCH study, even a 20 dB increase in aircraft noise at a child's school led to a decrease in reading scores equivalent to a two-month delay in progress, explain Matheson et al (2003) Both types of noise led to poorer performance in terms of the children's sustained attention and speed of reaction.

2.3 Mitigation strategies against noise pollution

As result of the previously mentioned effects, regulatory institutions have shifted their focus around the most prevalent sources of environmental noise in every day's life, this includes road traffic noise, railway noise and construction site noise. Such regulations have been developed with the aim to:

- Reduce noise exposure while stablishing and preserving quiet areas
- Coordinate strategies to reduce noise sources
- Involve the exposed communities that may have been potentially exposed and making information related to noise exposure levels public

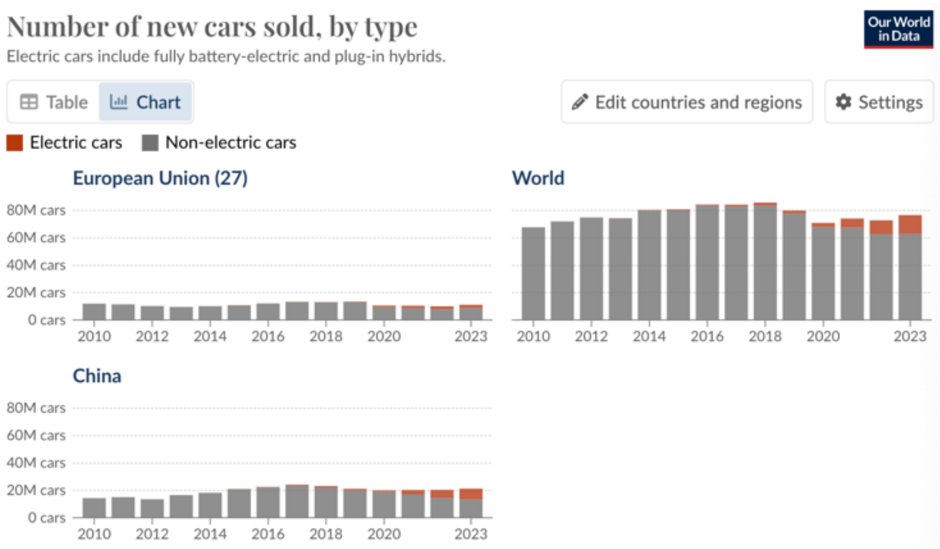
The following mitigation strategies focus on addressing concerning noise sources in urban and suburban feature in addition to the marine ecosystems.

2.3.1 Road traffic noise

In recent years, with the rapid expansion of urban centers and population the vehicle market keeps gaining strength and car ownership across households raises dramatically contributing to alarming levels of noise pollution withing urban centers, leading to concerns regarding the long-term impact of noise pollution on public health since road traffic noise affects in a large scale to a big proportion of the global population reaching the alarming number of over 100 million people, in the European

Union only, being directly affected to harmful levels of road traffic noise which exceeds the threshold value established by the WHO during the day period (53 dB). (WHO, 2018) – Figure 7 shows the vehicle market behavior from 2010.

Figure 7: Number of vehicles sold in the different markets. Source (Our World in Data, 2024)



Since the early 1970's car manufacturers have strived to develop new technologies that help reducing interior vehicle noise as a response to the governmental demand for vehicle that make less noise, and while this has been achieved with the past of the time, exterior noise remains a major problem in contrast to interior noise. Murphy and King (2014) explain that the main two sources of traffic noise are engine noise and noise originated from the tire/road interaction (also called rolling noise), and both being determined by the vehicle's speed.

The parameters that contribute to the increased severity (in terms of loudness) and spread patters of traffic noise include:

- Traffic volume: there is a stablished link between the quantity of vehicles in a specific area and the magnitude/duration of the sound levels produced by them, relation which is determined by the uprising sales in the car manufacturing industry.
  The presence of highly concentrated and busy roads results in more vehicles braking and accelerating, in addition to claxon noises which then sums to the highly polluted noise environment conditions. The research done by Yang et al highlights how the traffic volume during peak hours in the Chancheng District, Foshan in China leads to elevated levels of noise pollution which is also linked to the vehicle volume, since the authors mention that despite high traffic volume the distribution of cars across main road helps mitigating the dispersion of noise within less busy areas, however, when the peak hour comes, vehicles are spread across secondary and less occupied roads which leads to a more widespread

noise impact across the city. Additionally, the study found that for every doubling in traffic flow (exact quantity of vehicles), the produced noise increases by 3 dB. (Yang, He, He, & Cai, 2020).

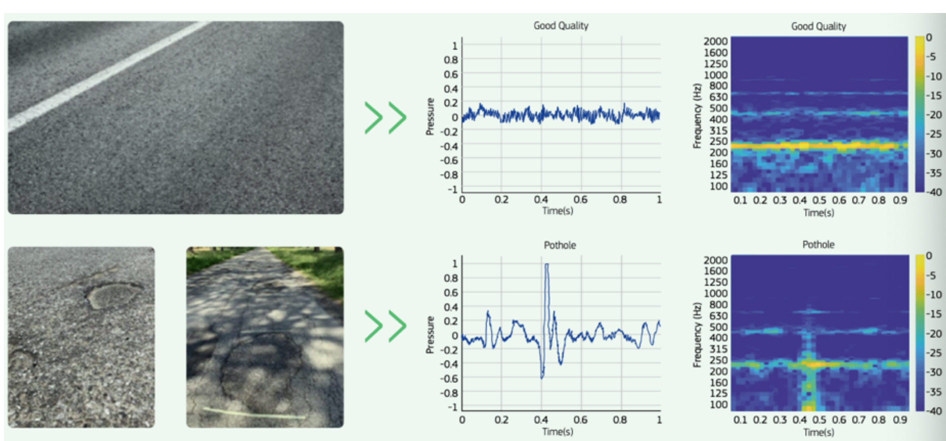
Finding such as this, suggest that when it comes to mitigation strategy development, factors such as managing vehicle speed and quality of the roads should be considered as well instead of focusing only on traffic volume reduction.

- Vehicle speed and road surface: aiming to understand the dynamics of the traffic-made noise for this Murphy and King (2014) establish a relation between the vehicle's speed and the noise intensity. While moving at lower speeds, the prevailing source of noise comes from the engine being that; first, there is less friction between the tires and the road, and second, the engine works harder in relation to the speed at which the vehicle moves.

  In contrast to this, as the speed increases, the friction between the tires and the road increases as well, leading to increased rolling noise, even reaching points where the external noises produced from the road and tires exceed the engines noise, also known as "crossover speed". This concept becomes important when understanding the traffic and noise dynamics since it variates depending on the type of vehicle, which will be explained next. (Murphy & King, 2014)

- The maintenance of roads also plays an important role since cavities in roads produce impacts between the surface and the tires leading to increased noise levels as is demonstrated in the Figure 8 by the European Commission (2024).

Figure 8: Noise spectrum comparison between a flat surface and a damaged road surface. Source (European Commission, 2024)



- Types of vehicles: the relationship between the vehicle type and the crossover speed shows a directly proportional increase. For instance, heavy vehicles, have a higher crossover speed due to the larger-sized engines and tires, as Murphy and King (2014) explain the larger the engine the louder it is during its operation stage meaning that the point in which the external noise (coming from the tires and road interaction) overtakes the internal noise (engine) takes places at higher speeds.

On the contrary, electric vehicles which implement a minimal noise engine have a much lower crossover speed, as a result this, even at low speeds the external noise produces by the tires the development of this near-silent technology helps reducing the engine noise component in the environment noise. (Murphy & King, 2014)

To illustrate the primary mitigation strategies against road traffic noise pollution, we can refer to the European Noise Directive (2002/49/EC) which requests all the European Union Member States to develop action plans to address this issue, one of the most used strategies is low noise road surfaces, which designed to reduce the rolling noise caused by the friction generated at high speeds. The focus is to modify the surface texture and material composition to reduce the spread of sound waves, this is achieved through smoother surfaces by using materials that absorb sound waves. Additionally, the European Parliament draws attention to the Netherlands with nearly 6.600 Km, representing 90% of the main roads being covered with low-noise materials. (European Comission, 2024)

Figure 9: Main 3 materials used in low noise surface road in the EU Source and their main features (European Commission, 2024)

Type	Description	Noise reduction	Durability
Double-layer porous asphalt	The top layer consists of finer aggregate and the bottom contains coarser aggregate, while the porous material at both layers allows air to pass through, thus reducing the noise	Offers the best noise reduction, up to 6 dB	The average lifespan fluctuates between 8 to 12 years, which is shorter than average asphalt (15-20 years)
Thin surface layers	Additional asphalt layer added in already existing roads, which contain fine aggregates that create a smooth surface	They provide moderate noise reduction between 2-4 dB	Their durability is relatively low, requiring more often maintenance, although they are quick and easy to apply.
Stone mastic Asphalt (SMA)	Gap-graded asphalt mix with a high concentration of coarse aggregate	While is less effective than double layered asphalt, it reduces noise by 2-3 dB	High durability, often lasting as regular asphalt (15-20 years) and require less maintenance.

2.3.1.1 Innovative approaches

A different approach is based on developing new materials that enhance road surfaces and reduce traffic noise while remaining durable, such as the ones developed by EUROVIA and COLAS under the framework of the LIFE SILENT in the EU. Their target was the production of a road surface that aims to improve the acoustic properties of asphalt. To introduce the idea three pilot sites were announced by the Paris City Hall were 200-meter sections made from this coating were installed along with continuous noise monitoring stations to measure their effectiveness. The first yearly assessment published in 2020 showed a reduction of 3 dB compared to the existing recorded values, emphasizing that such reduction is more evident at night when the number of vehicles is lower along with the speed. (EU, 2020)

In addition to this, new technologies and materials are being implemented to build noise barriers, from different materials along with integrated functions such as photovoltaic panels that produce renewable energy, a remarkable example of this can be found in the Netherlands and Italy, where photovoltaic systems with a the capacity to produce up to 48.5 kWp has been integrated into the already existing noise barrier in the A27 highway near Utrecht, whereas in Marano d'Isera, the photovoltaic barrier implemented in the A22 highway has a total capacity of 730 kWp which produces an estimate of 690 MWh per years, serving as main electricity provider to the nearby villages and although both cases might present flaws either in efficiency (mostly due to pollution which obstructs the panel's efficiency) or noise pollution decrease, they both showcase the importance of such innovative approach that takes advantage of the already existing infrastructure to produce energy. (Jong, 2015)

Another remarkable example can be found in Switzerland, where the A22 motorway hosts the first photovoltaic noise barrier (FVNB) ever installed in the country, constructed in 1989 with the support of the Swiss Federal Roads Office (FEDRO), Poe et al (2017) explain that the barrier produces an estimate of 108,000 kWh per year. A few years later, the model was integrated in multiple roads across Germany, with the aim to explore new FVNB technologies aligning with the frameworks stablished by the Renewable Energy Source Act and the Energiewende policy that promotes using low-carbon energies.

2.3.2 Railway noise

The expansion of cities and towns increases the proximity of human settlements to railway tracks which aim to interconnect and make transportation easier and faster, however, this becomes a thread in dangerous noise exposure, especially for residential areas across the railway paths. In the same way, the rapid urbanization rhythm has led to the development of residential zones near railway corridors that were previously isolated from major urban centers and railways often pass through such areas that have now become densely populated urban spaces, explains Kumar and Chowdary in their study. (Kumar & Chowdary, 2023)

Similar as to traffic noise and, the noise sources can be categorized based on the source factor and the characteristics of it, and while they all contribute to noise pollution it's important to mention that the intensity of them change based on speed and infrastructure conditions.

- Rolling noise: under the same principle as with vehicles, its derived from the interaction between the wheels and the rails, and its intensity changes depending on the train's speed, resulting in higher noise levels in high-speed rail operation areas. Furthermore, the conditions of the wheels and rail surfaces determine the rolling noise emission, since any irregularity or damage in the surface changes the friction between both surfaces. Kumar and Chowdary (2023) found that difference in noise levels between smooth and rough surfaces often exceed 20 dB, due to the increase in the surface roughness which results in additional vibrations of the train.

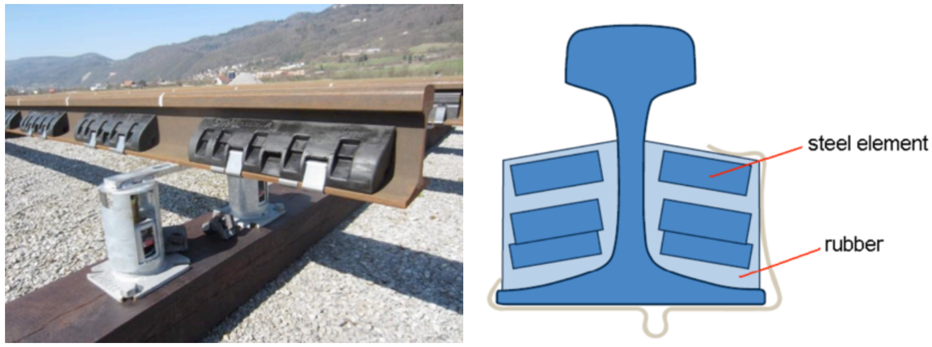
- Aerodynamic noise: the aerodynamic noise becomes a critical source of railway noise in developed countries such as Japan, China, the US and Western countries in the EU, which count with the proper high-speed infrastructure. Kumar and Chowdary (2023) explain that the causes of aerodynamic noise are cause due to design features, like the front section, pantograph (the structure that connect the train to the contact wires for electric input), the gaps between the wagons and the ventilation holes places across the entire structure of the wagons, as the train moves airflow intensity interact with the surface of this components, which at higher speeds (usually above the 200 km/h point) produces intense noise.

- Engine noise: as it happens with traffic, the engine noise is only a problem when the speed is low enough, so engine noise prevails over the external noise sources, Gidlöf-Gunnarsson et al (2011) explain that at speeds below 50 km/h, the mechanical movements in the engine and components such as the exhaust system, air intake, and engine block vibrations generate enough noise to prevail over the external noise sources.

Although mitigation strategies can be approached by train component design and infrastructure design, it's important to mention that the previous findings emphasize on the importance of a combined approach when designing mitigation strategies, for instance, reducing wheel noise alone will not serve effectively but only if multiple strategies are combined at the same time, some of the essential methods include:

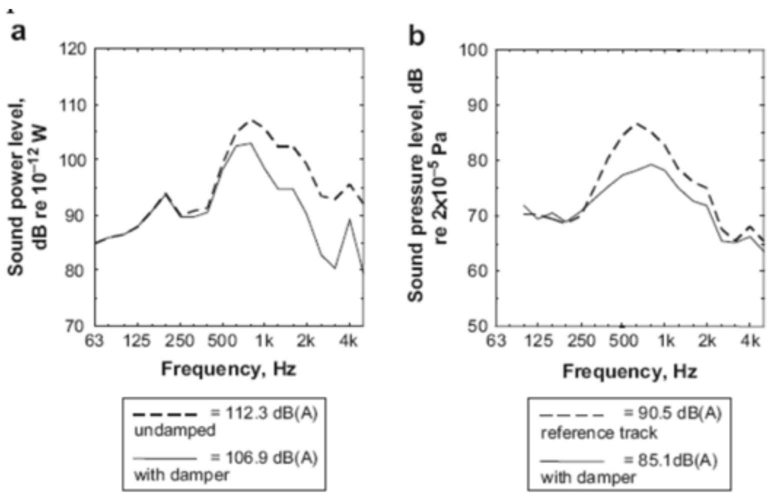
- Rail dampers: attached to the sides of the rails to reduce the vibrations produced by the rail/wheel interaction due to the rubber-made base that connects the rail and steel components. Dampers are usually mounted using clips of bolts and strategically placed so they don't interact with the track maintenance. In the system, the rail dampers work by adding a mass to the vibrating rail via a rubber material (elastomer). (Dumitriu & Cruceanu, 2017)

Figure 10: How dampers are built and integrated into the track system. Source (Dumitriu & Cruceanu, 2017)



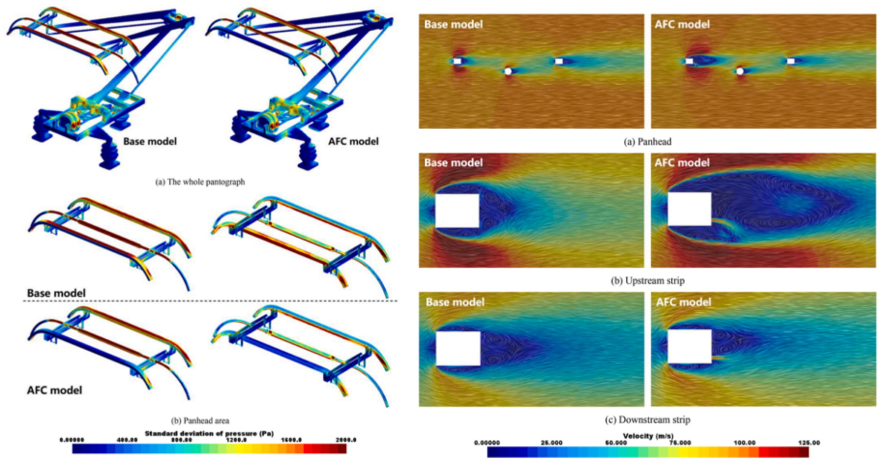
In their study, Dumitriu and Cruceanu (2017) highlight the reduction of approximately 4-5 dB rolling noise after the implementation of rail dumpers, also shown in the Figure 11.

Figure 11: Impact of the rail damper from rolling noise at 100 km/h. Source (Dumitriu & Cruceanu, 2017)



- Improved pantograph design: The idea behind redesigning the pantographs originates due to added aerodynamic noise produced by their non-streamlined shape, which creates turbulent airflow and, thus, aerodynamic noise which increases as the speed does it too. In their study, Shi et al (2023) explain that the component responsible for the noise production is the part that connects the train to the electric lines, known as the panhead. To mitigate this, planar jets are added on the side of the panhead, these modify the airflow by suppressing lift and aerodynamic drag to reduce noise – as shown in the Figure 12.

Figure 12: Base pantograph model and the AFC model that implements the jets, describing the surface pressure fluctuation. Source (Shi, Zhang, & Li, 2023)



While the study done by Shi et al (2023) found that the planar jet design reduces noise for the upstream strip showing a lower performance on the downstream strip, it also resulted in a reduction of approximately 7 dB in noise.

- Noise barriers: Reflective noise barriers are designed work as a mirror and reflect the soundwaves back in the source's direction or up towards the atmosphere, Sarpalius and Grubliauskas (2022) explain that they are usually constructed from acoustic material – these include concrete, steel or bricks, their design varies in shapes from Y and T forms, which are mainly focused on absorbing or reflecting the sound waves depending on the specific shape. Noise barriers are also built in different heights for various purposes:

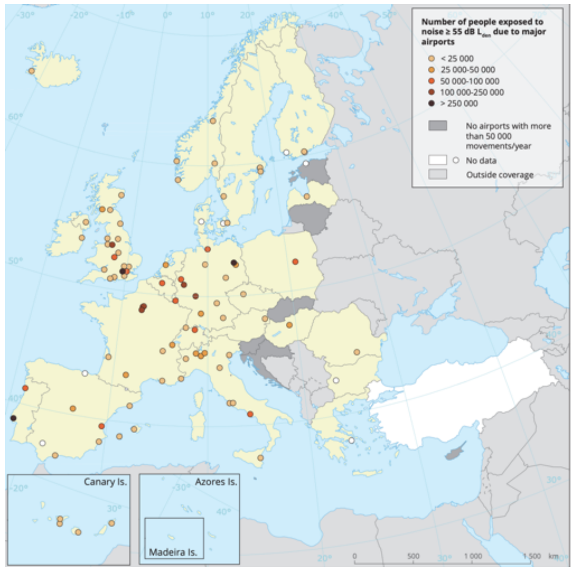
  Low height barriers vary from 1-meter to 2-meter height, whereas high height barrier which are usually built from 3 to 5 meters, they are commonly used in high-speed railway systems due to the high noise levels since they are way more effective at mitigating noise across bigger areas. (Sarpalius & Grubliauskas, 2022)

In conclusion, the mentioned strategies showcase the positive impact barriers have in reducing sound levels in residential areas across the train path, in the case of high-level barriers they can reduce noise by up to 15 dB, while 2-meter barriers reduce noise by 5-10 dB. Also, it confirms that the combined approach of the 3 strategies helps creating proper railways systems with optimal mitigation features. (Sarpalius & Grubliauskas, 2022)

2.3.3 Aircraft noise

Aircraft noise becomes an imminent thread in urban and suburban areas as the global air travel industry keeps growing – the figure 13 shows the estimated number of people exposed to Lden values above 55 dB in major cities across Europe.

Figure 13: Estimated number of people exposed to Lden above 55 dB due to major airports inside and outside urban areas in 2017, highlighting Germany, France and the UK as the countries with the highest number of individuals impacted. Source (WHO, 2020)



The most vulnerable populations are the ones located in the external rings of the city due to airports being constructed near residential areas in the city's suburbs, and while there are certain limitations in gathering quantitative data that stablishes a relation between how people perceive noise sources and the public health outcomes, there are perception surveys which reflect people's perspective on how they feel about environmental noise caused by aircraft noise, explains the WHO. (WHO, 2009)

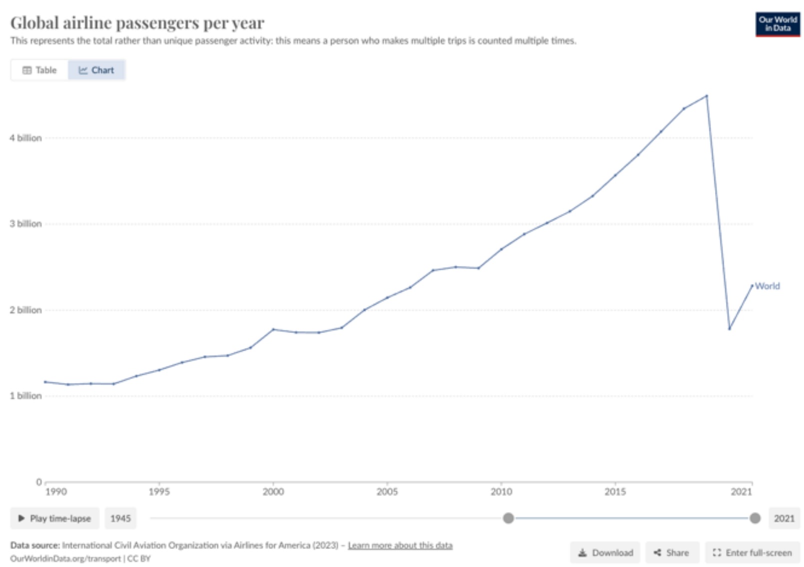
The aviation industry shows and increase number of commercial flights frequency which brings higher incidence of noise exposure, making it a priority for local governments to invest in the proper infrastructure and maintenance in the equipment since its expected that the air traffic flow will continue to grow, almost doubling by 2025, as Münzel et al (2017) describe. Some of the factors driving the increase rate of flights are:

- Uprise of the low-cost company's model:
  The low-cost airline concept originated as a proposal to change the aviation industry, looking to offer affordable fares and more accessible and fair travel model for a higher percentage of the population. While the lower operational costs and higher seat density were factors that helped the model succeed in the market, it's important to highlight that it led to operation practices that contribute in a higher scale to the noise pollution levels – this includes the increase in flights frequency, use of secondary airports and nighttime operations. (Forsyth, 2006)

- Expansion of air travel demand

  The expansion of air travel demand has been driven by the increased number of commercial flights in the past few years driven by tourism and expansion of business activities, in addition to the COVID-19 travel restrictions that brought an increased desire of people to resume air travel and explore new destinations, as it is shown in the Figure 14. While uncoordinated policies caused the international air travel recovery to be slow, domestic air travel was resumed at a faster rate, especially in countries with less travel restrictions. For instance, the tourism reopening of China in 2023 contributed to this acceleration in demand, boosting the global air traffic recovery. Furthermore, the pre-pandemic global revenue passenger kilometers (RPKs) increased 41.7% in 2021 in contrast to 88% in early 2023. (IATA, 2023)

Figure 14: Increment on global airline passengers per year, showcasing the immediate decrease at the beginning of 2020 with the COVID-19 pandemic regulations. Source (Our World in Data, 2023)



- Use of secondary airports and proximity to residential areas

  One of the key strategies that low-cost airlines has used to reach success is the use of secondary airports. Secondary airports are smaller and less congested if compared to main airports and thanks to this the operation fees are lower, making it more suitable for their business model. However, secondary airports are often located in the outskirts of metropolitan areas in contrast to large international airports, these smaller airports often lack the advanced noise pollution infrastructure and regulations such as noise barriers, soundproofing layers in the nearby buildings and strict regulations regarding late night operations, which increases the air traffic and easy spread of noise in areas where a few decades ago it was not even present, explain Efthymiou and Christidis (2023).

To provide an overview on the most common mitigation strategies, Mitzkat and Strümpfel (2019) highlight the importance of Noise Abatement Department procedures (NADP) that focus on the noise reduction at the moment the plane takes off, the approach focuses on different techniques that adjust the acceleration altitude of the aircraft (ranging from 1000 to 3000 ft above ground level) in relation with the engine power. The case study concluded that at higher acceleration altitude the quieter noise footprint is produced, for instance, in the 3000 ft profile the noise reduction showed as up to 5dB in areas within a 2.5 to 6 km range around the airport.

On the other hand, the case study from Vienna's airport also highlights the positive impact of noise management models. Brüel and Kjæ (2003) explain that the airport uses a real-time noise monitoring and a flight-tracking systems that is distributed across 13 monitoring points that provide an exact analysis of noise levels matching them to specific flights. In addition to the enforcement of nighttime restrictions, and use of more quiet runways which is based on the real time traffic flow and how this determines which aircraft goes to which runway to cause the least disturbance, especially for nighttime flights.

Lastly, the role of a proper land use planning is crucial in the mitigation against noise pollution, an example of this is found in the Guangzhou Baiyun International Airport (BIA) where Xie et al (2023) explain that based on previous noise assessments, the area around the airport is split into high and moderate noise zones (above 85 dB and between 70 – 85 dB respectively); based on this arrangement, restrictions on whether residential buildings are allowed in the zone of not are established. For instance, in the high noise zone, only industrial facilities are constructed, whereas in the moderate noise zone are allowed only if soundproofing layers are integrated into the structure of the building.

The mentioned insulation layers range from 25 dB to 45 dB, with areas with higher exposure require more robust materials like double or triple-glaze windows, sounds proof doors and thick insulation panels, all installed with acoustic seals to prevent small gaps that let noise waves pass through them instead of absorbing most of them. These standards are applied to noise-sensitive building like homes, schools and hospitals.

2.3.4 Construction work noise

In recent years, noise mitigation strategies have been specially focused towards this area, given the impact on urban spaces and public health due to the high level of noise coming from heavy machinery, construction equipment (cranes, bulldozers, jackhammers, among others) and transportation associated to these sites. This is why, to address these concerns regulatory frameworks have been developed, looking to prioritize the reduction of noise emission and protect nearby residents and workers. (WHO, 2009)

The Occupational Safety and Health Regulations stablished that the threshold value for work environment is either exposure to an average dose of 85 dB over an 8-hout shift or a peak noise level of 140 dB measured at ear level. (Mohamed, Paleologos, & Howari, 2021) – As summarized in the Table 1.

Due to the high risk associated to this type of sound noise mitigation strategies typically focus on a combined approach of regulatory measurements and implementation of more quiet construction methods and machinery. The regulatory measurements include stablishing noise limit values for various types of machinery, use of noise barriers, mandatory use of protective gear for workers and sticking to time restrictions during the day. Furthermore, governments public and private entities to use technologies that produce less noise such as electric machinery or minimizing the use of heavy machinery. The role of the local authorities is also important as they are responsible of monitoring and ensuring compliance with regulations and acting against the parties that are responsible when lack of compliance is detected, which causes delays in the projects and even fines. (Ministry of Environment and Climate Change Canada, 2023)

Table 1 Recommended values for various tasks at contractions site. Source (Mohamed, Paleologos, & Howari, 2021)

Recommended values for different construction tasks.

Tasks	Professional skills	Average noise level, dB(A)	Maximum noise level, dB(A)
Installation of trenches and channels	Electricians	95.8	118.6
Operation of vehicle at workplace	Bricklayers	98.0	116.7
Operation of manhole	Operating engineers	98.1	117.6
Welding of steel materials	Ironworkers	98.4	119.7
Operating scraper on surfaces	Operating engineers	99.1	108.6
Destruction activities	Laborers	99.3	112.1
Placing steel materials	Ironworkers	99.6	119.9
Crushing materials	Masonry trades	99.7	118.6
Operating heavy machinery	Operating engineers	100.2	112.5
Preparation of concrete surfaces	Laborers	102.9	120.3

Modified after Department of Environmental and Occupational Health Sciences, School of Public Health and Community Medicine, University of Washington.

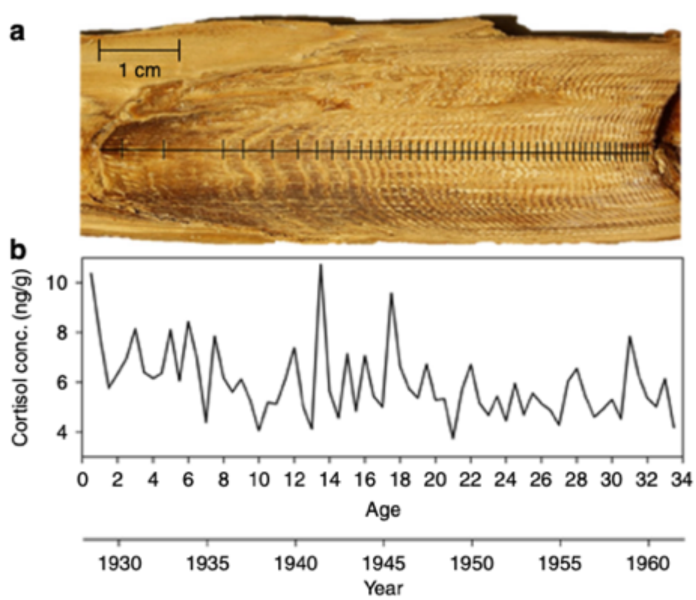
2.3.5 Noise pollution in marine medium

As consequence of the increased rhythm of human actives such as marine traffic, fishing at industrial level and petrol extraction noise pollution has also become an environmental challenge since it affects the physiology, behavior and overall well-being conditions of different sea organisms, as well as different biological processes, particularly in species that rely on sound of other echolocation methods for their survival. (Bravo, 2007)

One of the main concerns turn around boats, with emphasize in coast areas and commercial trade routes around the world since they generate low frequency noise (under 1 kHz) that interfere with different whale species which use echolocation systems that turn the movement of particles through waves into electric and neural pulses, which also interferes with their ability to communicate, reproduction processes, produces increased stress responses and subsequently brings adverse effects, whereas in dolphin species their complex and sensitive echolocation mechanisms turn them into vulnerable individuals when exposed to low frequency noises that might interfere with the natural detection of sound waves in their environment, which brings challenges when searching for preys and navigating, explains Bravo (Bravo, 2007)

For instance, the study done by Trumble et al (Trumble, et al., 2018) analyzed the stress levels on whales by using the earwax plugs that form though whales life spans, the layers forming the plugs are similar to how tree rings form, adding a new layer every 6 months of life. Based on the different concentrations of cortisol in different layers a chronological profile could be formed in relation to the factors causing stress to whales in their environment correlating to anthropogenic activities during the 20th century – The figure 15a shows the different layers from bisected whale earplug while the Figure 15b illustrates the lifespan profile

Figure 15: Cortisol profile on whales - Source: (Trumble, et al., 2018)



To mitigate the impact caused in marine ecosystems, Bravo (Bravo, 2007) explains that changes in the boats design can contribute to vibration minimalization, in addition to regulation on boats speed across sensitive areas. This was demonstrated by Dinh et al (2018) who analyzed how low frequency noise emitted by boats affect the coral reefs in the U.S Virgin Islands and how it changes the fish behavior. To mitigate this, the study proposes the regulation in traffic (mainly seasonal restrictions) and creating noise-free zones that restrict the entrance of ships in marine protected areas. Furthermore, a strong emphasize is done in the implementation of electric and hybrid vessel-type boats which produce much less noise than the traditional gas-powered engines along with the implementation of passive acoustic monitoring systems that provide data and spatial spread patters of boat noise.

2.4 Legislations and legal material

Legislation and implementation of guidelines are the key mechanisms used on a global scale to correctly manage and control of noise pollution and with the help of governments and international organizations such as the World Health Organization (WHO), the Environmental Protection Agency (EPA) in north America, and the European Environmental Agency (EEA) in Europe, the adverse health effects of noise pollution have been recognized. To address the issue, a systematic approach has been established, which is based on initial environmental risk assessments, followed by development of laws and regulations to mitigate these effects. Through legal frameworks governments are able to set threshold values and also define measurement standards, and development of noise mitigation strategies that must be strictly followed by entities within the industrial, transportation and construction sectors. (WHO, 2009)

An important tool in the development of noise regulations is the use of noise maps. Noise maps are a graphical representation of the measured sound levels within a specific area which provides a better perspective on the noise profile, the use of predictive models and the data from measurements is used as the basis to create noise maps. These maps are a fundamental aspect in urban planning and policy making processes as it allows to identify not only the origin points but also the noise hotspots, assessing the impact of noise on exposed groups of individuals, and creating strategies for noise minimalization. While noise maps are the main tool used to understand noise spreading, not in all regions noise maps are legally mandated, whereas in regions like Europe they must be updated regularly to ensure compliance with environmental noise regulations, especially in high-risk areas such as near highways, airports, and industrial zones. (EEA, 2020)

2.4.1 Environmental Noise Guidelines for the European Region - World Health Organization (WHO)

The purpose of these guidelines is to stablish clear recommendations that seek the protection of healthy standards from exposure to the anthropogenic noise sources explained in the previous chapter.

While the guidelines primarily focus on the WHO European Region they are meant to be relevantly used globally, by setting recommendations for noise exposure limits, the guidelines are meant to be a guide for Member States in protecting public health under policy procedures that align with the noise indicators used in the European Union's Environmental Noise Directive, which will be explained in the next section. The development of the guidelines was structured around two main concerns, the first one being related to the exposure-response relationship between noise level and already known health effects and the second one focusing in already affected population and whether interventions are effective on decreasing the exposure and improving the health outcome. Considering these two points, the WHO defined recommended exposure values for each sound type, based on the Lden and Lnight metrics, which are values commonly used in environmental noise assessments. The Lden metric averages noise levels over a 24-hour period, with also focus on the effects during the nighttime noise that reflect the highest sensitivity of humans to noise during this period. On the other hand, the Lnight value focuses on nighttime measurements, as this period is most critical for sleep quality. (WHO, 2009) The values are summarized in the Table 2.

Table 2: Lden and Lnight values recommended by the WHO based on each type of sound (WHO, 2009)

Type of noise	Reccomended value	
	Lden	Lnight
Road traffic noise	53 dB	45 dB
Railway noise	54 dB	44 dB
Aircraft noise	45 dB	40 dB

While the guidelines are meant to focus on source point assessment for outdoors noise, types such as occupational and industrial noise are excluded, along with neighborhood noise and multiple source exposures, referring to the case in which populations are often exposed to more than one source simultaneously. Another limitation in the guidelines is related indoor noise concerns, since no recommended values are established, although, some recommendations are listed such as reductions in noise level up to 25 dB with closed windows and 15 dB with partially open windows.

Based on this, the guidelines establish the categorized recommendations based on their strength (either strong or conditional), with a brief explanation about how the guideline strength was determined. (WHO, 2009)

2.4.1.1 Rationale for the guideline levels for road traffic noise

For traffic road noise, Exposure-Response Functions (ERFs), which link noise exposure in decibels (dB) to increases in specific health risks were used to determine the guidelines. For instance, the evaluated case studies and scientific data showed that exposure to 59.3 dB Lden, brought a 5% increase in the risk of cardiovascular conditions like ischemic heart disease (IHD). Based on this data, the guideline recommends keeping road traffic noise levels below 53 dB Lden at urban centers. (WHO, 2009)

Among the important outcomes that were considered annoyance was listed, with a significant quantity of the population reporting high levels of annoyance at 53.3 dB Lden of exposure, whereas for sleep disturbance, the guidelines recommend keeping night-time noise levels below 45 dB Lnight to avoid a 3% risk of sleep disturbance, based on moderate-quality evidence.

On the other hand, the guidelines highlight how effective intervention measures are, like improving road surfaces, restricting traffic, building noise barriers, and insulating homes. A different approach focuses on the use of urban planning techniques that aim to keep residential areas away from busy roads by creating green spaces in between or expand the existing ones, along with designing homes so residents have a “quiet zone” (having windows away from the road) which helps reducing the impact of noise during daily activities but mostly during the evening. (WHO, 2009)

2.4.1.2 Rationale for the guideline levels for railway noise

For railway noise, Exposure-Response Functions (ERFs) for annoyance and sleep disturbance were used in the development of the guidelines. For instance, based on existing studies concluding that 10% absolute risk of a highly annoyed population at this noise level, the average noise exposure from railways was set at 53.7 dB Lden. Since not only the quality but the reliance of the evidence was rated as moderate, then the recommendation to reduce noise exposure was classified as strong. (WHO, 2009)

For night-time exposure, the recommended level was set at 43.7 dB Lnight, based on the existing evidence which showed a 3% absolute risk of sleep disturbance caused by the exposure to night-time railway noise. This evidence was rated moderate quality as well, thus turning it into another strong recommendation.

In terms of effectiveness from different mitigation techniques, the guideline defines the importance of sticking to the recommendations as strong, additionally, it acknowledges the lack of strong evidence regarding the effectiveness of specific tactics. While some approaches like installation of rail dampers and of sound barriers, showed effectiveness in reducing annoyance, the evidence supporting these techniques was rated low in quality. For this reason, the guidelines did not approve any intervention over others. (WHO, 2009)

2.4.1.3 Rationale for the guideline levels for aircraft noise

For aircraft noise, a detailed evaluation about the Exposure-Response Functions (ERFs) for critical health outcomes such as cardiovascular diseases, sleep disturbance and cognitive impairment were used in the development of the guidelines.

For day-time aircraft noise exposure, the guideline recommends a level below 45 dB Lden. This is based on existing case studies showing an increased risk of high annoyance levels in populations exposed to noise above this value. The studies demonstrated that at exposure of 45.4 dB Lden and above, 10% of the population experiences high annoyance- This evidence was rated moderate quality, thus, turning it into a strong recommendation for reducing aircraft noise exposure. (WHO, 2009)

For night-time noise, the recommended threshold is 40 dB Lnight, based on evidence what confirmed that at this level, 11% of people presented high rate of sleep disturbances. Nevertheless, since the benchmark for sleep disturbance was set at 3%, the guideline recommends a higher level of compliance. Int eh same way, recommendation to limit night-time noise to 40 dB Lnight is supported by moderate-quality evidence, resulting in a strong recommendation. (WHO, 2009)

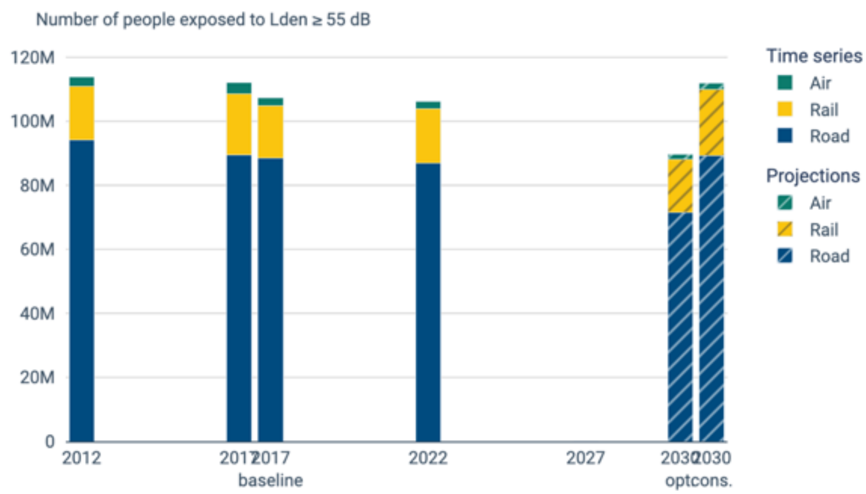
In terms of effectiveness from different mitigation techniques, the guideline states that measures like flight path (opening or closing tracks) successfully reduce noise exposure for residents living near airports. (WHO, 2009)

Even though the WHO guidelines are widely used as a global noise management standard, they are used as benchmark point for different governments and international bodies around the world to develop their own noise regulations, like the EU Environmental Noise Directive (2002/49/EC) stablished by the EU which used the recommended values by the WHO as basis to manage noise pollution across different Member States.

2.4.2 European noise directive 2002/49/EC

Firstly adopted in 2002, the European noise directive, funded under the parameters and recommendations established by the WHO, establishes the framework for the assessment and managing of environmental noise within the EU's Member States, with the aim to reduce the detrimental effect of high noise levels within urban areas near major infrastructure such as roads, railway stations and airports, aiming to protect populations, but especially vulnerable individuals such as children and elderly people in schools and hospitals, respectively. (European Parliament, 2002)

Figure 16: Estimated number of people exposed to transport noise levels above 55 dB during the day-evening-night period. Source (European Parliament, 2002)



2.4.2.1 Noise Mapping

The main aim of this directive is to set out an assessment and management method that can be used in all member states of the European Union, to avoid, prevent, or reduce the risk or any further environmental noise pollution. The Directive's approach begins with an initial environmental assessment stage, through the creation of the strategic noise maps that allow to create a noise profile, all Member States are obliged to produce maps every five years for major roads, railways, airports and agglomeration areas (rural areas with more than 100.000 individuals), these maps must be based on the Lden and Lnight metrics, which allows policymakers to determine the health risk. As second step, the directive mandates all State Members to make their assessments public, ensuring transparency and allowing citizens to be informed about the status of the situation in their zone. Lastly, the third step demands an action plan which underlines the used strategies with focus on the areas where noise pollution exceeds the threshold values, and involving public surveys, where citizens can use their voice to manifest concerns and provide feedback on the proposed action plan (European Parliament, 2002)

During the modeling process, there are some key elements that work together to achieve an effective and accurate assessment, Kephalopoulos (2012) explains that such as the population exposure, for this, the population data is mapped to buildings in specific based on registered population data for a specific building from the official statistical data. However, the case studies show that seasonal changes in population (e.g., holidays in South European cities) would lead to the consideration of other timing slots to calculate the noise levels. Another key factor is the arrangement of received points, the usual height of receiver points for noise mapping is 4 meters above the ground. Following this height, the noise exposure would be equally and identically shown in all urban areas. Nevertheless, this height at times might overestimate or underestimate the average noise exposure, mostly in the high-rise building. Likewise, in some urban areas noise barriers protect only the lower floors of the building. A hi-rise building tends to have noise exposure differences in different floors. For instance, there is a hi rise building next to a busy road, so the noise impact is different in different floors.

Despite the system and procedures that all Members States must stick to, the implementation of the Directive faces several challenges, as there exists considerable inconsistency in how each Member State implements the directive, the Directive explains that some countries make more progress towards the goal whereas other struggle to meet the expectations regarding the mapping stage and action planning. This is also affected by the variation in resources and experts available in different countries and regions, for example, the smaller and less wealthy Member States face challenges when it comes to accessing the necessary resources like modeling software, trained professionals and funds to create the do the mapping and adapting mitigation strategies. (European Parliament, 2002)

3. Materials and methods

3.1 Szent Istvan campus

This study was conducted in the Gödöllő area, to assess the environmental noise levels in both, the MATE Szent Istvan campus (2100 Gödöllő, Páter Károly utca 1) and Röges residential area (Klebelsberg Kuno street)

3.2 Used devices

3.1.2 TES sound level meter (TES1350A)

Produced by TECPEL, manufacturer based in Taiwan known in the market for their high-quality rest and measurement devices offering products such as power supplies, oscilloscopes, thermometers, clamp meters, digital multimeters, sound level meters and data loggers for continuous monitoring systems.

The TES1350A sound level meter, uses a ½ inch electric condenser microphone, designed to meet with the measurement requirements for industrial safety and environmental noise control across multiple industries. The device is fully capable to measure noise between the 35dB and 130dB range at frequencies between 31.5 Hz and 8 KHz. (TECPEC, 2018)

During the measurements, environmental conditions such as wind were important to be considered being that wind blowing across the microphone would affect the quality of the results. Thus, the usage of the foam-made windscreen was mandatory the whole time. For the sound detection feature, the device offers two settings, fast and slow, from which the slow setting was used as it is the recommended to measure average environmental noise.

3.2.1.1 How do condenser microphones work?

The basic principle under which these devices are operated is capacitance, as explained by Horowitz and Hill (Horowitz & Hill, 2015) it refers to the ability of the internal components of the device to store electrical charge; in the inside two conducting plates are placed inside of the microphone, one of them a static backplate and the other one a moving plate that oscillates in response to the captured waves. Since the space between the plates is filled with air, electric charge can be stored whenever an external voltage is applied to the system and the oscillation caused by the soundwaves causes the distance between the plates to change constantly, changing the capacitance as they move (the smaller the gap between them, the higher the capacitance, and vice versa). Finally, the changes in capacitance are converted into electric pulses that are then processed and amplified.

In terms of detection quality and sensitivity, condenser microphones are characterized for their flat frequency response, being that they are designed in a way that are fully capable to capture all frequencies within a desired range, all with equal sensitivity, which in simpler words refers that the response provided by the device is not altered in any way, providing highly accurate results, as Robjohns explains (2001).

3.2.2 Data logger ALMEMO 2590

Produced by AHLBORN, manufacturer based on Germany, uses the ALMEMO technology which differs from traditional data logger systems by implementing an EEPROM data memory between the sensor and the transducer which is the component in charge of transforming the physical parameter measured into a signal that is the stored in the memory. The EEPROM memory is attached to each sensor and stores all necessary parameter for the specific sensor. With the help of this technology, ALMEMO systems automate the sensor-transducer adjustment process and allow multiple types of sensors to be used with a single transducer that records data in the desired frequency and timeframe, increasing both efficiency and flexibility for the measurements.

Furthermore, the device is accredited according to the international standard DIN EN ISO/IEC 17025, which ensures that laboratories produce, both, valid and reliable results by defining a quality management system, applying to all organizations that perform laboratory testing and calibration. (ISO, 2017) – Both instruments are shown in Annex 1.

3.3 Methods used to measure

The measurements were split into two types, small manual measurements done at 6 different spots inside of the campus, the different spots were determined based on factors that would make them especially vulnerable due to its geographical location, the selected points were selected by being situated next to busy roads during peak hours, being close to the rail road, and being close to the ST Augustine church construction site that has been taking place for the past few months.

On the other hand, remote 24-hour constant measurements were taken from the discussed point in Premontrei Utca (coordinates 47.593128, 19.363188) and from a temporary measurement station situated in Röges residential area (Klebelsberg Kuno street)

3.3.1 Manual measurements

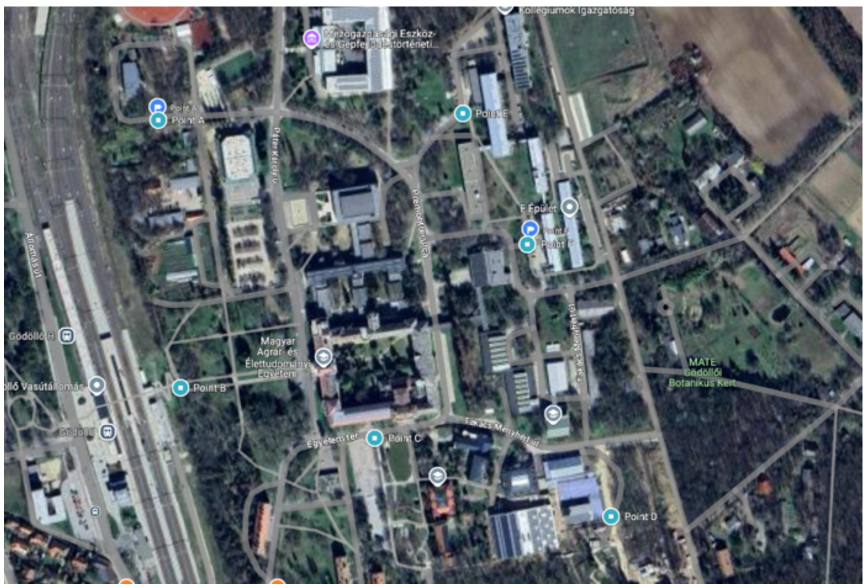
Noise levels were measured at the selected spots with a unique reading every 60 seconds, for 10 minutes, collecting 10 different results, from which then the minimum, maximum and mean values were summarized.

The data was collected in the 6 focus points shown in the Figure 17, the coordinates were:

- Point A: Heating center (coordinates 47°35'43.7"N 19°21'32.8"E)
- Point B: Railway station entrance (coordinates 47°35'34.3"N 19°21'33.9"E)

- Point C: Premontrei utca behind the main building (coordinates 47°35'35.3"N 19°21'47.4"E)
- Point D: Premontrei templom construction site (47°35'29.7"N 19°21'56.4"E)
- Point E: Entrance dormitory building B (coordinates 47°35'43.9"N 19°21'48.6"E)
- Point F: Entrance dormitory building F (coordinates 47°35'39.3"N 19°21'52.0"E)

Figure 17: Selected points where the manual measurements took place. Source (own work)



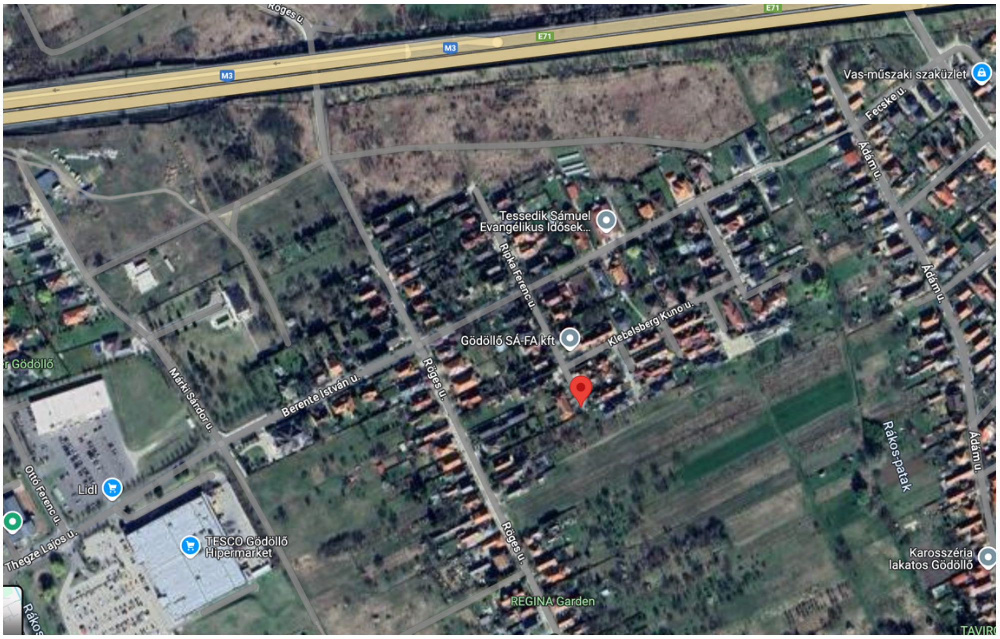
3.3.2 Remote 24-hour measurements

Based on the manual measurement results, the area with the highest noise levels was identified near the construction site, where the working machinery produce sound levels above 50 dB in average. However, challenges came up prior to the 24-hour measurement, since the data logger and sensor had to be connected to a power source and protected from external factors, such as weather. Because of this, the continuous measurements were instead carried out in the area with the second-highest noise levels, where the equipment could be safely left in the window, offering protection from external conditions – The figure 18 shows the point in which the remote station was established.

The device, which was plugged to the data logger was placed on the window frame facing the street, recording measurements every 60 seconds – Shown in Annex 2.

On the other hand, a secondary measurement point was established in the Röges residential area (47°36'43.7"N 19°20'37.7"E) – shown in the Figure 18.

Figure 18: Point where the remote measurement took place at the Röges residential area. Source (own work)



4. Results and discussion

Prior to the results analysis it's important to note that Hungary, under the EU rules is obliged to comply with the strategic noise mapping in urban areas, main roads, rail lines and airports along with action planning for noise management and publish these every five years, and while it was until 2018 that Hungary firstly complied with the rule and provided descriptive noise mapping modeling of major urban cities such as Budapest, Gyor, Pecs and Debrecen. (European Parliament, 2018)

It is important to consider that the EEA (2019) reported that Hungary's population exposure to noise levels above the threshold value in the EU as it follows: 12.41% exposed to 55-59 dB, 13.29% exposed to 60-64 dB, 12.18% exposed to 65-69 dB, 2.99% exposed to 70-74 dB and 0.11% exposed to greater than 75 dB. (EEA, 2019)

Even though Hungary must remain compliant with the threshold values established in the directive 2002/49/EC, there have been no previous mapping for noise around Gödöllő. It's also important to note that I have taken my measurements based on field practices, but none of them could be classified as an official noise map model. In other words, my results are mainly to provide a descriptive overview and do not involve any calculation, noise prediction pattern nor strategic noise mapping. Additionally, my measurements did not consider the communities opinion, so no surveys were implemented which could have provided a broader understanding on the possible effects individuals can relate to.

4.1 Manual measurements

It's important to consider that based on the revised legislations, the two main noise sources that represent a thread in the region, especially for students attending classes and living in the nearby region, including the Dormitory, are the railway line and the construction site, Points A and B being closer to the railways and Point D being closer to the construction site. Furthermore, since the measurements were done during the day, only Lden values are considered to assess the levels in the area – The results are summarized in the Table 3 and Figure 19.

Table 3: Manual measurement results, highlighting the maximum, minimum and mean values at each point - Source: own work

Point A	Interval: 13:00 - 13:09	Point B	Interval: 13:15- 13:24	Point C	Interval: 13:37 - 13:46
Time stamp	Noise level (dB)	Time stamp	Noise level (dB)	Time stamp	Noise level (dB)
13:00	39.1	13:15	38.5	13:37	47.9
13:01	37.9	13:16	37.6	13:38	40
13:02	35.9	13:17	40.6	13:39	55.6
13:03	47.1	13:18	36	13:40	45.7
13:04	37.8	13:19	36.6	13:41	60.6
13:05	50.7	13:20	37.9	13:42	50.7
13:06	36.6	13:21	38.8	13:43	42.6
13:07	38.1	13:22	40.6	13:44	54.9
13:08	38.3	13:23	42.2	13:45	49.7
13:09	39.1	13:24	41.6	13:46	59.6
Maximum	50.7	Maximum	42.2	Maximum	60.6
Minimum	35.9	Minimum	36	Minimum	40
Mean	39.8	Mean	39.0	Mean	50.3

Point D	Interval: 13:56 - 14:05	Point E	Interval: 14:32 - 14:41	Point F	Interval: 14:14 - 14:23
Time stamp	Noise level (dB)	Time stamp	Noise level (dB)	Time stamp	Noise level (dB)
13:56	55.6	14:32	45.6	14:14	46.5
13:57	55.3	14:33	43.7	14:15	46.1
13:58	48.4	14:34	42.1	14:16	45.9
13:59	54.7	14:35	42.7	14:17	50.2
14:00	50.2	14:36	45.9	14:18	52
14:01	57.6	14:37	46	14:19	45.2
14:02	49.5	14:38	43.2	14:20	46.1
14:03	60.3	14:39	51.2	14:21	46.6
14:04	52.7	14:40	47.3	14:22	45.9
14:05	62.2	14:41	43.5	14:23	43.2
Maximum	62.2	Maximum	51.2	Maximum	52
Minimum	48.4	Minimum	42.1	Minimum	43.2
Mean	54.5	Mean	45.0	Mean	46.7

Additionally, the graph at each point describes the fluctuation patters within the 10-minute intervals.

4.1.1 Meteorological conditions:

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on July 15th

- Temp Min: 20 C
- Temp Max: 36 C
- Wind speed: 19 m/s

While there were limitations measuring the wind speed at the time the manual measurements were done, based on the meteorological report it can be induced that the conditions during the day had impact on the results mainly because the wind interacts with trees, buildings, and other structures in the area.

This is expected to have caused higher noise during certain periods. For instance, it might have caused more noise in open areas where the wind was not blocked by buildings which was the case at point B where there are no structures nearby except but the vegetation in the garden entering the university's main building. In addition, wind can carry sound over more considerable distances or distort it to make it louder. Therefore, noise sources like traffic might have been louder than there is no wind was passing.

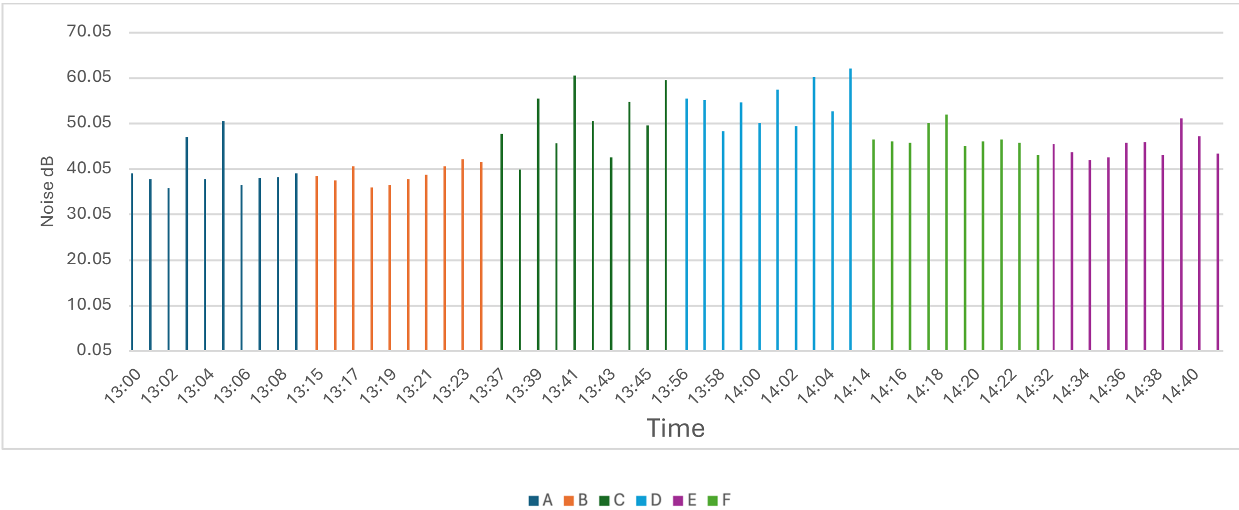
4.1.2 Maximum and minimum values:

- Point A: The noise levels at this location fluctuated between 35.9 dB and 50.7 dB, which adhere to the guidelines by staying under the 53 dB threshold value for the Lden dose. While the maximum here was relatively high, it was caused by a transient source since the train passed while the recording was done, meaning that even under the factor that represents the highest thread, the measurement stays within the recommended values, concluding that the railway, while might represent annoyance, it stays withing the safety value, representing no health risk.
- Point B: Recorded a tighter range of 36 dB to 42.2 dB which stays under the threshold value, indicating a more stable and quieter environment with smaller fluctuation, and while this was the second point close to the railways, during the time interval, no train passed in the near area.
- Point C: Saw higher fluctuation, ranging from 40 dB to 60.6 dB. The maximum of 60.6 dB shows louder noise disturbances happening with more frequency, coming from the vehicles passing across Premontrei utca and Takacs Menyheit utca. During the measurement in this point, a truck discharged their load in the parking lot next to the Coop supermarket, contributing to increased levels and fluctuations of values.
- Point D: With the highest recorded maximum noise level at 62.2 dB, Point D showed high levels of noise pollution, exceeding the threshold values recommended by the WHO due to the use of heavy machinery. While the point is relatively close to the dormitory building F (point F) no relative disturbance was measured in the population.

  It is also important to mention that, even though this was the noisiest region in the studied area, due to the limitations mentioned in the previous chapter it was not possible to perform a continuous remote measurement, thus, no comprehensive pattern or fluctuation in a longer timeframe could be measured here.

- Point E: The range here was 42.1 dB to 51.2 dB, which is moderate but still reflects some intermittent loud noise events caused mainly by the vehicles stopping in front of the building or people’s voices in the entrance of the building. It’s important to mention that although no measurement regarding indoors noise levels for both dormitory buildings was done to determine how much reaches the dormitory rooms, common areas and study rooms, it can be concluded the area represents no thread by the main loud noise sources around since even with trains passing at the long distance, vehicles eventually stopping in the building’s entrance, none of them represent a major increase that goes above the threshold value.
- Point F: With a range of 43.2 dB to 52 dB, Point F showed moderate noise levels with occasional louder noise sources caused by vehicles passing.

Figure 19: Measurements at points A, B, C, D, E and F in function of the time



4.1.3 Recommendations:

- For Point D: Due to the consistency of high levels of noise coming from the construction site, noise mitigation strategies should be considered, and although my research lacks the determination of which internal measures are implemented by the company carrying out the construction, the numbers do confirm the need to implement the right strategies when future constructions or renovation projects take place in the area to reduce the exposure and annoyance impact with possible detrimental effects.
- For Point C: Despite the measurements being performed in the summer period when no classes are taking place, the population density decreases in the streets around the university and nearby areas, additional remote investigation might be required during the study period and peak hours to better understand how the road traffic noise in the intersection between Premontrei utca and Takacs Menyheit utca represents an increase and contribution to the noise pollution in the area. Furthermore, taking into consideration that even during study period, and peak hours the traffic volume in these streets is not considered as major, therefore, no traffic restrictions would be required as the roads are small.
- For Points E and F: In further studies, continued monitoring including indoor noise levels to ensure noise levels remain stable, since a considerable high number of students live in the dormitory buildings.

Considering that at any of the points the mean values went above the recommended Lden values, the risk of health problems is not considered as high above annoyance in individuals, therefore, an additional recommendation that leaves the door open for further studies includes the use of surveys to have a better assessment on how the population living in the studied area reports to present annoyance as response to the noise.

Based on the data collected, the point that was chosen as relatively loudest in the studied are was point C, thus it was chosen for the remote 24-hour measurement to have a better understanding on how it fluctuates during the day and understand the reasons behind it and whether it represents a thread to human health on exposed individuals living around the university's main building, dormitory, and attending classes either at the university or at the Gödöllői Premontrei Szent Norbert Gimnázium.

4.2 Remote 24-hour measurements

The data used in the analysis was taken from the Point C, and from an external point in the residential are in Gödöllő, unlike the manual measurements, the remote measurement compiled information measured during the day and evening periods, allowing an analysis based on both, the Lden and Lnight values. The method used also allowed to measure the noise values under different weather conditions, which affects not only the measured value but also the dispersion patterns of noise. Since the data was collected for periods longer than 24 hours, to balance the distribution and make it easier to compare it, it has been divided in days.

4.2.1 Remote measurements in the University area

Measurement #1 – August 12, 2024

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 12th

- Temp Min: 18 C
- Temp Max: 35 C
- Wind speed: 9 m/s

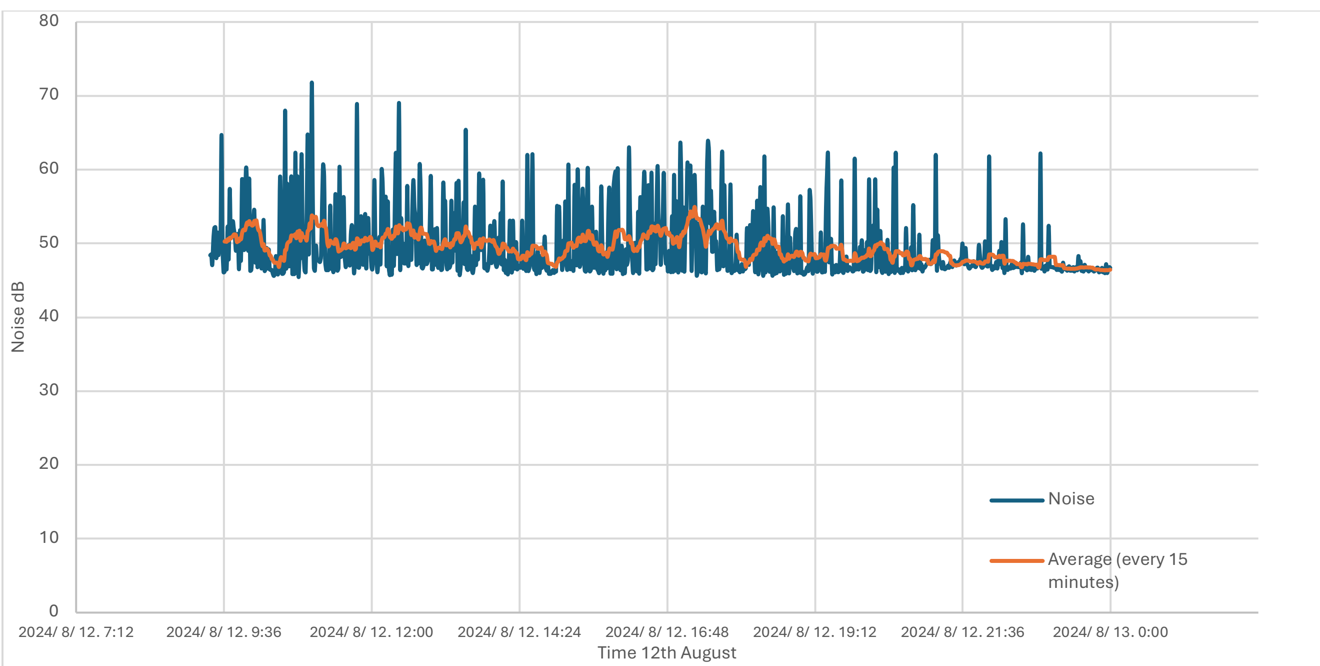
During this day, in the morning between 7:00 am to 12:00 am, there is moderate fluctuation in noise levels, ranging from 40 dB to 60 dB, which despite being above the threshold value due to the high entries above 60 dB remains within the recommended values, based on the orange line which provides the average value every 15 minutes. In addition to this, exceptional occasions were recorded where a few pikes close to 70 dB were detected. This noise level is mainly caused road traffic with occasional high peaks reaching up to 60 dB to 70 dB caused by vehicle noise, which despite the reduced activity during the summer period is still present since vehicles pass occasionally in addition to any indoor noise produced in the office where the device was placed, sounds coming from distant points such as the railway station and the normal sounds coming from the interaction with trees and airflow noise through windows and doors.

As the day progresses into the afternoon the fluctuations between the mentioned values remain constant. However, the noise levels decrease as the sun goes down, fluctuating between 45 dB and 47 dB, with a few entries above 60 dB which might have been caused by sporadic events like cars stopping by or people passing next to the window.

On the other hand, the orange line representing the average level every 15 minutes, demonstrates that during peak hours, hours where the university is working and people is working the average fluctuates between the 45 and 55 dB, which passes the threshold value by a few numbers during the day, whereas in the evening remains a bit higher than the 45 dB recommended for traffic and 44 dB for railway noise- as shown in the Figure 20.

In terms of temperature impact, the moderately low temperature in the morning, causing invasion (which tends to take place in the mornings) might have caused sound waves to travel closer to the ground surface carrying noise from distant points, such as the railways and the construction works in the late morning once they begin with their daily tasks, contributing to the spikes in both single measurements and average every 15 minutes.

Figure 20: Measurement's results on August 12th with the average measured in 15 minutes interval – Source: own work



Measurement #2 – August 14, 2024

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 14th

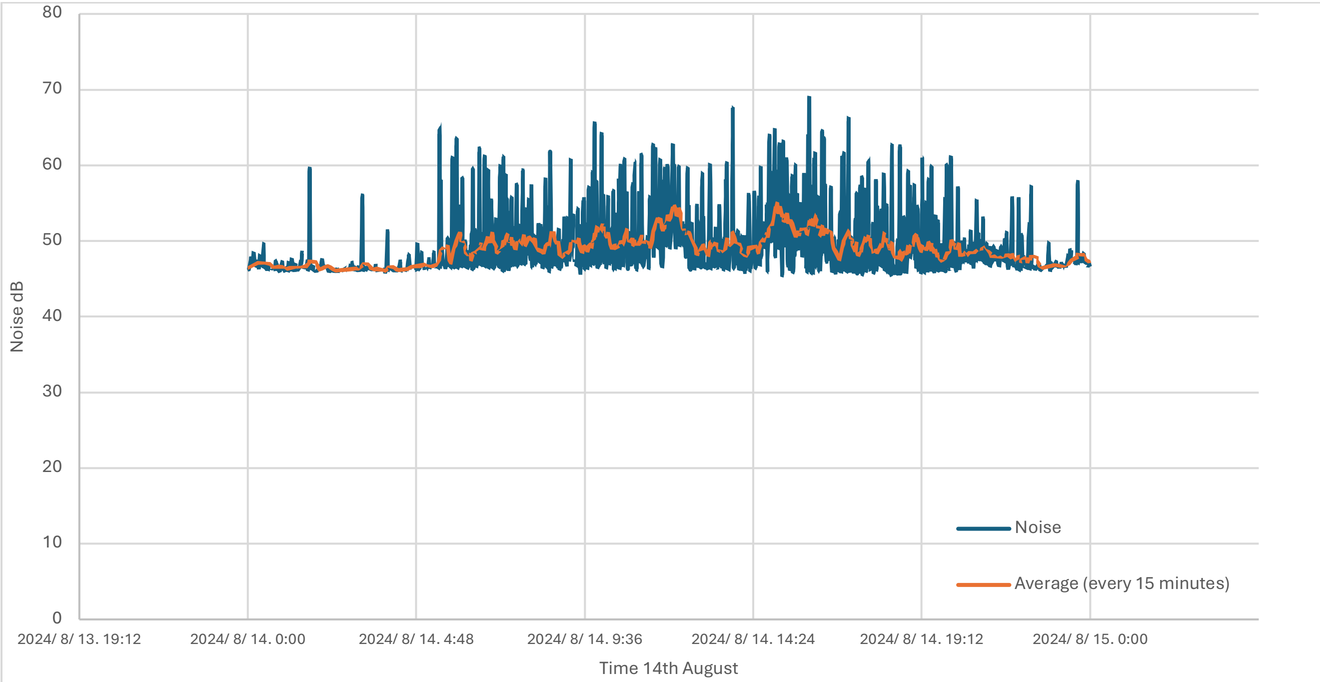
- Temp Min: 18 C
- Temp Max: 36 C
- Wind speed: 9 m/s

Throughout the day, noise levels have extreme fluctuation, showing multiple pikes that go above the 70 dB level. Since the early hours, noise levels have remained at a stable average of between 45 dB and 50 dB, staying within the recommended values, thus representing no thread for the surrounding area and inhabitants in the nearby buildings. However, as the morning keeps passing, around 5 am The most relevant finding during this day is that the moving average line (orange) remains relatively stable between 45 dB and 55 dB, which during the day doesn't represent an issue, however, between midnight and 5:00 am its visible how the oscillation changes from 45 dB to 55 dB, with recurrent pikes recorded above 60 dB, which it's above the threshold value, for this reason it might have repercussions, especially in the sleeping cycle of individuals living in the F building which is the closest one to Premontrei utca- as shown in the Figure 21.

During the day, the same tendency prevails, while the lowest values recoded remain under the threshold value, the average reaches the maximum of 55 dB around noon and 2:00 pm, with recorded values reaching almost 70 dB, which brings concerns.

In contrast to the noise levels during daytime, the nighttime noise levels describe a very calm and peaceful noise profile in the area, in which residents might not present any annoyance nor disturbance. But, not completely calm, or not drop to noiseless levels. This suggests that the people living in the area might still be exposed to other sources of noise that can disturb their sleep.

Figure 21: Measurement's results on August 14th with the average measured in 15 minutes interval - Source: own work



Measurement #3 – August 15, 2024

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 15th

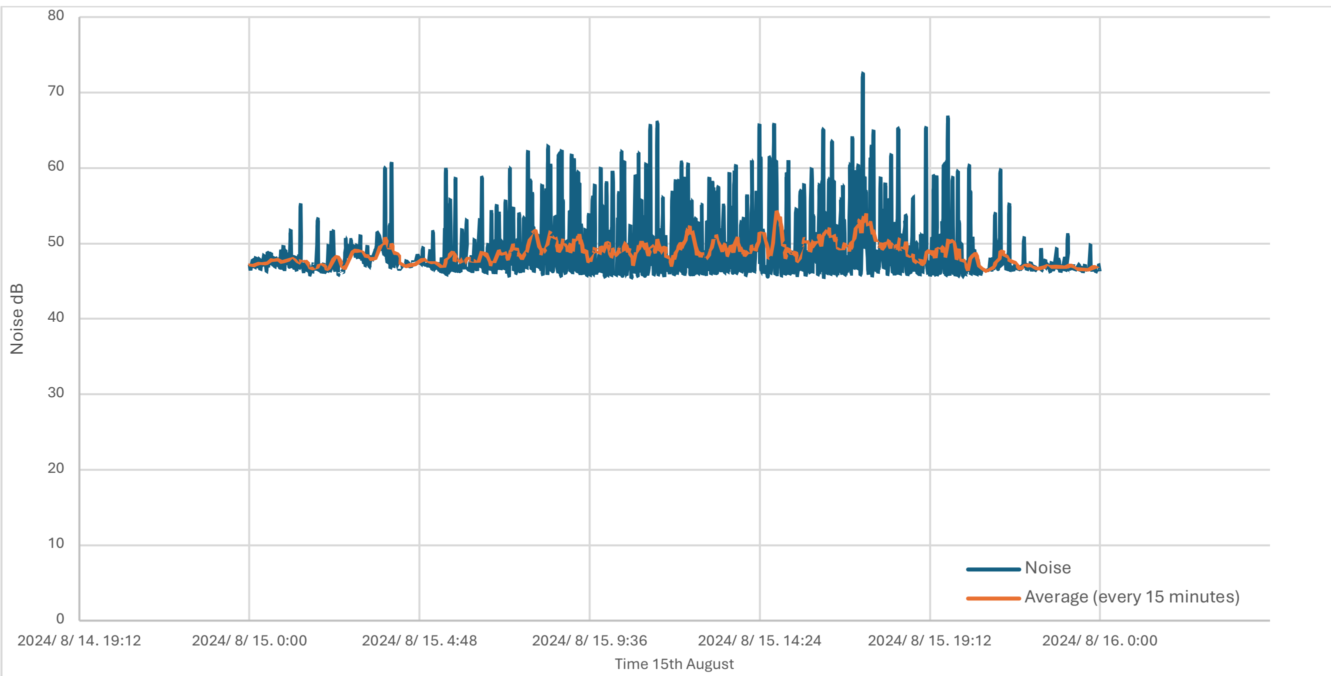
- Temp Min: 21 C
- Temp Max: 36 C
- Wind speed: 11 m/s

The day was characterized by fluctuations between 45 dB and 55 dB all day, but the focus again turns towards the sleeping hours of the day. Since the recorder values during nighttime remain above 50 dB even getting closer to the 60 dB sporadically, indicating that during the night it might be a potential cause of sleep disturbance as per WHO standards- as shown in the Figure 22.

The reason behind this might be the weather being that during the 14th and 15th of august were the only two days of the continuous measurement in which rainfall took place, leading to contribution in the increase of environmental noise in the area, in addition to this both days presented relatively high wind speeds, resulting in and increment in the noise when it interacts with different objects in the outside of the building.

By analyzing the behavior of the orange line showing the average every 15 minutes it can be established that recorded values remain withing the recommended values, with certain exceptions from 8:00 am and 6:00 pm, which represent the busiest hours in the day, meaning the traffic in the road and incoming noises from the railway station increase the risk of exposure to values above the Lden threshold value. Whereas in the evening, the pikes going above 60 dB might represent a thread for the sleeping schedule in the area's inhabitants, it might be useful to perform measurements inside of the dormitory buildings along with communal surveys to determine the percentage of the population that report annoyance and even interruptions in the sleep cycle.

Figure 22: Measurement's results on August 15th with the average measured in 15 minutes interval - Source: own work



4.2.2 Remote measurements in the residential area

Measurement #1 – August 2nd, 2024

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 2nd

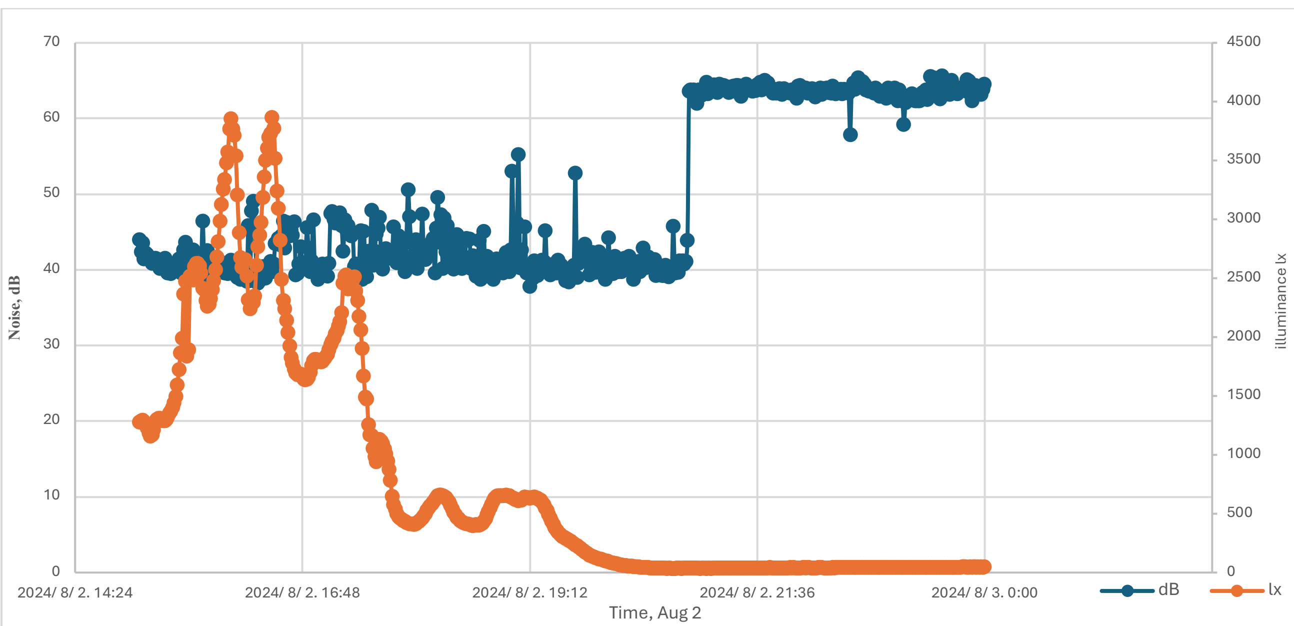
- Temp Min: 16 C
- Temp Max: 35 C
- Wind speed: 11 m/s

From 2:00 pm to 6:00 pm in the evening, the noise levels recorded show a stable rhythm but remain high, ranging between 45 dB to 50 dB. It means traffic in the area along with noises carried out by wind coming from the M3 motorway which if often busy within these hours result in the recurrent recorded peaks ranging between 52 dB and 56 dB, which based on the recommended values goes above the threshold values.

In comparison to the Lden values, during nighttime, especially after 7:00 pm, the recorded values start decreasing, ranging from 38 dB up to 46 dB, which remains within the recommended values, thus representing no major thread. However, an inconsistency might appear after 8:30 pm since the recorder values go above 60 dB and remain constant above this number, with only two dips under the 60 dB value, which might not be representative of the real environmental noise in the area as it will be explained at the end of this section.

Additionally, the measurements performed in this location, introduce the orange line that represents the luminous flux measurement, which during the day presents fluctuations triggered by shade or maybe the sensor being covered by external objects carried by the wind, but overall maintains constantly high during the day hours and low during the evening hours, as shown in the Figure 23.

Figure 23: Measurement's results on August 2nd with the luminous flux - Source: own work



Measurement #2 – August 3rd, 2024

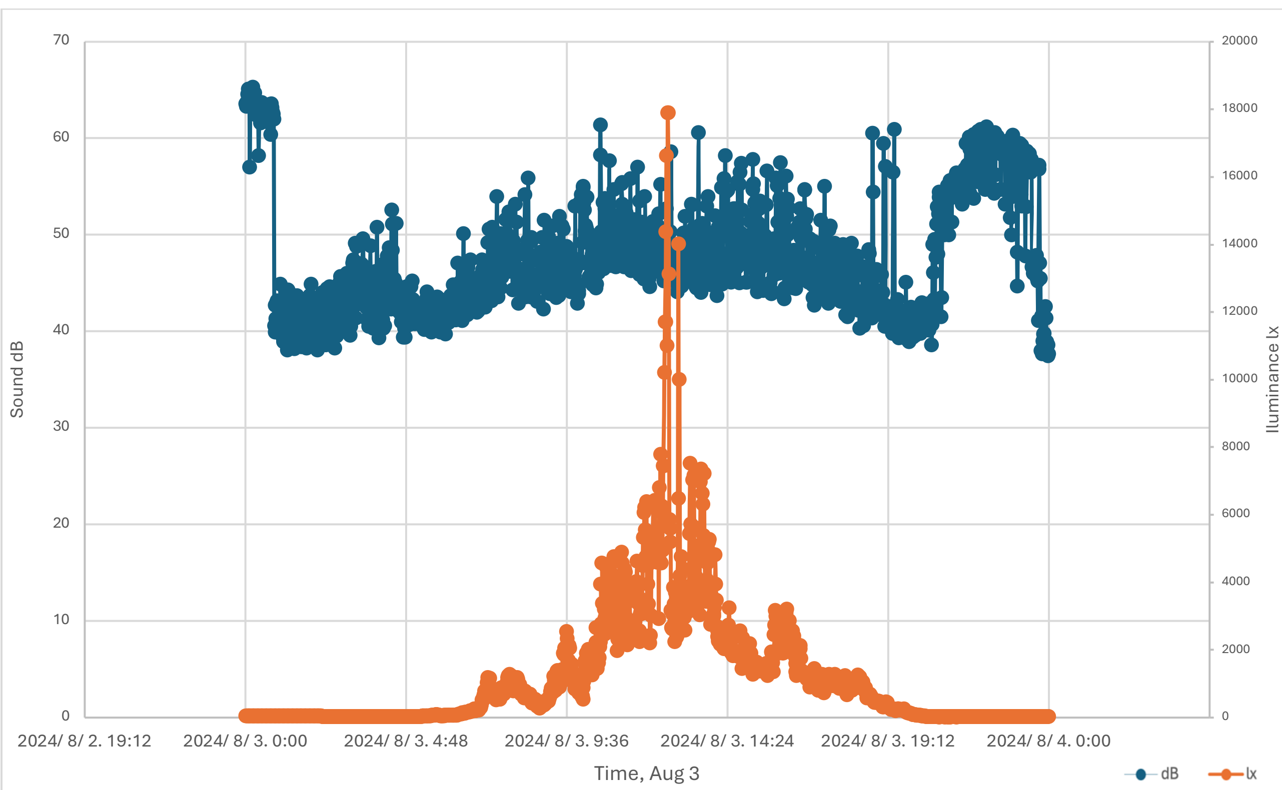
Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 3rd

- Temp Min: 17 C
- Temp Max: 28 C
- Wind speed: 15 m/s

The blue line showing the noise level values recorded upward slope from 00:00 at the beginning of the day until 6:00 am, while it keeps fluctuating back and forth but always staying between 38 dB and 55 dB. As the working day starts after 6:00 am the levels start to increase, reaching the maximum close to noon with a recorded value of 63 dB, which can be associated to the fact that there's people start their regular activities, leaving their homes, driving their vehicle and the motorway gets busier, resulting in noise being carried away in the environment due to the traffic actively passing nearby- as shown in the Figure 24.

Right after noon, the levels start decreasing gradually but maintaining within the same values as it does between 6:00 am and 11:30 am, reaching its minimum value in the evening close to 7:00 pm when the evening begins. At this point the recorded values start decreasing until 9:00 pm, where the recorded values increase, ranging between 50 dB and 62 dB, which while elevated, they might be crossed affected by the internal factors that will be explained at the end of the section.

Figure 24: Measurement's results on August 3rd with the luminous flux - Source: own work



Measurement #3 – August 4th, 2024

Based on the Hungarian meteorological service report (HungaroMet, 2024) the following meteorological conditions were considered during the time of the measurement on August 4th

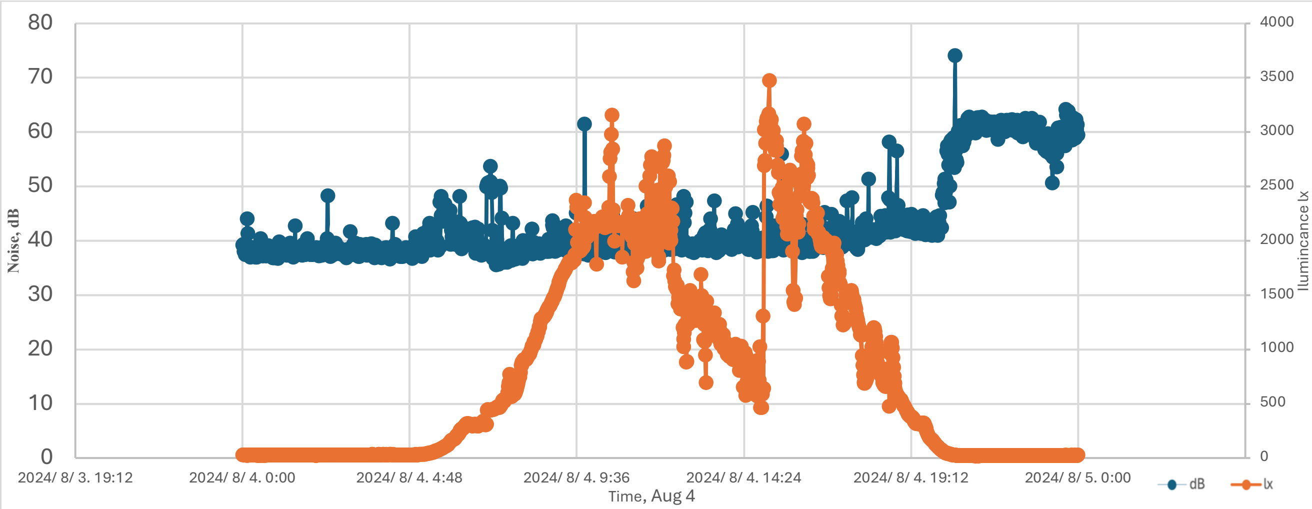
- Temp Min: 10 C
- Temp Max: 27 C
- Wind speed: 15 m/s

The levels of noise recorded are consistent in range during the early morning, from 12:00 am to 4:30 am, remaining at a steadily level of 38-42 dB, which remained stable throughout the early morning showing that nothing much caused disturbances which would make the decibel levels varies in a way, aligning with the low levels of traffic or any other type of human activity occurring in the M3 motorway and the town at night or early morning hours.

Furthermore, between 6 am and 12 pm, the fluctuation in noise levels becomes more noticeable. The measured noise increased slowly, and even though the rate of increase remains between 45-50 dB. There were some small deviations in the noise level possibly caused by fluctuating traffic, but at last, the noise levels remained to be moderate under the 50 dB, with a few exceptions above 53 dB which may have been cause by household noises in the area or even vehicles moving in the area- as shown in the Figure 25.

During the afternoon, 12:00 pm – 6:00 pm, the levels of noise for a stable 38-50 dB, which might be due to the background noise during the daytime which is common in the area. There were small fluctuations recorded in the noise levels during this time. The decibel frequency was on the rise in the evening, 6 pm-12 am, and it rose to about 50- 62 dB with a single-entry peaking above the 70 dB value. The decibel frequency stabilized to that frequency as there are on-going events or traffic as the time was set to the between 6 pm or 12 am.

Figure 25: Measurement's results on August 4th with the luminous flux - Source: own work



It's important to note that the noise measurements in the late evening could have been potentially affected by indoor sources of noise since the monitoring station was placed in the house's backyard, close to the open window and noises coming from the living room, such as the TV or regular household activities would have increased the noise levels during this period. For this reason, the value of noise recorded in this period likely does not reflect the outdoors ambient noise.

5. Conclusions

Through the literature review it was possible to provide a better description of the harmful impacts associated with exposure to high noise levels from different sources, with the examination of the legal frameworks and guidelines recommended which can be used to evaluate the mitigation strategies for the dangerous noise sources imposed on various surroundings; the World Health Organization guidelines broadly and specific European Noise Directive can be used to guide the four basic and risk noise sources imposed on the daily lives. The frameworks also provide some ideas about the different noise sources such as transportation such as road, rail, and air.

In relation to the measurements done to assess the noise levels, the analysis of the results gathered in the study of noise pollution in the Gödöllő area was meant to be performed within the university's campus, it was decided midway that the analysis of the residential area would provide a wider perspective and understanding on the exposure to high levels of noise caused by traffic noise and railway noise, this is why the study was performed in an extended area involving measurement points near to the university; near to the dormitory and near to the residential area.

In first instance, the manual measurements allowed to have a better understanding on the noise exposure levels in different points around the campus, and while there were certain limitations such as lack of modeling and noise mapping software, the values recorded provided a brief overview of what are the areas with highest exposure and the sources of these noises. The measurement made possible to determine that due to circumstantial events, Point D, presented the highest level of noise pollution due to the templon construction work taking place, and despite the construction of the templon being almost finished, it highlights the importance on why future projects in this area need to have proper measures for noise control for preventing such issues and reducing annoyances and disturbance among students attending classes in the university and high school nearby – the strategies might include, competing the works during summer period while students are on break and the area is less busy, only during day time to avoid disturbance in the sleeping schedule.

With the determination of the relative highest noise level in the campus, the relationship between the noise emissions and the road traffic could be established, and while the measurements lacked the establishment of a link between the exposure in the area close to the dormitory and the reported effects that residents living in the buildings nearby reported the door for further monitoring during the peak Study periods in order to be aware of the impact of traffic noise at the intersection of Premontrei utca and Takacs Menyheit utca. Furthermore, the study also leaves the door open to future measurements that provide a comprehensive view of the indoor noise levels in the dormitory's buildings, especially A, B and F since these are the ones closest to Premontrei utca, where the highest levels were recorded due to the traffic noise.

Lastly, the manual measurements helped to assess different spots within the campus and determine whether they align with the Lden values followed by the European Union under the Noise Directive's framework, and while none of the noise levels measured at these points exceeded the recommended Lden values indicating that the risk to health is minimal beyond potential annoyance, the use of community surveys is highly recommended for further studies to have a wider perspective on the effects of noise and assess how residents perceive it and determine if it affects their well-being on a daily basis.

On the other hand, the remote measurements provided a better understanding on the fluctuation patterns during day and nighttime, for the nighttime measurements highlighted that noise levels, particularly in the university, frequently exceeded the recommended limits (45 dB for nighttime noise and 53 dB for the daytime noise). Which raises concerns about the potential for sleep disturbances, which can have significant long-term health impacts on the local population, especially international and local students living in the dormitory. Based on the data recorded with the data logger, the highest recorded nighttime values reached over 60 dB, which underscores the need for further investigation into how these elevated levels affect the well-being of residents.

It's also worth mentioning that based on the circumstances mentioned during the remote measurements for the night time in the residential area, the analysis of Lnight values cannot be used to provide a solid conclusion, for this reason, the study concludes with a strong recommendation for future studies in the area, where monitoring systems are installed in the areas close to the M3 motorway to record Lnight values and provide an accurate assessment regarding the noise levels in this area.

Due to the increase in the number of vehicles on the market, there would also definitely be an increase in road traffic noise, especially in areas that are near university and main roads nearby the city center because many people in the area still depend on cars for transportation, mainly due to comfort and convenience. The noise of the road traffic could affect the students who are staying in the dormitory, driven by the fact that newcomers will keep arriving to the university campus, not only locals but international students as consequence of exchange and scholarship programs, whose first accommodation option will be dormitory due to convenience at being closer to the university, hence the urgency to proceed with further studies regarding the assessment of the noise inside of the buildings and the nearby buildings, focusing in those located close to the railway tracks and the construction site.

Under the European Noise Directive's framework is a requirement for every Member State of the European Union to have maps and action plans and reduce noise pollution in Europe. Hungary has been able to provide noise maps for all the major cities in Hungary, including the capital city of Budapest. However, the noise data for smaller towns and villages are still missing, therefore smaller towns, villages, and rural acidities might be facing more and more noise pollution now without a clear understanding on the exact levels. With cities like Gödöllő, which are home to colleges and universities, noise pollution is important to consider ensuring the well-being of the residents within the area.

6. Summary

The thesis work investigates the impact of noise pollution coming from anthropogenic activities which widespread rhythm keeps increasing in the fast-paced world we live in and deep dives into the mitigation strategies developed by different international entities such as the WHO and the European Union. Additionally, the discussion used case-studies to illustrate on both, the health effects related to dangerous levels of noise and technological innovations that seek to reduce urban noise exposure.

The methodology used in the assessment done in the Gödöllő Campus includes manual measurements in key areas within the campus which served as base to determine that the construction site and the area across Premontrei utca are the relatively loudest points in the area, showcasing Lden values above 53 dB. Based on this, continuous remote measurements were performed in front of the road, in addition to the external remote measurement done in the residential area close to the M3 motorway, both allowed to collect important data regarding the values during day and night times and analyze them with base in the European Guidelines established by the WHO and the European Directive 2002/49/EC to determine whether the studied areas are exposed to Lden and Lnigth values that go above the recommended threshold values.

The assessment provided an insight into the campus noise pollution dynamics characterized by average values above the Lden and Lnigth recommended doses, in case of the university area, the remote measurements collected enough information to raise concerns about both; the Lden values since they might become a challenge for students attending classes and university personnel, especially the ones whose workspaces are on the side of the road and require to complete different tasks that require cognitive abilities such as concentration. On the other hand, for the nighttime measurements, enough the data collected leads to concerns around the sleeping schedule hand how it might cause fragmentation and annoyance, especially for the students in the dormitory buildings close to the road, due to the recurrent values above 55 dB, even reaching above 60 dB occasionally.

As for the measurements done in the residential area, unfortunately, the Lnight values are not completely reliable and representative for the real environmental noise in the area, however, the Lden values show a normal behavior in most parts of the day, with recorded values that remain within the established threshold values for the EU State Members, and a few exceptional cases in which alarming values above 60 dB were recorded likely from far away noises coming from the motorway M3 or the nearby roads in the area or even household noises from the neighbor houses.

While the investigation and measurements done lacked a final conclusion that clearly stablishes a link between the exposure and health effects for both areas, it concludes with a strong recommendation on using further studies that involve not only surveys to assess the opinion and perception of the inhabitant in the region but also further and detailed monitoring in both studied areas, in the to the dormitory area and the nearby buildings, especially the ones situated closer to the railways and construction site whereas for the residential area detailed measurements in the nearby roads and the motorway.

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ANNEXIS

Annex 1:

Annex 2:

DECLARATION

the public access and authenticity of the thesis/dissertation/portfolio[1]

Student's name:	Santiago Rodriguez Rodriguez
Student's Neptun code:	FNK1SK
Title of thesis:	Measurement and assessment of noise pollution levels across key areas of the Gödöllő campus
Year of publication:	2024
Name of the consultant's institute:	Institute of Environmental Sciences
Name of consultant's department:	Department of Environmental Analysis and Technologies

I declare that the final thesis/thesis/dissertation/portfolio submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography.

If the above statement is untrue, I understand that I will be disqualified from the final examination by the final examination board and that I will have to take the final examination after writing a new thesis.

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Santiago Rodriguez R.

Student's signature

DECLARATION

I Gabor Geczi (Neptun code: I5AYJ4) as a consultant, I declare that I have reviewed the final thesis and that I have informed the student of the requirements, legal and ethical rules for the correct handling of literary sources.

I recommend the thesis to be defended in the final examination.

The thesis contains a state or official secret: yes <u>no</u>*[1]

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consultant

[1] The appropriate one should be underlined.