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LCA APPROACH TO EVALUATE THE SUSTAINABILITY OF INNOVATIVE LOW-HEIGHT NOISE BARRIERS

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ABSTRACT

As part of the LIFE SILENT project[1] (focused on developing innovative and eco-friendly solutions for noise mitigation in road and railway contexts - innovative materials and advanced technologies are being explored to design Low-Height Noise Barriers (LHNB) with enhanced acoustic properties and a significantly reduced environmental impact. For this scope a comparative Life Cycle Assessment (LCA) was conducted to evaluate the environmental impacts of different typologies of LHNBs.
The LCA focused on the production phase ("from cradle to gate") of three LHNB solutions, analysing their material composition and overall environmental performance. Solution 1, the STRAILastic barrier, incorporates recycled rubber, which significantly reduces its Global Warming Potential (GWP) compared to barriers made mainly of virgin materials. Solution 2, composed primarily of reinforced concrete and recycled rubber, and Solution 3, including steel, aluminium, and PET foam which both exhibit higher environmental impacts due to the predominant use of high-emission materials such as concrete and aluminium.
The study highlights the crucial role of integrating recycled materials in reducing environmental impacts and underscores the need to optimize designs to minimize the use of high-impact components. This standardized LCA approach provides a comprehensive framework for assessing and fostering sustainable practices in noise mitigation infrastructure.

Keywords: *Life Cycle Assessment, Low-Height Noise Barriers, Environmental Impacts, Recycled materials, Acustic performance*

1. INTRODUCTION

The aim of this study is to design an innovative Low Height Noise Barrier (LHNB) made from recycled materials, with improved acoustic properties thanks to the implementation of metamaterial technology. Furthermore, the last step of this work package is to test a new LHNB prototype in a controlled test environment (laboratory or similar) and characterise its acoustic performance.
As the metamaterial technology is applicable to any material, it is essential to start with a material capable of guaranteeing the best environmental sustainability. In turn, this can be demonstrated by evaluating the most important Key Performance Indicators (KPIs) of the environmental impact of any material. This evaluation must be done in a systematic way, following a standardized method in order to ensure an objective and accurate understanding, based on objective data. Several methods of this kind exist, but the most widely accepted are reducible to the Life Cycle Assessment method (LCA) codified in some international standards [[1],[2],[3],[4]]. LCA is a quantitative approach that follows a systematic method to study and compare the impacts of products and systems throughout their life cycle.

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In the current study the GWP (Global Warming Potential) category is quantitatively evaluated, also considering the EU "net zero" objectives, aimed at urgently reducing greenhouse gas emissions.
Therefore, the objective of this study is to demonstrate, through a comparative Life Cycle Analysis (LCA) focused on the production phase (A1-A2-A3) and based on sustainability criteria, that the selected low-height noise barrier (Strailastic msw360), thanks to the use of recyclable materials, is capable to minimize the GWP environmental impact compared to the other low-height noise barriers available on the market. Moreover, this highlights important sustainability considerations in the design and implementation of the analysed products.
Through the application of the Life Cycle Assessment (LCA) methodology in the "*from cradle to gate*" phase, we were able to assess the impact of the different components of the barriers, identifying the solutions that most effectively minimize environmental impacts.
From the preliminary sustainability assessment conducted on the Strail LHNB, compared to two other types of LHNB, it emerges that the LHNB supplied by Strail represents the solution that most effectively minimizes environmental impacts.
The presence of recycled rubber in the composition of the Strail barrier has contributed significantly to reducing the overall environmental impact compared to the exclusive use of virgin materials. This highlights the positive potential of recycling and reusing materials to mitigate environmental impact, while also providing a sustainable solution for waste management.

2. OBJECTIVES AND SUCCESS CRITERIA

The LCA methodology allows the quantification of the impacts of a product or process, and in this study, it will be used to evaluate, analyse and compare the impacts of the Strail low-height noise barrier with two other low-height noise barriers currently available on the market [5].
LCA is a quantitative approach that follows a systematic method, regulated by international ISO standards [[1],[2],[3],[4]], to study and compare the impacts of products and systems throughout their life cycle. It is essential to have a quantitative sustainability assessment tool in order to ensure an objective and accurate understanding, based on objective data.
According to the current ISO reference standard regulations, an LCA study consists of the following phases, which will be further detailed in the following sections.

1. Goal and scope definition: preliminary phase where the study's objectives, declared unit, boundaries of the system studied and assumptions are defined;
2. Inventory analysis: quantification of input and output flows for all analysed processes;
3. Impact assessment: aggregation of inventory results, with scientific models, into a number of potential environmental impacts;
4. Interpretation: analysis of the results obtained in order to draw conclusions.

The four steps of a life cycle analysis are interrelated, making the whole process iterative (**Errore. L'origine riferimento non è stata trovata.**). Each phase is based on the results obtained in the previous phase, thereby promoting the completeness and coherence of the study. If there is a need to integrate further information in a previous step or to revise the initial settings, any changes are also carried over to the subsequent levels of the analysis.

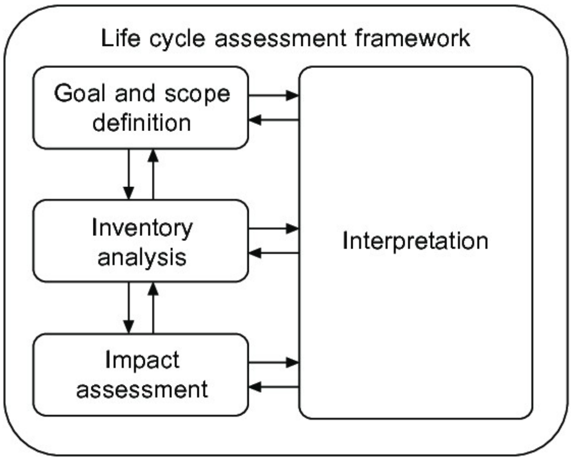


Figure 1. LCA phases according to ISO 14040/14044

Life cycle analysis approaches provide various perspectives for assessing the environmental impact of a product or system over time. These include the assessment of the entire life cycle, from production to disposal (Cradle to Grave), adopting circular practices that allow for the complete reuse of materials (Cradle to Cradle), and focusing on the initial stages of the life cycle until the product is ready for use (Cradle to Gate). These approaches offer complementary perspectives for understanding and addressing the challenges related to the sustainability of products and industrial processes.

The success of this study is demonstrated by the successful completion of the LCA analysis of the Strail low-height noise barrier and two main competitors.

3. GOAL AND SCOPE DEFINITION

The LCA analysis in question focuses on assessing the environmental impacts of the Strail low-height noise barrier, compared to two competing products currently available on the market. In this study, the life cycle analysis was conducted 'from cradle to gate', considering all stages of the product life cycle from the production of raw materials to the manufacture of the noise barriers. This approach allowed us to comprehensively evaluate the environmental impact of different types of noise barriers until they are ready for installation.
In the comparative study of the three LHNBs, it is important to note that the analysis focused exclusively on the materials constituting the sound-insulating part of the barriers themselves. Support and anchoring structures of the barriers, which may include elements such as steel and reinforced concrete, as well as packaging and packing processes, were deliberately excluded from the assessment.

Declared unity
The unit declared examined, against which all the quantitative input and output data collected in the study are calculated, is the production of 1 linear meter of noise barrier.

System boundaries
The modules for which the environmental impact of barriers is quantified in this study are the following:

- A1: Procurement of raw materials for barriers production;
- A2: Transportation of raw materials for barriers making;
- A3: Processing of raw materials to obtain the barriers.

Data quality and Impact Assessment Methodology
The study uses generic secondary data from the Environmental Footprint 3.1 databases [6], which is part of the broader Ecoinvent 3.10 database [7]. The data, representing the period 2020-2023, reflect both European and global contexts. Impact assessments are conducted using OpenLCA 2.0.0, applying the "Environmental Footprint (Mid-point indicator)" method to evaluate Global Warming Potential (GWP) as a key performance indicator (KPI).

4. INVENTORY ANALYSIS

Inventory analysis is the most crucial phase of an LCA study. It involves collecting data to quantify the inflows and outflows from the system during its life cycle in relation to the declared unit. Inputs include the use of natural resources, materials, and energy while Outputs include emissions to air, water and soil associated with the system and the generated waste.
Once the processing is complete, the sum of inputs and outputs for each unit process yields the "inventory," which is a catalogue of all mass and energy flows entering and leaving the system.
The environmental impacts of the secondary data used in the analysis are automatically counted by selecting the material to be modelled from the databases used, which already contain all the information from its supply chain, from raw materials extraction to production.
Below are all the technical specifications considered in the inventory analysis of the barriers considered.
The Strail Barrier will be identified as “Solution 1”, while the other two barriers will be referred to as “Solution 2” and “Solution 3”.

4.1 Solution 1: STRALastic_mSW 360

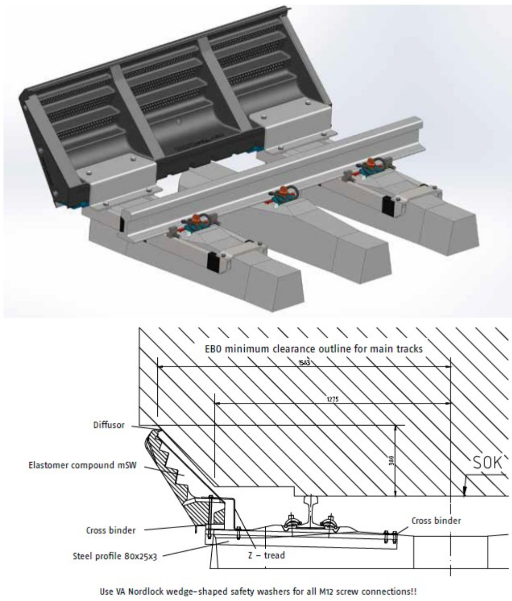


Figure 2. STRAILastic_Msw 360
Barrier Module: length 1.8 m, height 0.53 m and thickness 0.30 m.

Weight of recycled material 61,564 kg per 1,8m of length (data provided by Strail), which is approximately 34,202 kg/m.
Weight of virgin material 58,605 kg per 1,8m of length (data provided by Strail), which is approximately 32,558 kg/m [8].
The processes used are summarized in the following Table.

Table 1. Processes Used in STRAILastic_mSW 360 Low Height Noise Barrier Definition

	Database	Process	Amount [kg/m]
Recycled Material	Strail Self Calculation	Buffering meal retreading (Waste tire industries)	3,801
	Strail Self Calculation	Rework STRAIL shredded & broken (old used panels)	4,881
	Strail Self Calculation	Roughing Rubber meal (waste tire industry)	4,881
	Strail Self Calculation	Rubber granules (waste tire industry)	20,641
Virgin Material	Ecoinvent 3.10	Grinding sulphur Sodium silicate production, spray powder, 80%	1,318
	Ecoinvent 3.10	Stearic acid Chloropropionic acid	0,133
	Ecoinvent 3.10	MBTS 2-methyl-2-butanol production	0,079
	Ecoinvent 3.10	ZBEC market for dithiocarbamatePro-compound	0,052
	Ecoinvent 3.10	Plasticizer oil Softener rubber production	1,929
	Ecoinvent 3.10	Latex latex production	0,502
	Ecoinvent 3.10	New rubber layer (DP 1350x2,5) market for seal, natural rubber based	11,772
	Ecoinvent 3.10	New rubber layer (DP high light protection 3,0x960D300DPU) market for synthetic rubber	16,772

4.2 Solution 2

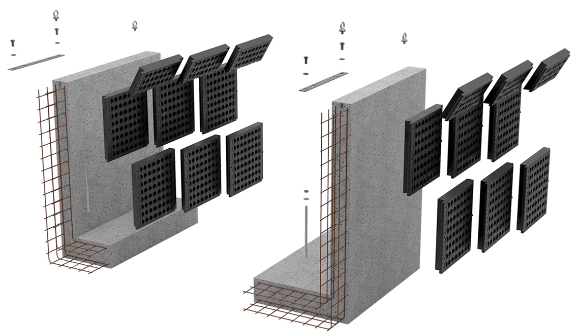


Figure 3. Representative image of Solution 2

Barrier Module: length 1,0 m, height 0,67 m and thickness 0,20 m.
Assuming that the thickness of this barrier is made up of 0,15 m of reinforced concrete and 0,05 m of recycled rubber, we have:
Volume of reinforced concrete = 1,0 m × 0,67 m × 0,15 m = 0,1005 m^3
Weight of reinforced concrete = Density of concrete (average 1400 kg/m^3) × Volume ≈ 140,07 kg (assuming a weight of 14 kg for steel and 6 kg for construction timber)
Volume of recycled rubber per meter = 1,0 m × 0,67 m × 0,05 m = 0,0335 m^3
Weight of recycled rubber per meter = Density of recycled rubber (average 800 kg/m^3) × Volume ≈ 26,8 kg
The processes used are summarized in the following Table.

Table 2. Processes Used in the definition of solution 2

Database	Process	Amount [kg/m]
Ecoinvent 3.10	Recycled Rubber - market for waste rubber, unspecified	26,8
Environmental Footprint 3.1	Concrete C20/25 (Ready-mix concrete), production mix, at plant, technology mix, C20/25	140,07
Environmental Footprint 3.1	Reinforced steel (wire), production mix, at plant, EAF route, wire	14,0
Environmental Footprint 3.1	Solid construction timber (softwood) (EN15804 A1-A3), production mix, at plant, technology mix, 529 kg/m3 at 15% moisture	6,0

4.3 Solution 3

Figure 4. Representative image of Solution 3

Barrier Module: length 2,04 m, height 1,04 m and thickness 0,24 m.
Total module weight 150 kg.
Therefore, the weight per meter of barrier is about 75 kg/m.
It is assumed:
Steel weight ≈ 40,0 kg
Aluminium weight ≈ 25,0 kg

PET foam weight ≈ 10,0 kgnot modify headers, footers or page numbers in your submission. These will be added electronically at a later stage, when the publications are assembled.
The processes used are summarized in the following Table.

Table 3. Processes Used in the definition of solution 3

Database	Process	Amount [kg/m]
Environmental Footprint 3.1	Reinforced steel (wire), production mix, at plant, EAF route, wire	40,0
Environmental Footprint 3.1	Aluminium foil , single route, at plant, primary production, 2.7 g/cm3 - EU-28+EFTA	25,0
Environmental Footprint 3.1	Polyurethane rigid foam, production mix, at plant, from methylene diisocyanate (MDI) and polyols, 18- 53 kg/m3 - EU-28+EFTA	10,0

5. IMPACT ASSESSMENT

Impact assessment is the phase where the inputs and outputs, reported in the inventory, are translated into potential environmental impacts. The environment is a complex system of physical, chemical and biological factors, living and non-living elements, and relationships in which all the organisms that inhabit the planet are immersed, where any variation of one of these components affects the whole system. Therefore, to study such a complex reality, the LCA methodology involves the compartmentalization of the entire environmental system into a limited number of impact categories.
Each impact category is determined by a different reference unit that allows quantifying the impact following classification and characterization operations.

Classification
The classification is a qualitative step in which emissions from modelled elementary flows, collected in the inventory, are associated with the impact categories according to the potential environmental effects. It answers the question "what does this emission contribute to"?

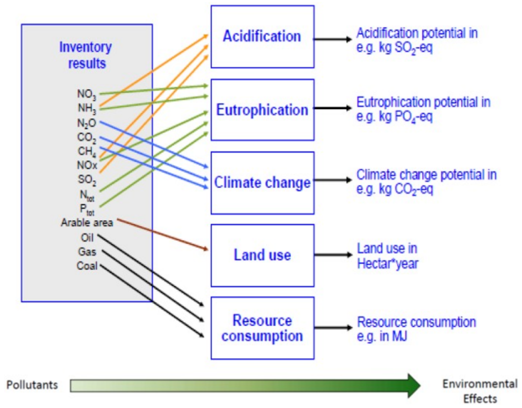


Figure 5. Example of classification of some substances (JRC Scientific and Technical Reports) [9]

Characterization
Characterization allows quantifying the contribution of different elementary flows within an impact category. It answers the question "how much does this emission contribute to the impact compared to the others?". The environmental impacts assessment was carried out through the "*Environmental Footprint (Mid-point indicator)"* impact assessment method. In the current study, we will consider only the GWP (Global Warming Potential, reference unit kg CO_2 eq.) category, also considering the EU "net zero" objectives, aimed at urgently reducing greenhouse gas emissions.

We will examine the results of the LCA analysis conducted on different types of noise barriers. Through a critical and in-depth analysis of these results, we will provide a clear and informative view of the environmental impact of the available options and the contribution of specific materials that compose them.
At the end of our research, we aim to conduct an in-depth comparative analysis of the different solutions examined to identify the most sustainable and least impactful from an environmental point of view. Through this process, we aim to provide a comprehensive and objective assessment of the options available, allowing for an informed and conscious choice in line with sustainability principles.

5.1 Results of the STRAILastic_mSW 360 Analysis (Solution 1)

The results obtained from the LCA analysis for the Strail barrier are represented through the following bar chart that shows the LCA modelling process of the barrier with the respective contributions of the materials that compose it.

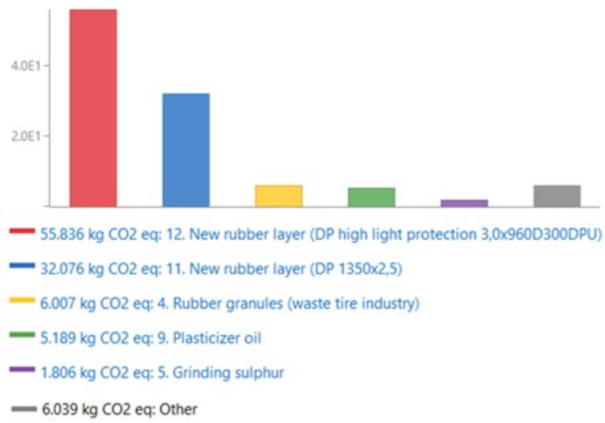


Figure 6. GWP Contribution of the materials composing the "Solution 1: Strail" (OpenLCA)

Based on the results of the LCA analysis conducted on the Solution 1 Strail barrier, composed of a combination of recycled rubber and virgin rubber, it is evident that the significantly more impactful components in terms of Global Warming Potential (GWP) are those related to the production of virgin rubber. These results unequivocally underline the importance of recycling and reusing materials in the design and production of infrastructure such as noise barriers.

5.2 Results of the SOLUTION 2 analysis

The results obtained from the LCA analysis for the Solution 2 are represented through the following bar chart that shows the LCA modelling process of the barrier with the respective contributions of the materials that compose it.

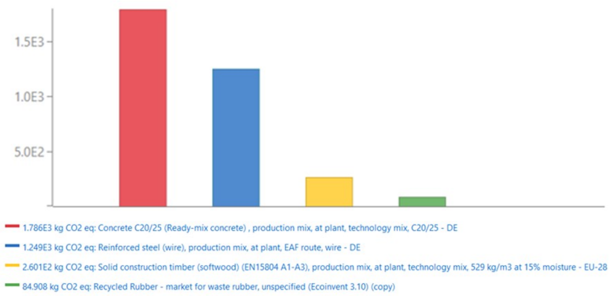


Figure 7. GWP Contribution of the materials composing the "Solution 2" (OpenLCA)

Based on the results of the LCA analysis conducted on the "Solution 2", composed mainly of reinforced concrete with a reduced percentage of recycled rubber, it is clear that the most impactful component in terms of Global Warming Potential (GWP) is the reinforced concrete. It is important to note that despite the use of recycled material, the substantial presence of reinforced concrete has a significant impact on the overall environmental impact of the barrier.

5.3 Results of the SOLUTION 3 analysis

The results obtained from the LCA analysis for the Strail barrier are represented through the following bar chart that shows the LCA modelling process of the barrier with the respective contributions of the materials that compose it.

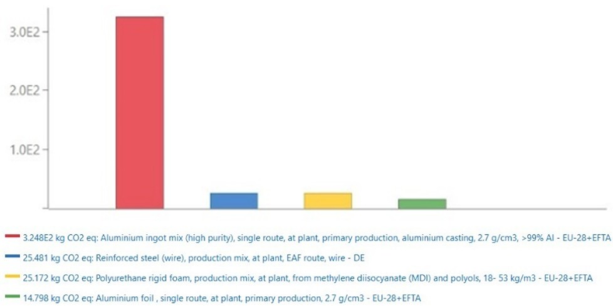
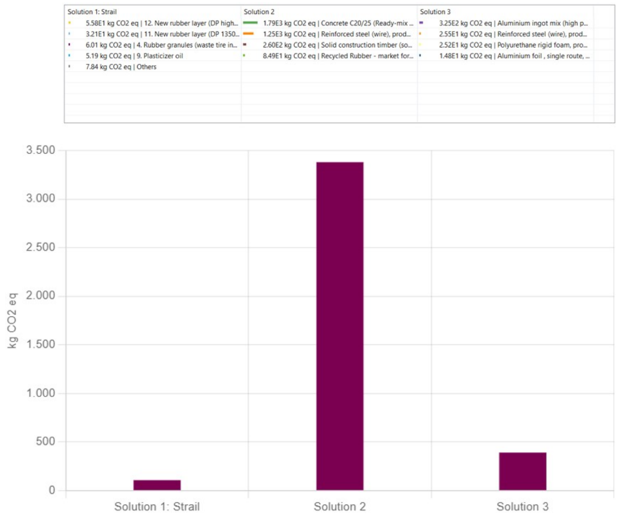


Figure 8. GWP Contribution of the materials composing the "Solution 3" (OpenLCA)

Based on the results of the LCA analysis conducted on the "Solution 3", composed of steel, aluminum and PET foam, it reveals that aluminum has the most significant impact in terms of Global Warming Potential (GWP), while steel and PET foam have very similar CO2 equivalent quantities.

5.4 Results of Comparative Analysis

After examining the impacts associated with the Global Warming Potential (GWP) component of the three low-height noise barriers, the results of our comparative analysis are presented in Figure 14 to identify the solution that best fits the environmental sustainability criteria defined by this indicator.



6. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this study provided an in-depth analysis of the environmental impact of different types of noise barriers, highlighting important sustainability considerations in their design and implementation.

Through the application of the Life Cycle Assessment (LCA) methodology in the "*from cradle to gate*" phase, we were able to assess the impact of the different components of the barriers, identifying the solutions that most effectively minimize environmental impacts.

From the preliminary sustainability assessment conducted on the three solutions of noise barriers, the LHNB supplied by Strail represents the solution that most effectively minimizes environmental impacts.

The presence of recycled rubber in the composition of the Solution 1 Strail barrier has contributed significantly to reducing the overall environmental impact compared to the exclusive use of virgin materials. This highlights the positive potential of recycling and reusing materials to mitigate environmental impact, while also providing a sustainable solution for waste management.

Although the use of recycled materials is essential, it is necessary to consider the overall contribution of predominant high-emission materials (such as reinforced concrete in the Solution 2 and aluminium in the Solution 3) that can contribute significantly to the overall environmental impact. This highlights the importance of considering not only the presence of recycled materials, but also the overall composition and relative amount of each material within the final product when assessing environmental impact. The high impact of these materials underscores the importance of carefully examining alternatives during the design process to reduce the overall environmental impact of these barriers. This may include identifying substitute materials or optimizing the design to reduce the use of high-emission materials.

This study represents a significant step towards a deeper understanding of the environmental implications associated with LHNBs, providing a solid basis for future development in the design of more sustainable barriers. We are confident that the results and conclusions drawn can influence and guide informed and responsible decisions in the context of environmental sustainability, thus contributing to promoting positive progress towards a future characterized by greater environmental respect and fairness for future generations.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] UNI EN ISO 14025 (2010): requirements and guidelines for type III environmental labeling.

[2] UNI EN ISO 14040 (2006): general description of LCA concepts.

[3] UNI EN ISO 14044 (2006): incorporates the previous ISO 14041, 14042 and 14043. It defines the guidelines and provides practical information useful to the LCA operator.

[4] UNI EN 15804: Development framework regulation for the product category "construction product" and subsequent update to EN 15804:2012+A2:2019/AC:2021.

[5] UIC International Union of Raylways (2012): Rail Dampers, Acoustic Rail Grinding, Low Height Noise Barrier: https://img3.uic.org/IMG/pdf/2012_dampers_grinding_lowbarriers.pdf

[6] Environmental Footprint v. 3.1 - https://nexus.openlca.org/database/Environmental%20Footprints

[7] Ecoinvent v. 3.10 - https://ecoquery.ecoinvent.org/3.10/cutoff/search

[8] Strail: https://www.strail.de/en/strailastic-sound-protection/

[9] Simone Manfredi and Rana Pant – Joint Research Centre (JRC), Insitute for Environment and Sustainability (IES), Sustainability Assessment Unit (2011): Supporting Environmentally Sound Decision for Construction and Demolition (C&D) Waste Management: https://op.europa.eu/en/publication-detail/-/publication/5a4330e8-aed4-4bf6-8d92-8cb6ad7cceda/language-en