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Noise Maps of the Existing and Projected Linde plant in Alenquer, Portugal

Revision of Final Report

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CONTENTS

NOISE MAPS OF THE EXISTING AND PROJECTED LINDE PLANT IN ALENQUER, PORTUGAL

REVISION OF FINAL REPORT

Datasheet

Project name	Noise Maps of the Existing and Projected Linde plant in Alenquer, Portugal
Client	Linde Portugal, Lda.
Address	Est. Nac. nº 1- Km, 38,4 Cheganças 2580-381 Alenquer
Project location	Alenquer, Portugal
Particular / Specific noise sources	Industrial equipment and machines
Field work date(s)	19th April 2021
Noise modelling software	CadnaA software was used with BMP, BPL, XL, FLG, SET and Calc options (20 computers licence) applying ISO 9613 standard for industrial noise
Report date	August 2021

This report is a revision of the report delivered in May 2021 with the reference 0162/21DBW_MRRM0019/21 and replaces it entirely

Technical Team

The present job was prepared by the following team

- Luís Conde Santos, Electrical Engineer (IST), MSc. Sound and Vibration Studies (Un. Southampton) – Project Leader and Field Work.
- Jorge Preto, Urban and Land Planning Engineer (IST), Post-Graduate Course in GIS (Geopoint) – Field Work and Acoustic Modelling

1. SUMMARY

Linde site is located in Chegancas, in Alenquer Municipality, close to Lisbon in Portugal. Linde Portugal, founded in 1946 as Sogás, was incorporated into the Gases division of the Linde Group in 1987. Currently, the Industrial Gases business area of Linde Portugal, supplies gases to more than 8,000 customers, with a modern production center in Alenquer, as well as industrial units in Maia and Sines

According to the Portuguese law (D.L. 9/2007 – Public Law on Noise) all permanent activities producing noise must comply with established noise emission limits defined by two noise criteria (Maximum Noise Exposure Criterion and Noise Increase Criteria). In May 2020, a noise measurement report was delivered do Linde stating that Maximum Noise Exposure Criteria is met at two noise monitoring points (P2 and P3) but not at the remaining point (P1). Due to operational reasons (the plant could not stop its activity) the Noise Increase Criterion could not be observed.

In this context dBwave.i, S.A. was appointed by Linde Portugal, S.A. to evaluate in detail the environmental noise emissions from the factory and, by means of noise modelling and mapping technology, based on ISO 9613-2 calculation methodology, and validated by measurements on site, produce a clear and robust assessment of the present acoustic situation in order to establish a baseline for the NLU and DOURO projects, to be installed at the premises, also described in the present report.

The present noise map reflects the specific noise emitted by Linde plant, allowing one to calculate the specific noise at any location within the mapped area and, moreover, to determine the individual contribution of each noise source in order to rank the sources according to its relevance at any chosen locations. Also, it allows the simulation of different scenarios, namely future scenarios (detailed ahead) resulting from proposed either new developments and projects for the site, or noise abatement measures in case they are to be applied.

This report provides the following descriptions:

- The first stage of the job undertaken by dBwave, from field measurements to the noise map and presents detailed results of measurements and calculations for the baseline situation (as detailed in the previous delivered report).
- The second stage of the job based on the existing noise map and which includes the projected plant according to the NLU and DOURO projects. This map will allow calculations on noise sensitive locations for the projected situation and therefore to assess the acoustic impact of the projects and the need for noise control solutions.

2. SCOPE OF THE NOISE STUDY

The general scope of the work is as follows:

Phase 1:

- Noise modelling of the existing Linde plant, by means of building a 3D computer model of the plant and its surroundings; identifying and measuring the sound emission of each noise source and inserting these sources in the model, to produce a Noise map and calculate the specific noise of the Linde plant at the 3 evaluation points;
- Estimation of the residual noise that would exist at the 3 points without the existing Linde plant, according to the method approved by APA (Portuguese Environmental Agency), described in procedure 1 of Note 8 of the Practical Noise Guide of APA, issued in July 2020 (see Guide in annex);
    - Note: Knowing the residual noise is mandatory to check compliance of the installation (the existing and the future expanded plant) with the Noise Regulations;

Phase 2:

- Modify the computer model to include the NLU and DOURO projects, based on drawings and noise source sound power level information supplied by Linde;
- Calculate the predicted noise map and noise levels at the 3 points for the future scenario, and check for compliance or requirement for noise abatement measures;
- If noise reduction is required: perform a source ranking at the 3 points, to identify the main noise sources contributing to noise level exceedance and propose required noise reductions at each source and/or specify maximum sound power levels for the major noise sources /equipment;
- If needed, dBwave can also help in specifying noise control actions and in the procurement of suppliers to implement them.

The present report includes both phases of the Study.

The first phase encompassed the following works:

1. Field work on site, consisting basically of:
    - Noise measurements close to every relevant noise source in the plant, to estimate its sound power level in frequency bands and directivity characteristics and correlate it with the noise monitoring results away from the sources.
    - Noise measurements at mid distance from the sources and the sensitive receivers, essentially for model validation purposes.
    - Photographic report and brief noise source description to produce a noise source data base.
2. Development of an acoustic model for prediction of noise levels generated by the Plant and associated installations and transportation circuits at the surrounding areas, based on plant layout, time schedules of operation, cartographic data and equipment noise data provided by the client and measured on site.
3. Calculations for the current plant operation and production of results such as:
    - Detailed results at specific point receivers.
    - General results in surrounding areas – noise maps.

- Calculation for different day periods / indicators as required (e.g. day-night, day-evening-night)., according to time schedules of operation.

4. Providing final noise map and noise levels at receivers based on above mentioned points.
5. Final noise report containing all noise measurements, calculations and noise contour maps.

The second phase encompassed the following works:

1. Development of an acoustic model for the future scenario. This model is based on the update of the acoustic model of the current situation (Phase 1) and includes all the existing and new noise sources and installations.
2. Calculations for the projected plant operation and production of results such as:
   - Detailed results at specific point receivers.
   - General results in surrounding areas – noise maps.
   - Calculation for different day periods / indicators as required (e.g. day-night, day-evening-night)., according to time schedules of operation.
3. Evaluation of the legal compliance at the 3 points identified in noise measurement reports and if noise reduction is required. If so, for each point, a source ranking will be prepared to detail which sources contribute the most in each location and should be the subject of noise control solutions.
4. Specification of noise control solutions for the main sources at each point and indication of the estimated reduction.
5. Providing final noise map and noise levels at receivers based on above mentioned points.
6. Final noise report containing all noise measurements, calculations and noise contour maps.

3. NOISE GUIDELINES AND CRITERIA

Noise guidelines relevant to this study are summarized in the following sections, where just selected parts have been included, all translated from Portuguese. All direct transcription from the original texts are in *italic*. Some aspects that we have considered particularly relevant are underlined.

3.1. D.L. 9/2007 – PUBLIC LAW ON NOISE

Relevant definitions:

- ***Permanent noise activity*** *means activity carried out on a permanent basis, albeit seasonal, which produces harmful or annoying noise for those who live or remain in places where the effects of that noise source are felt, namely the working of industrial establishments, commercial and service*
- ***Daytime-Evening-Night-time noise indicator (Lden)*** *the noise indicator, expressed in dB (A), associated with the overall annoyance, given by the expression:*

$$L_{den} = 10 \times \log \frac{1}{24}\left[13 \times 10^{\frac{L_d}{10}} + 3 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}}\right]$$

- ***Daytime noise indicator (Ld) or (Lday)*** *the long-term average sound level, as defined in Standard NP 1730-1: 1996, or the corresponding updated version, determined over a series of daytime periods representative of one year;*
- ***Evening noise indicator (Le) or (Levening)*** *the long-term average sound level, as defined in Standard NP 1730-1: 1996, or the corresponding updated version, determined over a series of evening periods representative of one year*
- ***Night-time noise indicator (Ln) or (Lnight)*** *the long-term average sound level, as defined in Standard NP 1730-1: 1996, or the corresponding updated version, determined over a series of night-time periods representative of one year*
- ***Reference period*** *the time interval to which a noise indicator refers, in order to cover typical human activities, delimited in the following terms:*
    - *i) Daytime - from 7h00 to 20h00;*
    - *Evening period - from 20h00 to 23h00;*
    - *iii) Night time - from 23h00 to 7h00;*
- ***Noise sensitive location*** *the residential dwelling, school, hospital or similar building or leisure space, with human use.*
- ***Ambient noise*** *the global noise observed in a given circumstance at a given moment, due to the set of sound sources that are part of the near or distant neighborhood of the place / location considered.*
- ***Specific noise*** *the part of the ambient noise that can be specifically identified by acoustic means and attributed to a specific sound source.*

- ***Background noise*** *the ambient noise to which one or more specific noises are suppressed, for a given situation.*
- ***Sensitive area*** *the area defined in a master or local plan as intended for residential use, or for schools, hospitals or similar, or existing or planned leisure spaces, which may contain small trade and service stores intended for the local neighborhood, such as cafes, restaurants and other catering establishments, stationery stores and other small traditional shops, all closed during night-time period;*
- ***Mixed area*** *the area defined in a master or local plan, the occupation of which is assigned to other uses, existing or planned, in addition to those referred to in the definition of a sensitive area.*

Relevant sections:

- ***Section 11 – Maximum Noise Exposure Criterion***

  a) Mixed areas must not be exposed to external ambient noise above 65 dB (A), expressed by the Lden indicator, and greater than 55 dB (A), expressed by the Ln indicator;

  b) Sensitive areas must not be exposed to ambient noise above 55 dB (A), expressed by the Lden indicator, and greater than 45 dB (A), expressed by the Ln indicator

- ***Section 13 – Permanent Noise Activities and Noise Increase Criterion***

  b) Compliance with the Noise Increase Criterion, defined as the difference between the value of the LAeq indicator for ambient noise measured during the occurrence of the specific noise of the activity or activities under assessment and the value of the LAeq indicator for background noise, difference that cannot exceed 5 dB (A) for the daytime period, 4 dB (A) for the evening period and 3 dB (A) for the night-time period, according to annex I to the present Regulation, of which it is an integral part.

- ***Annex I – Guidance for the application of Noise Increase Criterion***

  1 – The LAeq of the ambient noise determined during the occurrence of the specific noise must be corrected if pure tones (correction K1) or impulsive (correction K2) sounds are detected as part of the specific noise, being called assessment level, LAr and applying the following formula:

  $$LAr=LAeq+K1+K2$$

  These values are K1=3 dB(A) or K2=3 dB(A) if pure tones or impulsive sounds, respectively, are found in the specific noise, or are K1=0 dB(A) or K2=0 dB(A) if these sounds are not present. If there is a coexistence of both pure tones and impulsive sounds, the correction to add is K1+K2=6 dB (A).

  The method to detect pure tones within the evaluation time interval, consists of verifying in a one third octave band spectrum if the sound level of a given band exceeds that of the adjacent ones by 5 dB(A) or more. If so the noise should be considered as tonal and the correction K1 should be applied.

  The method to detect the impulsive sounds within the evaluation time interval, consists of determining the difference between the equivalent continuous sound level, LAeq, measured simultaneously using impulsive and fast time weightings. If this difference is greater than 6 dB (A), the noise must be considered impulsive and correction K2 should be applied.

2 – A value defined as D must be added (as indicated in the table below) to the difference between the assessment level (LAr) and the LAeq of the background noise, for each noise reference period (day-time, evening, night-time), as established in paragraph b) of Section 13. The D value is determined by calculating the ratio between the cumulative duration of the specific noise and the total duration of the respective noise reference period .

Ratio between the cumulative duration of the specific noise and the total duration of the respective noise reference period (q)	*D in* dB(A)
q ≤ 12,5 %........	4
12,5 % < q ≤ 25 %........	3
25 % < *q* ≤ 50 %........	2
50 % < *q* ≤ 75 %........	1
q > 75 %........	0

3 – Exceptions to the previous table: for the night-time period, values of D=4 and D=3 are not applicable, keeping D=2 for ratio values lower or equal to 50%. Except for this restriction, a value of D=3 is applicable for activities opened only till midnight

3.2. CRITERIA TO BE USED IN THE STUDY

As a conclusion from the above referred guidelines, this study will rely on the following assumptions and criteria:

- Three periods will be considered, as stated in the D.L. 9/2007:
  - ***Daytime****: 07:00 hrs to 20:00 hrs.*
  - ***Evening time****: 20:00 hrs to 23:00 hrs.*
  - ***Night-time:*** *23:00 hrs to 07:00 hrs.*
- Two noise indicators will be considered for noise evaluation purposes, as stated in the D.L. 9/2007:
  - **Lden**
  - **Ln**
- Two criteria will be considered for noise evaluation purposes, as stated in the D.L. 9/2007:
  - **Maximum Noise Exposure Criterion**:
  - **Noise Increase Criterion**:
- The NSLs are represented by the monitoring points presented in the latest noise report, i.e.
  - **P1:** located to the North West of Linde near a residential dwelling and the other side of the main road (IC2 / EN1).
  - **P2**: located East of Linde near a villa and Estrada do Camarnal.
  - **P3**: located South of Linde near a small group of residential dwellings

4. SITE DESCRIPTION

4.1. SITE LOCATION

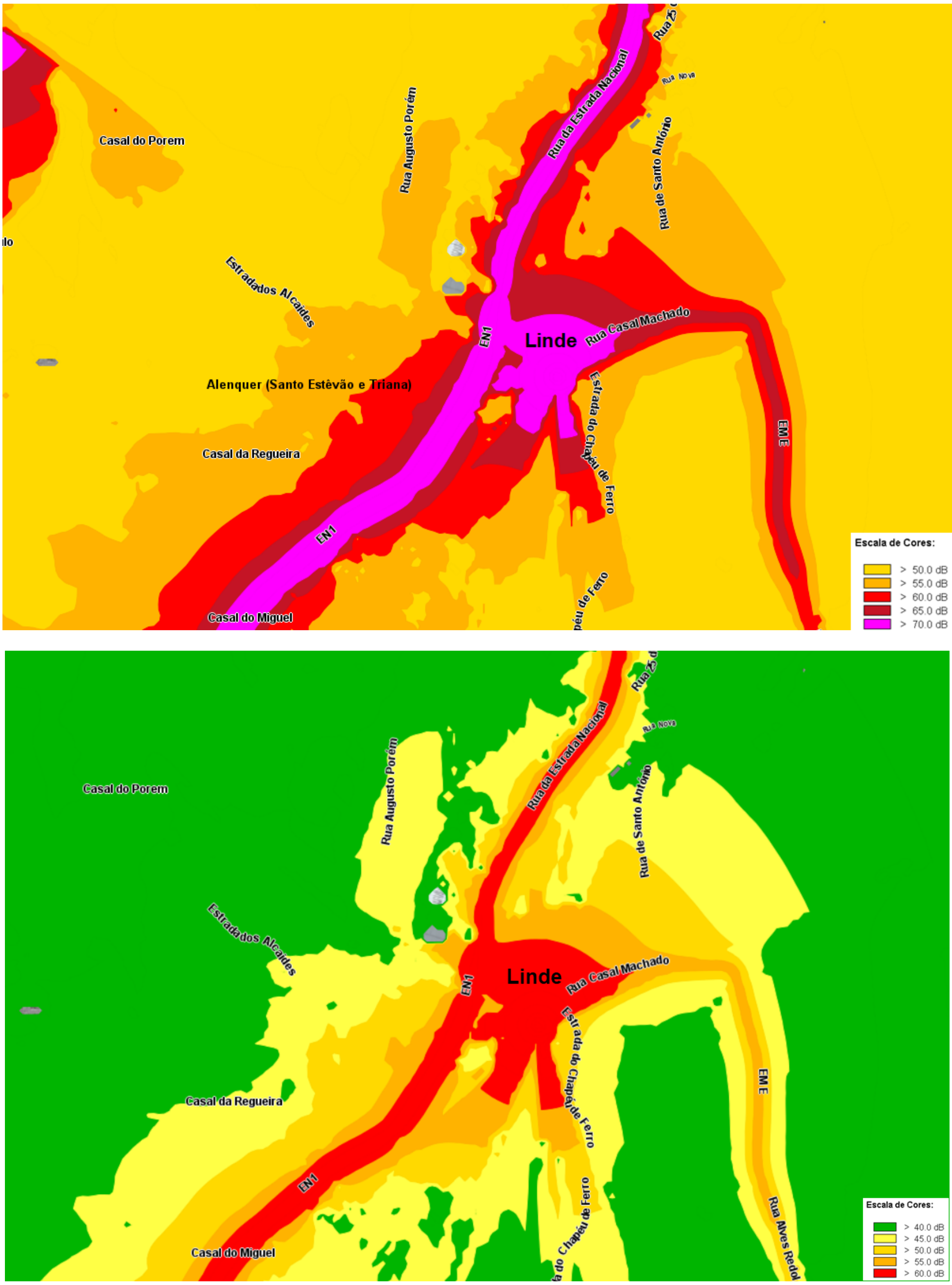
1.1 Figure 4-1 – General location of the plant

Linde plant in Alenquer is located near the town of Cheganças and close to major road IC2/EN1. There are other small plants and some noise sensitive locations nearby, namely isolated houses and small cottages to the northwest, south and east of Linde property limits.

The area is relatively plain, with no relevant topography, and surrounded by small bushes and wild grass. Local and passing by traffic, namely from IC2/EN1 and Estrada do Camarnal, constitutes also the major background noise sources in the area. These two roads are intensively used by heavy vehicles that account between one-fourth and one-third of the total traffic. Other industrial and commercial installations are located near Linde plant, which will add up some contribution to the background noise.

2.1 Figure 4-2 – Vicinity of the plant, showing typical noise assessment points, at the closest sensitive locations

Nonetheless, the contribution of IC2/EN1 is the more relevant to the existing noise in the area around Linde plant, as displayed in Alenquer Municipal Noise Map in the figure below, available from http://websig.oestedigital.pt/alenquer, for L_{den} and L_n indicators.



3.1

4.1 Figure 4-3 – Alenquer Noise maps around Linde Plant, for Lden (above) and Ln (below).

4.2. LINDE PLANT

As described in its Portuguese website, Linde plant in Alenquer is modern gas producing plant with a top of the line Air Gas Separation Unit (ASU), several gas production units (Acetylene, Hydrogen, Oxigen and Nitrogen) including medical gases, a gas filling plant and a few warehouses. The gases produced there can be delivered in small cylinders or in large tanks transported by trucks.

- The production capacity resides in the gas production units and the ASU that includes a cold box and supplies two 800 m^3 storage tanks (one for oxygen and the other for nitrogen) and a smaller argon storage tank. The following equipment is used in the production processes: gas compressors, piping, pumps, valves, control equipment and services.

To support the production activities of the bulk facilities, a number of utilities are generated or used: cooling towers, electrical substation, pumping station and storage tanks for liquid gases

The main noise sources are the cooling towers, pumping station and some equipment and machines belonging to the ASU (air supply units, fans, gas discharge)

With respect to noise, the plant has been carrying out annual noise surveys, in accordance with the IPPC License. The estimation method for the specific noise has been varying and the following parameters have been used: L_{Aeq}, L_{A90} and L_{A50}, depending on observed conditions of specific and residual noise. The table below summarizes the historic noise levels measured at the monitoring points which, although showing some variance, have always evidenced compliance with the noise limits set in the IPPC License.

5. DEVELOPMENT OF THE ACOUSTIC MODEL

5.1. METHODOLOGY

For the development of a noise map it is necessary to model all the variables involved in the complex environmental problem that is noise, so that the computational prediction obtained from the physical model of sound propagation can be as accurately as possible.

The next paragraphs describe in more detail the information needed for the production of an accurate and reliable acoustic model.

- Software: The software used in this study for the preparation of noise maps is CadnaA. This software is on the market since the 80s, having been used since then, with international recognition as one of the best and more accurate environmental noise modelling programs. CadnaA fully complies with the requirements outlined in EU Directive (2002/49/EC), as well as its further developments. Moreover, having been developed from the beginning for industrial applications, it is particularly robust for modelling noise from industrial plants. For this project the program is set to follow the international standard recommended by EPA for industrial noise, i.e., ISO 9613-2: "Acoustics - Attenuation of sound propagation outdoors, Part 2: General method of calculation.

- Topography: In preparing a noise map, information is needed on the land altimetry, including contour lines and spot elevations. From this information, the digital terrain model is built and used as the basis for the simulation. The topographic data has been provided by the customer.

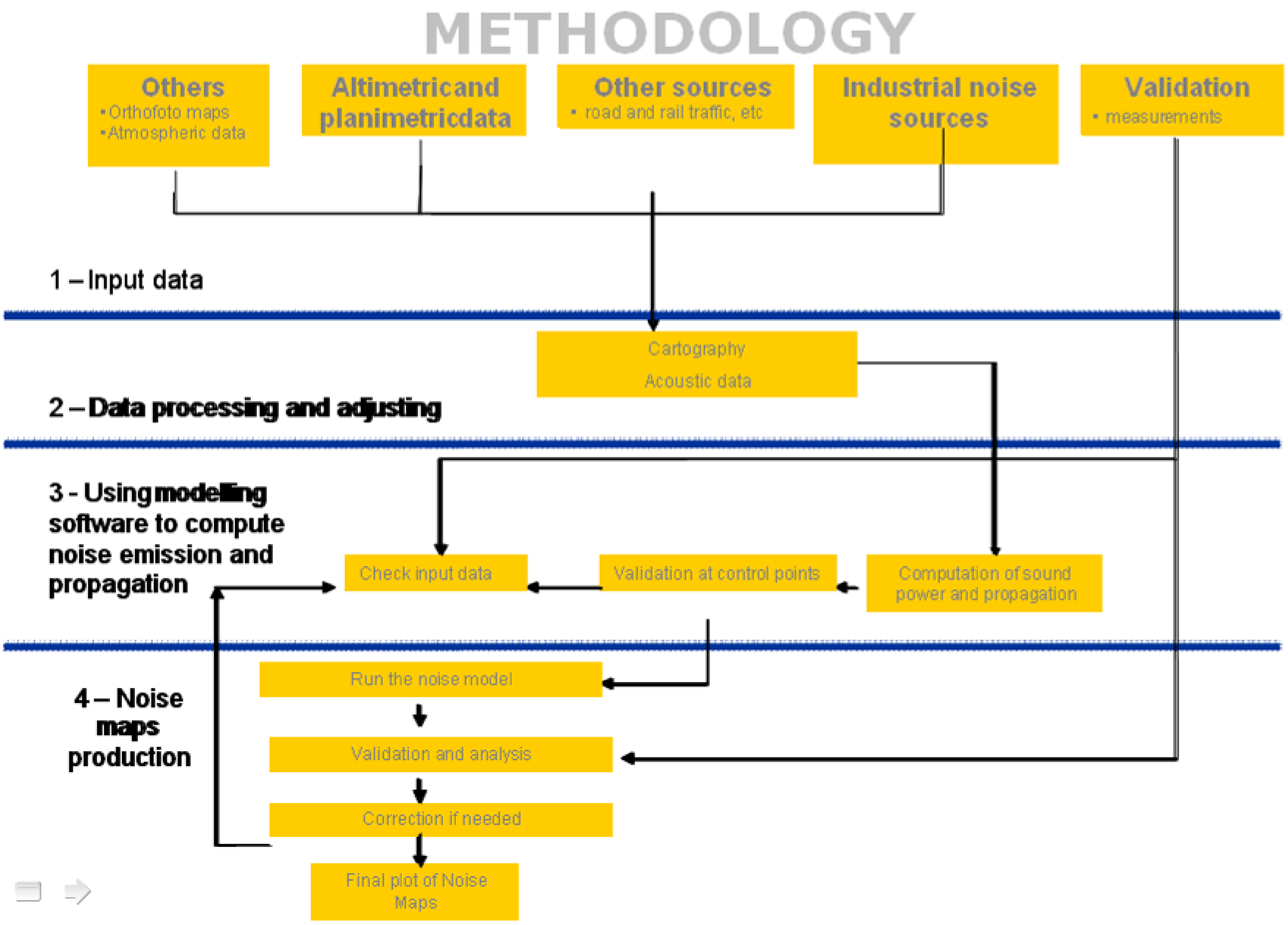
- Map Area: The map area is the area defined as the surrounding area outside the industrial plant. It is chosen so as it can consider the influence from the plant on residential surrounding areas.

- Data on buildings and other construction elements has been provided by the client. The buildings belonging to the factory, all the surrounding residential and industrial buildings, as well as some objects of interest such as walls and embankments, which act as "noise barriers" in the sound propagation outdoors have been identified and introduced into the model.

- Noise source characterization: Field work is done to identify all the main noise sources from the plant, and assessment of the sound power emitted from each identified source. A noise source database has been created (presented in an Annex) with technical information needed to the modelling of each source. The sound pressure levels, L_p, measured close to each source are subsequently converted into sound power levels, L_w, taking into account the corrections applied to the type of source and type of sound propagation.

- Validation/Calibration of the model: a correct acoustic model is strongly dependent on the quality of input data. To reduce the uncertainties associated with the estimation of the sound power levels of sources, obtained from near-field sound level measurements, an extensive validation/calibration process is implemented after all the input data is introduced in the model and a first map calculation is done. The validation of the acoustic model is made by comparing the sound pressure levels measured in the field with the calculated values at the same points, taking into account the actual operating conditions of the plant during those field measurements. The process includes “source validation”, where short-term measurements are made under the direct influence of only a small number of sources and compared with the results of the model at the same points, and "model validation", where noise measurements are performed for longer periods in the far field of all plant noise sources for a final validation of the model as a whole.

The following diagram describes in a simplified way the general approach used by dBwave.i to produce noise maps. The next pictures illustrate typical examples of noise maps.



5.1 Figure 5-1 – Schematics of dBwave.i procedure for industrial noise mapping.

From the model, it is then possible to identify, characterize and rank all the relevant noise sources based on its acoustical influence at relevant receiving points around the Plant. Typically, these are located at the property limits of the Plant and/or at sensitive receivers (such as houses), at given locations.

After comparing predicted noise levels at relevant receivers with established criteria, and having identified and ranked the sources according to their individual contributions to the overall noise levels at those receiver, it is then possible to propose required noise reductions for each source, as necessary to comply with noise limits, preferably with a reasonable safety margin in order to account for the uncertainties of both measurements and calculations.

In this way, the risk of future complaints from neighbours, or of non-compliance with legal limits, can be highly reduced. Moreover, the noise map and the associated information delivered with it, can become an important noise management tool for the HSE team of the Plant.

5.2. NOISE SOURCES SURVEY

The noise sources survey is a fundamental part of the noise mapping process that aims to faithfully represent the current acoustic environment, especially when noise emission data is not available for the noise sources - which is the case with existing industrial noise sources in general.

For the preparation of the noise map of the installation under study, survey noise measurements were made close to all equipment, machine or activity that emit relevant noise. With the measurements, a first estimate of the sound power of each noise source is obtained. The values thus estimated are imported into the model, assigning each power to the respective source, previously inserted in the model in its correct geometric position and with the most appropriate type (point source, line source or area source). In total, 38 sources were included in the model.

Noise measurements for individual characterization of sound sources were carried out on 19/04/2021 at the company's facilities, which were fully operational.

The following pictures illustrate the process of surveying the noise sources through measurements on site.

Figure 5-2 – Examples of close field sound measurements to characterize noise sources.

From this noise survey, a noise sources registration file is obtained, through an automated process developed internally by dBwave.i, which both generates a deliverable for the client, the Noise Sources Register (Annex **II**), and an input to the acoustic model: the file includes metadata which is transferred to the noise modelling software.

Each noise source is briefly identified and acoustically characterized in the Noise Sources Register (Annex **II**), from which we include an example in the figure below.

Empresa Linde PT Ref.ª 0162/21DBW

Referência dBwave	Referência Cliente / Descrição da Fonte
F001	Torre de Refrigeração 1 Lado Este

Dist à fonte (m)	Área (m2)	Emissão esferica (%)	Data da Medição
0	1		19/04/21

Tipo de Medição: 3 | Lp + areas + near field correction

Horário de Funcionamento (min): D | E | N

Comentários

Localização

f (Hz)	LA_{eq}
Global	86,4
20 Hz	19,8
25 Hz	38,5
31,5 Hz	34,7
40 Hz	40,7
50 Hz	49,8
63 Hz	53,3
80 Hz	71,7
100 Hz	65,0
125 Hz	63,9
160 Hz	65,6
200 Hz	66,9
250 Hz	67,9
315 Hz	67,8
400 Hz	67,5
500 Hz	72,4
630 Hz	72,0
800 Hz	73,1
1 kHz	74,0
1,25 kHz	75,1
1,6 kHz	75,4
2 kHz	76,2
2,5 kHz	75,9
3,15 kHz	76,2
4 kHz	76,4
5 kHz	75,2
6,3 kHz	72,0
8 kHz	70,6
10 kHz	69,4
Tonal	Sim

Empresa Linde PT Ref.ª 0162/21DBW

Referência dBwave	Referência Cliente / Descrição da Fonte
F017	Grelha Admissão Ar Lado Este ASU

Dist à fonte (m)	Área (m2)	Emissão esferica (%)	Data da Medição
0	1		19/04/21

Tipo de Medição: 3 | Lp + areas + near field correction

Horário de Funcionamento (min): D | E | N

Comentários

Localização

f (Hz)	LA_{eq}
Global	68,0
20 Hz	28,4
25 Hz	35,5
31,5 Hz	35,7
40 Hz	39,5
50 Hz	48,6
63 Hz	52,4
80 Hz	53,0
100 Hz	57,5
125 Hz	50,9
160 Hz	47,5
200 Hz	43,7
250 Hz	43,9
315 Hz	45,5
400 Hz	50,2
500 Hz	50,8
630 Hz	53,8
800 Hz	59,8
1 kHz	60,0
1,25 kHz	60,0
1,6 kHz	58,3
2 kHz	57,2
2,5 kHz	52,6
3,15 kHz	48,1
4 kHz	48,2
5 kHz	48,1
6,3 kHz	42,9
8 kHz	39,2
10 kHz	35,2
Tonal	Não

Figure 5-3 – Examples of noise source registrations.

5.3. VALIDATION MEASUREMENTS

During the field work validation measurements of the noise sources were carried. Validation points are depicted in Figure 5-4. The validation process should be understood as a quality control job and an important part of the noise map.

Figure 5-4 – Location of monitoring / validation points

For the Source Validation, 9 measurements were performed in the surroundings of specific noise sources or groups of noise sources, to crosscheck the respective sound powers to input in the model and validate them, individually or in group. As part of the validation process, a few measurements were carried out and allowed to adjust the sound power level of many sources. These adjustments also influenced the results of the validation of the acoustic model and will be presented in subsequent tables. The position of these validation points is depicted in Figure 5-4, where they are referenced as *PVnnn* (point of validation+number).

The following pictures illustrate the process of noise sources validation through measurements on site.

Figure 5-5 – Examples of sound measurements to validate noise sources.

5.4. RESULTS OF THE VALIDATION PROCESS

The **validation of noise sources** process was performed at a number of measurement points, in controlled conditions.

In the process, adjustments were made in the sound power of some noise sources, in order to meet the validation criterion in as much points as possible. The validation criterion specified by dBwave.i procedure for this process states is:

$$\left| L_{Aeq\ calc.} - L_{Aeq\ meas.} \right| \leq 2\ dB(A)$$

i.e. the difference, in absolute value, between calculated and measured levels equal or lower than 2 dB(A).

Ideally, all 9 validation points would meet this criterion. In practice however, many factors contribute to the uncertainty of each individual measurement, such as variations in operating conditions of the noise sources close to each point, interference from noisy activities or equipment not included in the model, local geometric details not included in the model (with little influence on far field propagation), etc. Therefore, one can assume a statistical approach and accept that a number of points will not meet the criterion, as long as these deviations are analysed and understood.

The analysis of the source validation results is presented in the following table and graphic.

Table 5-1 – Global results of the validation process of noise sources

Criterion diff ≤ 2 dB(A)	Number of points	%	Average difference	Average absolute difference
Complying	8	89%	0,0	1,2
N. Complying	1	11%	5,2	5,2
Total	9	100%	0,5	1,6

The previous table shows that:

- The criterion is fulfilled in nearly 90% of the points;
- The average difference for the total number of points is 0,5, being 0,0 for the points complying with the criterion; in average, the model calculated 0,5 dB(A) above the measured values;
- Taking the absolute values of the differences, the average over all points is 1,6 being 1,2 for the complying points – this shows that, globally, the absolute difference between calculation and measured values complies with the validation criterion.

Table 5-2 – Detailed results of the validation process of noise sources

Validation Point	Calculated level dB(A)	Measured level dB(A)	Calculated level - Measured level [dB(A)]	Point coordinates (EPSG 3763)			Criterion
				X(m)	Y(m)	Z(m)	
PV1	69,9	69,7	0,2	-74316,9	-65905,3	45,9	≤ 2 dB (absolute value)
PV2	64,2	64,1	0,1	-74307,1	-65905,1	45,9	≤ 2 dB (absolute value)
PV3	64,9	66,0	-1,1	-74307,0	-65908,1	52,2	≤ 2 dB (absolute value)
PV4	63,8	61,5	2,3	-74294,1	-65911,2	40,1	≤ 2 dB (absolute value)
PV6	75,5	70,3	5,2	-74315,8	-65931,0	39,8	≤ 2 dB (absolute value)
PV5	55,2	57,3	-2,1	-74281,0	-65915,7	40,0	≤ 2 dB (absolute value)
PV7A	69,4	71,0	-1,6	-74319,0	-65937,8	39,7	≤ 2 dB (absolute value)
PV7B	63,3	62,6	0,7	-74319,0	-65937,8	39,7	≤ 2 dB (absolute value)
PV8	66,9	65,7	1,2	-74339,1	-65891,5	40,4	≤ 2 dB (absolute value)

The table shows that:

- No point exceed an integer value of 5 dB(A) difference;
- The 2 dB(A) criterion ins complied at every point except for PV6.

Analyzing the point where validation criterion was not met:

- PV6 measurement (see photo) was taken between the Cold Box and the façade of ASU building, very close to both, and, therefore, it is very probable that reactive fields and interference may have occurred, specially due to low frequency tones, which are not accounted for in the model.

These results show a very good degree of robustness of the acoustic model.

5.5. ACOUSTIC MODEL

Noise modelling of the site was undertaken using the CadnaA software package. As explained above, the model of the existing site was calibrated and validated using sound pressure levels measured on site.

The main configurations of the noise simulation program were as follows:

- Calculation method/standard: ISO 9613
- Receiver grid height: 4 m
- Receiver grid spacing: 5 x 5 m
- Grid interpolation: none
- Maximum error: 0,0 for noise maps and 0,0 for single receivers' calculations
- Maximum search radius: 1500 m
- Maximum order of reflexion: 2 for all calculations
- Meteorology: homogeneous conditions assumed, temperature 15ºC and rel. humidity 80%
- Ground absorption: G = 0,1 (essentially reflective: paved and packed ground areas inside Linde plant) and G = 1 (sound absorbing; porous ground outside Linde plant).

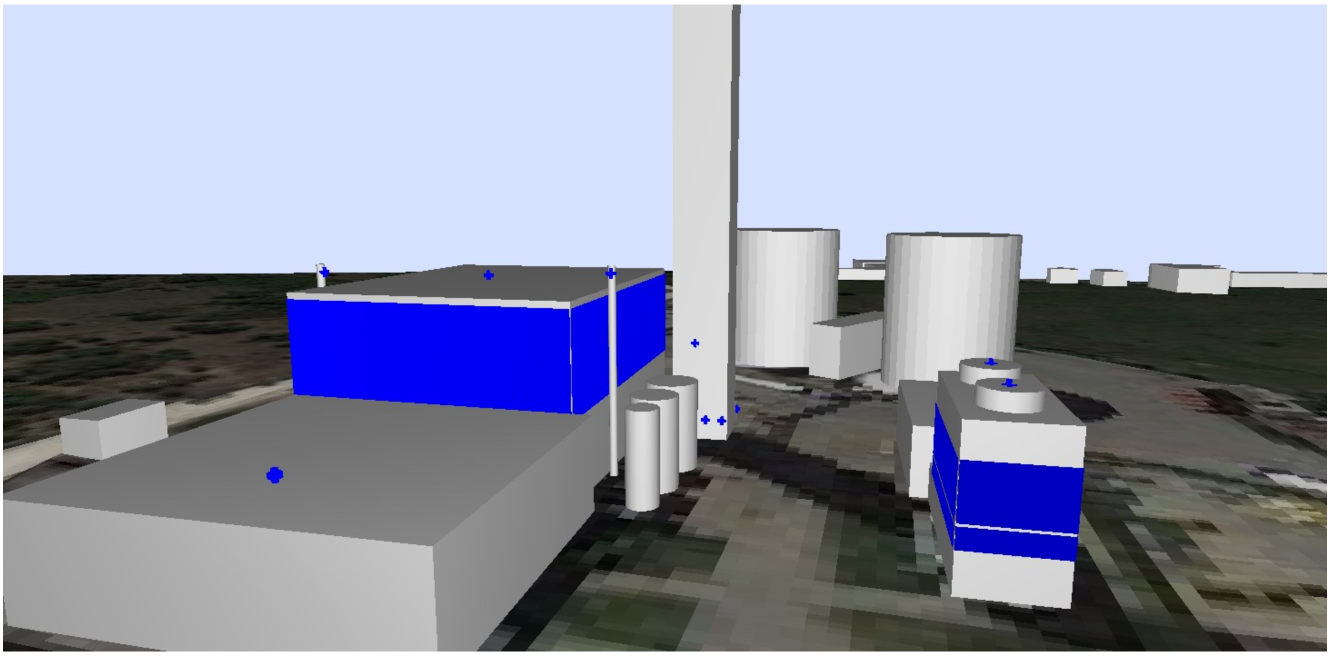
The 3D digital terrain model was generated from the cartography supplied by Linde. The 3D buildings and other acoustically relevant structures were introduced on top of the terrain, according to the information in the plant drawings supplied by the client, with as precise as possible coordinates and heights. Four types of objects were used: "Building" (building, structures), "Cylinder" (chimney structures, deposits), "Barrier" (existing walls, proposed noise barriers), "3D-reflector" (sheds).

A total of 38 sound sources were included in the model of the plant. The measured sound pressure levels in third octave bands were subsequently converted to sound power levels (Lw) by octave bands, according to standard procedures, following the corrections applicable to the type of source and type of sound propagation. Three different types of noise sources were considered:

- Point sources: machines with small dimensions, such as fans, motors, pumps, chimney exits;
- Line sources: noisy ducts or piping, conveyors or other line-shaped sources;
- Area sources (horizontal / vertical): building façades or openings, roofs, large equipment surfaces radiating noise.

The next figures show 3-D view of the plant as well as the location of the noise sources (blue coloured shapes)

6.1 **Figure 5-6 – General view of the acoustic model from above.**



7.1 **Figure 5-7– Detailed 3D view of the north side of the cooling tower and ASU (noise sources in blue).**

8.1 Figure 5-8 – General 3D views of the model.

The list of all the various types of sources are listed in the following tables.

Table 5-3 – List of point noise sources and associated sound power levels

ID	Noise source name	Sound Power Level Lw (dB(A))
F004.1	Torre de refrigeração 2 Ventilador Exaustão	86,4
F004.2	Torre de refrigeração 1 Ventilador Exaustão	86,4
F005	Válvula junto à fachada Cold Box	78,4
F007	Motor Bomba Criogénica 2 Cold Box	71,7
F006	Motor Bomba Criogénica 1 Cold Box	70,5
F009	Escape Descarga Fachada Oeste ASU	93,5
F010	Ventilador Cobertura Escritório	73,7
F011	Ventilador Cobertura ASU	84,3
F012	Escape Descarga Fachada Este ASU	68,1
F020	Admissão de Ar ASU	83,1
F021	Admissão de Ar Ventilador de Emergência ASU	82,1
F022	Ventilador de Emergência ASU	81,8
F035	Chaminé do Ventilador de Emergência ASU	100,2
F027	Zona de Entrada de Conduta no Primeiro Patamar Cold Box	98,9
F033	Bomba de Ar da Prensa Grande Fábrica Acetileno	88,0

Table 5-4 – List of linear noise sources and associated sound power levels

ID	Noise source name	Sound Power Level Lw (dB(A))
F018	Aresta da Ligação da Conduta da Grelha Admissão Ar Lado Este ASU	81,3

Table 5-5 – List of vertical area noise sources and associated sound power levels

ID	Noise source name	Sound Power Level Lw (dB(A))
F013.1	Torre de Refrigeração 2 Lado Norte	89,1
F013.2	Torre de Refrigeração 2 Lado Oeste	92,9
F003	Torre de Refrigeração 1 Lado Oeste	93,6
F001	Torre de Refrigeração 1 Lado Este	95,8
F013.3	Torre de Refrigeração 2 Lado Este	94,8
F002	Torre de Refrigeração 1 Lado Sul	93,8
F008.1	Grelha 1 Portão Este Casa das Bombas	71,2
F008.2	Grelha 2 Portão Este Casa das Bombas	71,2
F016	Grelha Lado Oeste Casa das Bombas	72,1
F017	Grelha Admissão Ar Lado Este ASU	74,8
F014.1	Painel Lateral Torre de Refrigeração 2 Lado Oeste	89,0

ID	Noise source name	Sound Power Level
		Lw (dB(A))
F014.2	Painel Lateral Torre de Refrigeração 2 Lado Norte	87,8
F014.3	Painel Lateral Torre de Refrigeração 2 Lado Este	89,0
F015.1	Painel Lateral Torre de Refrigeração 1 Lado Este	89,2
F015.2	Painel Lateral Torre de Refrigeração 1 Lado Sul	89,0
F015.3	Painel Lateral Torre de Refrigeração 1 Lado Oeste	89,2
F024.2	Painel Fachada Norte ASU	80,5
F025.2	Painel Lado Interior Fachada Oeste ASU	84,3
F024.1	Painel Fachada Sul ASU	80,5
F025.1	Painel Lado Interior Fachada Este ASU	84,3
F028	Portão Norte Fachada Este Enchimento IG	85,7
F029	Portão Central Fachada Oeste Fábrica Acetileno	82,3
F030	Porta de Homem Fachada Oeste Fábrica Acetileno	76,9
F031	Portão Sul Fachada Oeste Fábrica Acetileno	73,5
F032	Portão Norte Fachada Oeste Fábrica Acetileno	69,9
F034	Porta-Grelha Compressor Ar Fábrica Acetileno	85,6

6. RESULTS OF THE SIMULATIONS WITH THE MODEL

6.1. NOISE MAPS

One of the outputs of the acoustic model is the Specific Noise Map for any given parameters and indicators (L_{den} and L_{night} in this case) showing a detailed distribution of specific noise levels in and around the plant. The following figures show a noise map for L_{den} and another for L_{night}, at a height of 4 m above the ground.

Note that these noise maps only represent the specific noise generated from Linde plant's activity.

Monitoring points are also shown in each map (noise measurement report from May 2020).

Figure 6-1 – Noise map of Linde plant for L_{den} indicator at 4 m – baseline (current scenario).

Figure 6-2 – Noise map of Linde plant for L_{night} indicator at 4 m – baseline (current scenario).

These L_{den} and L_{night} specific noise maps show that:

- All sensitive receivers are below 50 dB(A) for L_{den} indicator;
- P1 is between 40 and 45 dB(A) for L_{night};
- P2 and P3 are below 40 dB(A) for L_{night}

These noise maps are detailed in Annex **I**.

6.2. ANALYSIS AT NOISE SENSITIVE RECEIVERS

The noise sensitive locations closer to the plant are represented by the noise monitoring points P1, P2 and P3, as defined in the latest noise measurement report delivered in May 2020.

Next figures show the acoustic model, as viewed from P1, P2 and P3.

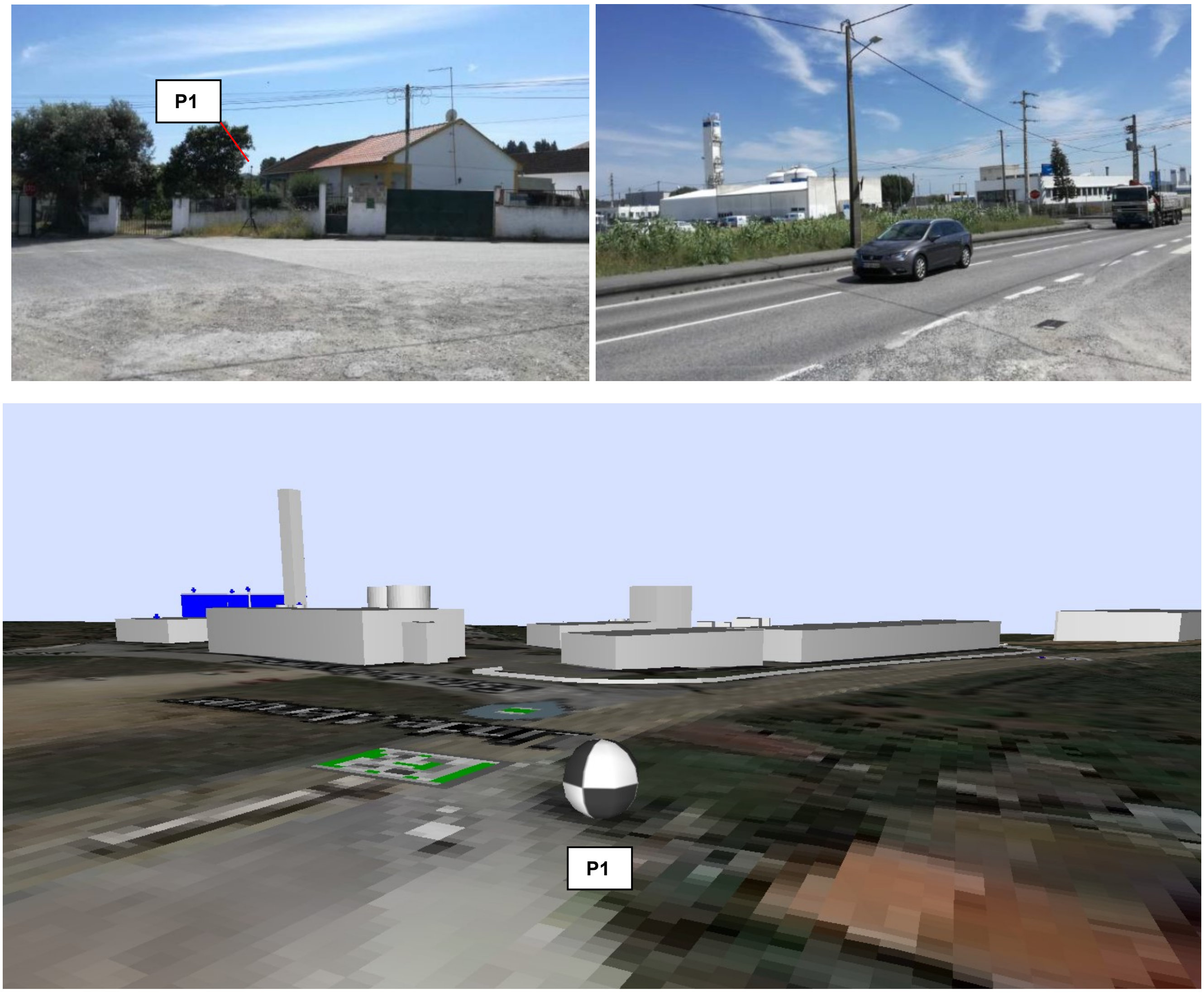


Figure 6-3 – Real and virtual views of receiver P1.

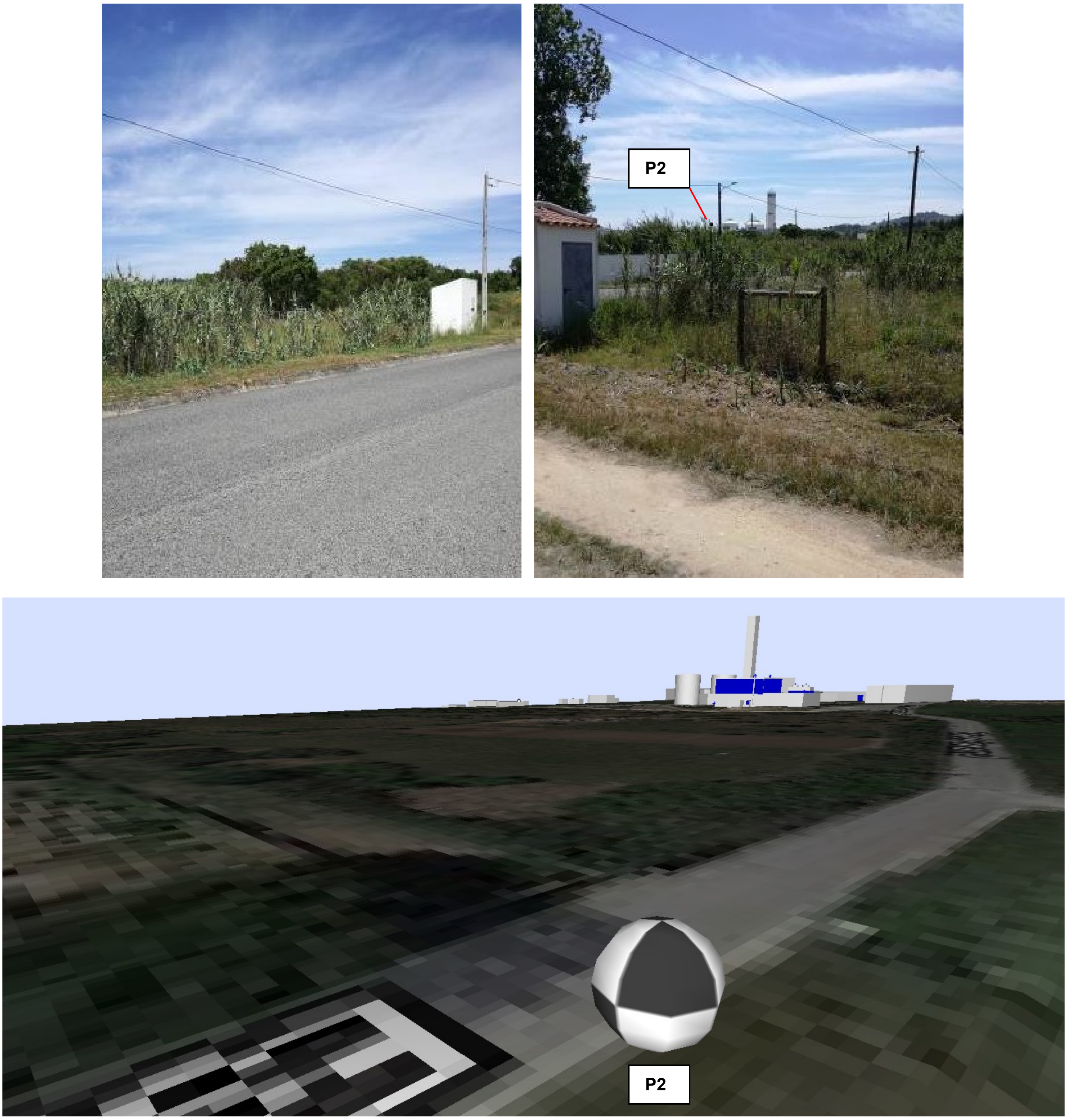


Figure 6-4 – Real and virtual views of receiver P2.

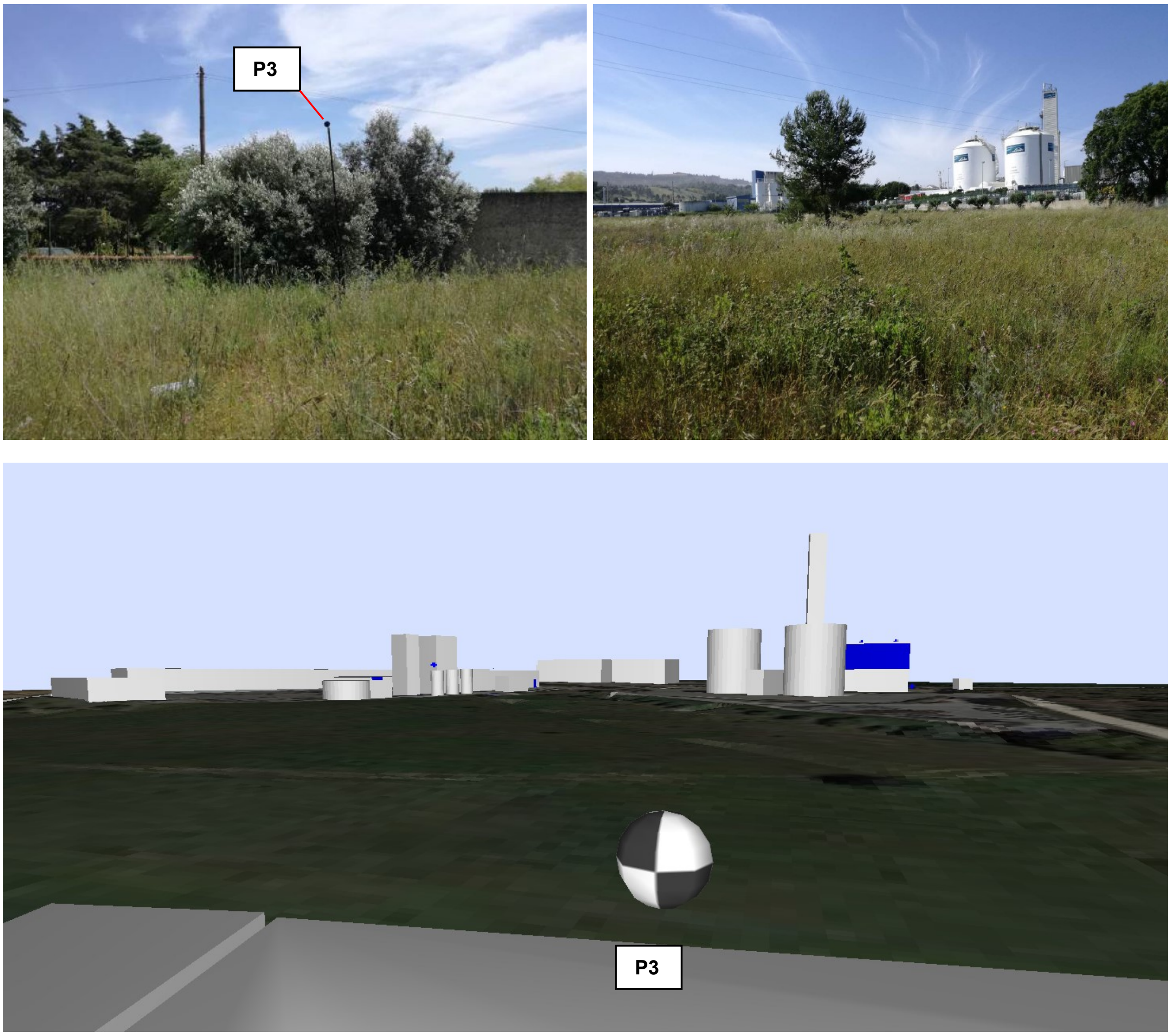


Figure 6-5 – Real and virtual views of receiver P3.

These points (P1 to P3), where noise measurements were performed in 2020, were now taken as reference receivers where detailed calculations of the specific noise, generated by the plant, were made with the model. Now, having the total noise (ambient noise), obtained directly by in situ measurement (continuous monitoring), and the specific noise, obtained from the model, it is possible to estimate background noise at those same points, by logarithmic subtraction between total and specific noise levels. Background noise includes all the noises (road traffic, commercial/industrial activities, natural sounds) except those produced directly by Linde plant’s activity.

This is in accordance with the Portuguese Environmental Agency (APA) Noise Guidelines[1] which defines, on its Note 8 of clause 3.3, a procedure (procedure 1) to estimate background noise by measuring the total noise and simulating the specific noise, according to the formula:

$$L_{Aeq,T}(RA)\ominus L_{Aeq,T}(RP) = L_{Aeq,T}(RR),\ se\ L_{Aeq,T}(RA) - L_{Aeq,T}(RP) > 3dB$$

where RA denotes "ruído ambiente" (ambient, or total noise), RR "ruído residual" (background noise) and RP "ruído particular" (specific noise).

Next tables show the measured noise levels for ambient noise and the calculated noise levels for specific noise and background noise as well as the legal compliance for both criteria as defined in D.L. 9/2007 (Maximum Noise Exposure Criterion and Noise Increase Criterion).

Table 6-1 – Measured and calculated noise levels for all noise monitoring points

Noise Monitoring Point	Measured			Calculated from model					
	Ambient Noise - LAeq [dB(A)]			Specific Noise LAeq [dB(A)]			Background Noise - LAeq [dB(A)]		
	Day-time	Evening	Night-time	Day-time	Evening	Night-time	Day-time	Evening	Night-time
P1	68,8	64,1	66,1	41,6	41,6	41,6	68,8	64,1	66,1
P2	57,3	51,5	52,3	37,2	37,2	37,2	57,3	51,3	52,2
P3	55,5	42,7	42,5	40,6	40,6	40,6	55,4	38,5	38,0

Table 6-2 – Legal compliance for Maximum Noise Exposure Criterion

Noise Monitoring Point	Measured Noise Levels [dB(A)]		Acoustical Zoning	Limit levels [dB(A)]		Legal compliance	
	Lden	Ln		Lden	Ln	Lden	Ln
P1	73	66	*Mixed Area*	65	55	No	No
P2	60	52		65	55	Yes	Yes
P3	54	43		65	55	Yes	Yes

Note: No legal compliance at P1 is only due to background noise, with no co-responsibility from Linde.

Table 6-3 – Legal compliance for Noise Increase Criterion

Noise Monitoring Point	Difference Ambient Noise - Background Noise - dB(A)			Legal limits - dB(A)			Legal compliance		
	Day-time	Evening	Night-time	Day-time	Evening	Night-time	Day-time	Evening	Night-time
P1	0	0	0	5	4	3	Yes	Yes	Yes
P2	0	0	0	5	4	3	Yes	Yes	Yes
P3	0	4	5	5	4	3	Yes	Not Applicable	Not Applicable

Note: if, in a given reference period, the measured ambient noise level, plus eventual corrections for tonal or impulsive noise, is equal or lower than 45 dB(A) then the Noise Increase Criterion is not applicable, as stated in Section 13, point 5 of D.L. 9/2007.

[1] ***Guia prático para medições de ruído ambiente*** *- no contexto do Regulamento Geral do Ruído tendo em conta a NP ISO 1996*, APA - Julho 2020.

It is seen that:

- P1 is not fully complying for the Maximum Noise Exposure Criterion;
    - But this is entirely due to the background noise (road traffic noise) and specific noise from Linde Plant is not co-responsible for that, according to the co-responsibility definition in clause 3.4 of APA Noise Guidelines, because specific noise levels are more than 10 dB(A) lower than ambient noise levels.
- At P2 and P3 full compliance with the noise limits is confirmed for the Maximum Noise Exposure Criterion.
- At all points full compliance is confirmed for the Noise Increase Criterion, noting that, although the night limit is surpassed at P3, this criterion is not applicable in this case because measured ambient noise level is below 45 dB(A).

7. FUTURE SCENARIO

7.1. BRIEF DESCRIPTION

The future scenario consists of an update of the current scenario that includes all the existing noise sources and installations and new ones (see next figure), namely:

- Machine House C1961 including Fan MH2 on top of the building
- Turbine X3771
- Coldbox Y3610
- Piping E3721

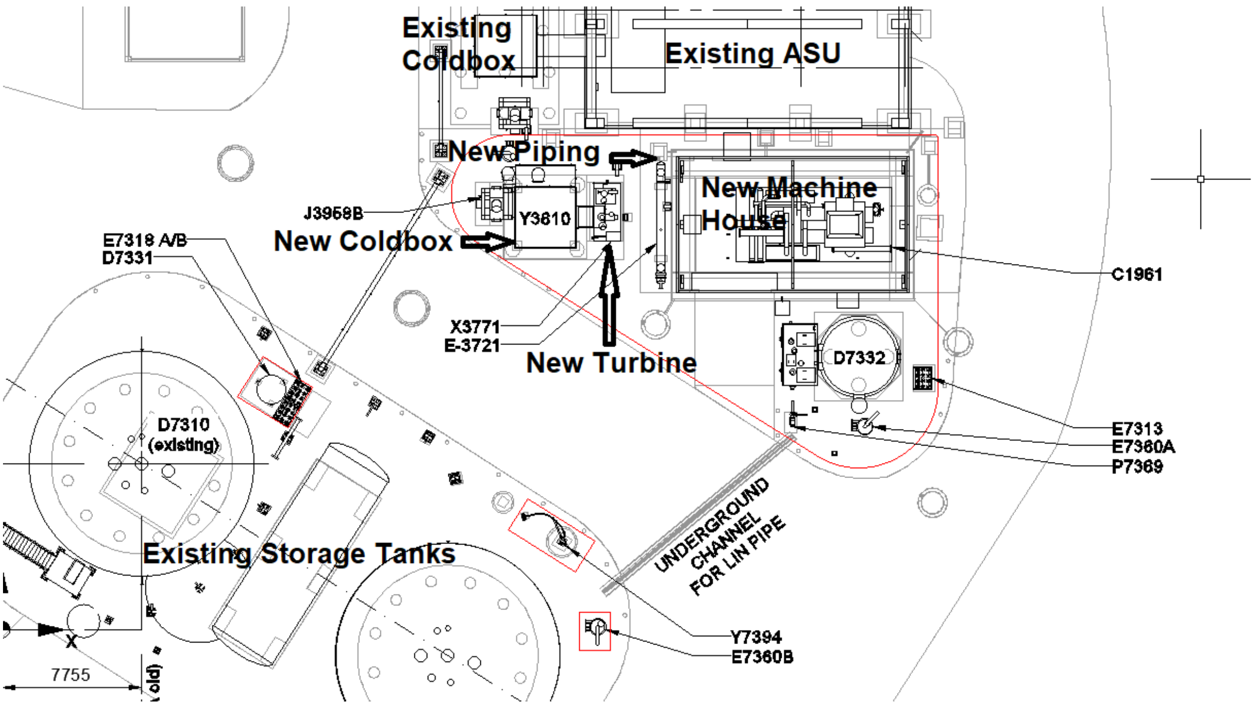


Figure 7-1 – Future scenario plant layout.

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7.2. NEW NOISE CONTROL SOLUTIONS

The noise levels for the future scenario, presented in the previous report (Ref. 0162_21DBW_MRRM0019_21), showed that full legal compliance would not be achieved at P3. These levels were based on the proposed noise control solutions below, namely for the Machine House :

- Sandwich Panel FTB PF 1000 – Acoustic façade panel with 100 mm thickness (R_w = 34 dB, α_w ≈ 1)
- Sandwich Panel FTB PC 1000 – Acoustic roof panel with 100 mm thickness (Rw = 34 dB, αw ≈ 1)
- Rolling door with R_w = 30 dB

In order to achieve full legal compliance at P3 receiver, the proposed noise control solutions for the Machine House should be:

- ACH Wall Panel (PF1) type M 100 mm thickness (R_w = 37 dB, α_w = 0,85)
- ACH 5 RIB Roof Panel (P5G) type L 100 mm thickness (Rw = 35 dB, αw = 0,85)
- Effertz rolling door with R_w = 31 dB

One should note that there was an update of indoor noise levels for the Machine House based on the technical sheet of the proposed compressor, supplied by the client. The sound power level considered for the compressor is 121 dB(A). Later on, calculations were made considering this sound power level and the newly proposed noise control solutions detailed before.

7.3. ANALYSIS AT NOISE SENSITIVE RECEIVERS AFTER APPLYING NEW NOISE CONTROL SOLUTIONS

Next tables present the calculated noise levels for ambient noise, specific noise and background noise as well as the legal compliance for both criteria as defined in D.L. 9/2007 (Maximum Noise Exposure Criterion and Noise Increase Criterion), after applying new noise control solutions

Table 7-1 – Measured and calculated noise levels for all noise monitoring points after applying new noise control solutions

Noise Monitoring Point	Background Noise - LAeq [dB(A)]			Specific Noise LAeq [dB(A)]			Ambient Noise - LAeq [dB(A)]		
	Day-time	Evening	Night-time	Day-time	Evening	Night-time	Day-time	Evening	Night-time
P1	68,8	64,1	66,1	42	42	42	68,8	64,1	66,1
P2	57,3	51,4	52,2	40,3	40,3	40,3	57,4	51,7	52,5
P3	55,4	40,0	39,7	41,6	41,6	41,6	55,6	43,9	43,8

Table 7-2 – Legal compliance for Maximum Noise Exposure Criterion after applying new noise control solutions

Noise Monitoring Point	Measured Noise Levels [dB(A)]		Acoustical Zoning	Limit levels [dB(A)]		Legal compliance	
	Lden	Ln		Lden	Ln	Lden	Ln
P1	73	66	Mixed Area	65	55	No	No
P2	60	52		65	55	Yes	Yes
P3	55	44		65	55	Yes	Yes

Table 7-3 – Legal compliance for Noise Increase Criterion after applying new noise control solutions

Noise Monitoring Point	Difference Ambient Noise - Background Noise - dB(A)			Legal limits - dB(A)			Legal compliance		
	Day-time	Evening	Night-time	Day-time	Evening	Night-time	Day-time	Evening	Night-time
P1	0	0	0	5	4	3	Yes	Yes	Yes
P2	0	0	0	5	4	3	Yes	Yes	Yes
P3	0	Not Applicable	Not Applicable	5	4	3	Yes	Not Applicable	Not Applicable

Note: if, in a given reference period, the measured ambient noise level, plus eventual corrections for tonal or impulsive noise, is equal or lower than 45 dB(A) then the Noise Increase Criterion is not applicable, as stated in Section 13, point 5 of D.L. 9/2007.

It is seen that after applying the proposed noise reductions, all points will achieve full compliance for both legal criteria with the exception of the Maximum Noise Criterion for P1. This exception, as explained previously in this report, is related to road traffic noise coming from IC2/EN1 and not to the operation of Linde Plant.

8. CONCLUSIONS

An evaluation of the environmental noise emissions from Linde plant was done, by means of noise modelling and mapping technology, based on ISO 9613-2 calculation methodology, and validated by measurements on site. The aim was to produce a clear and robust diagnosis of the existing acoustic situation and establish a solid noise baseline for the future Linde projects for the plant (NLU and DOURO projects).

The acoustic model which was developed, allows one to calculate the specific noise at any location within the mapped area and, also, to determine the individual contribution of each noise source in order to rank the sources according to its relevance at any chosen locations. Also, it allows the simulation of different scenarios, namely future scenarios resulting from proposed new developments and projects for the site, or noise abatement measures in case they are to be applied.

The present noise map reflects the specific noise emitted by Linde plant. The main findings were:

- Calculated specific noise levels are low and, in general, well below measured ambient noise levels.
- At P1 and P2 the contribution from the plant is more than 10 dB lower than the ambient noise levels. However, at P3, this is not so for the evening and night periods – this was found to be the more critical point, which needed particular attention for the future projects.
- Road noise coming from IC2/EN2 is by far the major noise source observed at P1. The calculated background noise levels at this point already exceed the limit levels established in the applicable noise law.
- Full compliance is observed in all noise monitoring points except for the Maximum Noise Exposure Criterion at P1 but it was clearly proofed that noise contributions from Linde Plant are negligible at this point, not being considered co-responsible for non-compliance, according to APA Noise Guidelines.

In general terms, the planned expansion south of the existing Linde plant will not change the findings observed for the present situation, with the exception of receiver P3. The expansion will increase specific noise levels at this receiver and the initial predictions indicated a non-compliance situation for the Noise Increase Criterion. In order to address this situation and achieve full legal compliance at P3, some noise control solutions were proposed for the new Machine House (acoustic panels and acoustic rolling door). These solutions will enable ambient noise levels below 45 dB(A), for evening and night-time periods, and therefore avoid the applicability of the Noise Increase Criterion and, therefore, achieving legal compliance.

Authors of this Noise Study:

Field work and acoustic modelling:	*Field work and Final Report*
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ANNEXES

- **Annex I - Actual Noise Map**
- **Annex II - Noise Sources Registers**
- **Annex III - Projected Noise Map**