AeroSolfd
filtration devices

D4.5 OVERALL SUSTAINABILITY ASSESSMENT WP4, TASK 4.4

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DATE	VERSION	AUTHOR	COMMENT
08/08/2025	0.1	Biase Liguori	First draft with outline
15/08/2025 - 31/10/2025	0.2 – 0.8	Biase Liguori Pablo Decelis Orozco Dalila Antunes	Completion of input and assessments in numerous interim versions.
21/08/2025	0.3	Paul Henning	Internal Quality control
31/10/2025	0.9	Biase Liguori	Contribution to conclusions, information in the front page and bibliography.
31/10/2025	1.0	Keld Alstrup Jensen	Review and finalization for submission.

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LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
BDPF	Brake Dust Particle Filter
BOM	Bill of Materials
DALY	Disability-Adjusted Life Years
EOL	End-of-Life
EU	European Union
GHG	Greenhouse Gas
GPF	Gasoline Particle Filter
kBq Co-60 eq	Ionising radiation
Kg	Kilogram
Kg 1,4-DCB eq	Ecotoxicity (freshwater, marine, terrestrial)
Kg 1,4-DCB eq	Human toxicity (cancer and non-cancer effects)
Kg CO_2 eq	Climate change (fossil, biogenic, land-use change)
Kg Cu eq	Metal use expressed in copper equivalent
Kg N eq	Marine eutrophication
Kg NMVOC eq	Photochemical oxidant formation
Kg oil eq	Fossil depletion
Kg oil eq	Fossil fuel use expressed in oil equivalent
Kg P eq	Freshwater eutrophication
Kg $PM_{2.5}$ eq	Particle matter formation
Kg $PM_{2.5}$ eq	Air pollution expressed as fine particle matter ($PM_{2.5}$) equivalent
Kg SO_2 eq	Terrestrial acidification

Kg CFC-11 eq	Ozone depletion
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
S-LCA	Social Life Cycle Assessment
PN	Particle Number Concentration per cm^3 or per km
RA	Risk Assessment

PUBLISHABLE SUMMARY

Problems and key questions addressed

Road-traffic particles still drive urban health burdens—tailpipe PN/PM, brake-wear dust, and resuspended PM in semi-closed spaces (e.g., metros). D4.5 investigates whether the three AeroSolfd retrofit solutions deliver net sustainability gains across their full life cycles, what trade-offs arise, and who benefits (public health, ecosystems, economy) when deployed at scale?

Objectives & implementation

Objective: Provide an Overall Sustainability Assessment (OSA) of three AeroSolfd retrofits: (1) a retrofit tailpipe (gasoline) particle filter, (2) a passive Brake Dust Particle Filter (BDPF), and (3) Filter Squares for semi-closed environments.

Method: Integrated framework combining Risk Assessment (RA), Life-Cycle Assessment (LCA), Social LCA (S-LCA) and Economic Assessment (EA), mapped to SDGs. Inputs build on D4.1–D4.4 and field measurements; system boundaries are "cradle-to-use" with informed EoL assumptions.

Partners & roles: NFA (lead, RA, worker exposure, synthesis), CENEX (environmental LCA and results), INTEC (S-LCA), with contributions from MANN+HUMMEL (product data), VERT (product data), CSIC (exposure measurements, filter Squares efficacy), IUTA (ecotox and brake-wear data).

What results does the deliverable contain?

Tailpipe retrofit filter (GPF): >95% tailpipe PN reduction; LCA endpoints show **Human Health DALY ↓ ~85%** and **Ecosystems species·yr ↓ ~61%** vs. baseline; strong positive SDG3/11 signals; manufacturing drives most residual burdens; recycling of stainless steel yields credits; ceramic recovery remains a gap.

BDPF: Captures ~**38.5% PM_{10}** and **27% $PM_{2.5}$** at source; endpoints show **DALY ↓ ~34%** and **Ecosystems species·yr ↓ ~56%**; neutral in CO_2 during use (passive device); moderate manufacturing burdens; slight EoL credits through metal recovery; service-time dust handling needs protocols.

Filter Squares (indoor): Metro trials show **18–25% average $PM_{2.5}$ reduction**, **up to 77%** locally; ~**174 mg $PM_{2.5}$ removed per kWh** (best-case parameterization). Net: large local health benefit (negative damage costs for toxicity), with burdens dominated by production mass and electricity use (grid-dependent). SDG3/11 strongly positive; SDG13 sensitive to power mix.

Cross-cutting: Consolidated SDG scoring per life-cycle stage, damage-cost and eco-cost summaries.

Expected main benefits

Evidence that targeted retrofits can rapidly cut exposure and deliver net life-cycle health gains while informing design, procurement and policy.

A reusable assessment framework (RA+LCA+S-LCA+EA) aligned to SDGs for future mobility retrofits.

Who should read this?

Industrial partners (design, sourcing, scale-up), policy-makers & municipalities (air-quality compliance and fast-track mitigation), transport operators (deployment & maintenance strategy), and funders/standardizers (evidence base for guidance).

Recommendations / follow-up actions

Manufacturing decarbonisation & materials: Increase recycled content (esp. stainless steel), pursue **ceramic substrate recycling** pathways, and shift to **renewable electricity** for production.

Operational optimisation: For Filter Squares, run **targeted duty cycles** (peak exposure windows) and specify **low-carbon power**; for GPFs, ensure **low back-pressure** to avoid fuel penalties.

Maintenance safety: Standardize **extraction/PPE procedures** for BDPF filter changes and Filter Square cartridge swaps; package spent media in sealed waste lines.

Data & methods: Close S-LCA data gaps (suppliers, salary audits), add **exposure modelling** to link concentration changes to health endpoints, and run **scenario LCAs** across EU grid mixes and duty profiles.

Pilots & policy: Extend city pilots (different climates/fleets), engage **standardization bodies** on retrofit certification and end-of-life handling, and integrate results into urban air-quality plans.

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1. INTRODUCTION

The Overall Sustainability Assessment (OSA), conducted as part of AeroSolfd Work Package 4 (WP4), evaluates the safety, environmental, social, and economic performance of the retrofit solutions developed within the project. These solutions include a retrofit tailpipe filter, a retrofit passive brake-wear dust particle filter, and a retrofit filter for semi-closed environments in the form of a square air purifier. The assessment is carried out using a dedicated OSA framework that integrates Risk Assessment, Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Economic Assessment methodologies along the product's life cycle.

This assessment builds upon the data and methodological foundations established in Deliverables D4.1, D4.2 (SEN), D4.3 and D4.4 (SEN), which compile the key information, required for consistent and comprehensive analysis. Aligned with the WP4 strategy, as outlined in Figure 1, the OSA framework aims to provide a holistic understanding of the sustainability implications of the AeroSolfd products in relation to the United Nations Sustainable Development Goals (SDGs), thereby supporting evidence-based decision-making and fostering the development of more sustainable mobility solutions.

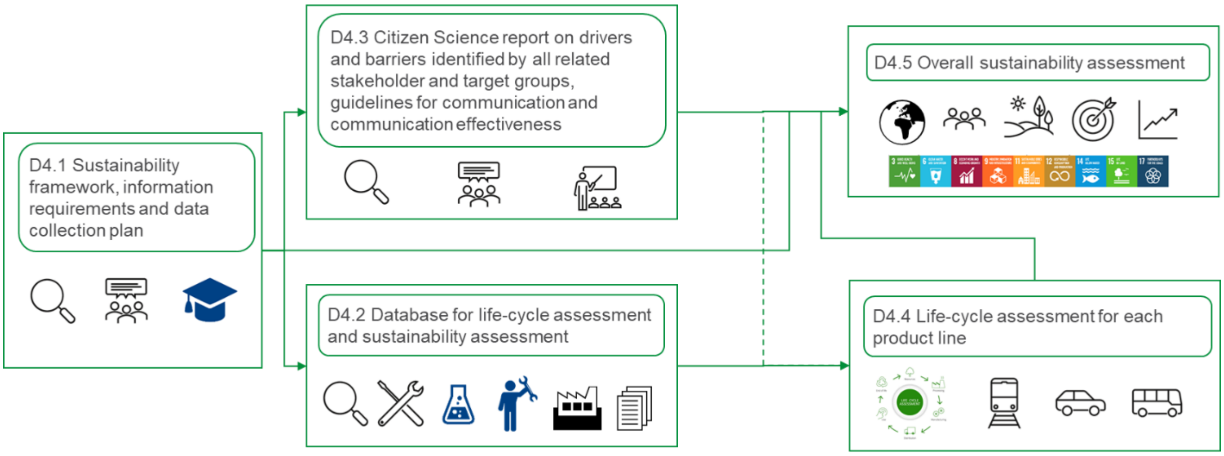

Figure 1. Link between D4.2 and other deliverables in WP4 ending with the life-cycle analysis and overall sustainability assessment.

1.1. PURPOSE AND TARGET GROUPS

The purpose of the D4.5 report is to present the overall sustainability assessment (OSA) conducted for each of the three product lines.

The intended target groups are:

1) The project industrial partners, to support the future development and commercialization of their retrofit solutions.
2) Policy-makers, municipalities, and transport operators for evaluation of the solutions and potential benefits of applying retrofit solutions to improve air-quality and be in compliance with guidelines and limit values.

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1.2. PARTNER CONTRIBUTIONS

The partner contributions for completion of D4.5 are summarized in Table 1.

Table 1 Partner contributions

PARTNER SHORT NAME	CONTRIBUTIONS
NFA	Led task 4.4 and D4.5. NFA performed worker exposure measurements, contributed to documentation of the efficacy of filter squares for semi-closed environments, reviewed epidemiological data on relevant human health effects and associated exposure metrics.
IUTA	Contributed with ecotoxicological data for relevant air-pollution constituents and experimental data on brake-wear dust characteristics and filter efficacy.
CENEX	Led the compilation of data for environmental LCA modelling and reported LCA results for OSA.
INTEC	Led the compilation of data for the Social LCA model and results for the OSA.
MANN+HUMMEL	Contributed with manufacturing and cost data for LCA analysis considering the brake-wear filter and filter square solutions.
VERT	Contributed with manufacturing and cost data for LCA analysis as well as efficacy of the petrol engine exhaust filter, climate and human health effects considerations.
CSIC	Contributed with human exposure measurements to particles and chemical elements and efficacy of filter squares in metro stations.

2. OBJECTIVES AND EXPECTED IMPACT

The main objective of WP4 is to perform a sustainability assessment for each of the retrofit solutions developed and tested in AeroSolfd to reduce of human exposure and environmental impact due to traffic emissions considering both direct emission (petrol engine exhaust and brake-wear) and general air-quality improvements in semi-closed environments exemplified by metro stations and a workshop in a bus depot.

2.1.OBJECTIVES

The objective of WP4 was to evaluate the environmental, social, and economic sustainability of the AeroSolfd retrofit solutions designed to reduce human exposure and environmental impacts from traffic-related emissions. This was achieved through an integrative assessment combining Life Cycle Assessment (LCA), Risk Assessment (RA), Social Life Cycle Assessment (S-LCA), and Economic Assessment (EA), aligned with relevant Sustainable Development Goals (SDGs). The assessment aimed to identify the effectiveness of the retrofit solutions, understand potential trade-offs across life cycle stages, and establish a sustainability evaluation to support evidence-based decision-making in cleaner and healthier urban environments.

2.2.EXPECTED IMPACT

Information on the overall sustainability of producing and implementing retrofit solutions for reduction of ambient particle air-pollution from traffic sources in open and semi-closed environments. The OSA may help the developers of the retrofit solutions to further fine-tune their innovations in direction of further improved sustainability during the final commercialization process. Opposite, external stakeholders (municipalities, policy-makers, investors) are expected to benefit from the OSA results in their considerations on possibilities for rapid reduction in ambient particulate air—pollution and complince with existing and future air-quality standards.

3. DESCRIPTION OF TECHNICAL/SCIENTIFIC ACTIVITIES

The overall sustainability assessment was conducted for each of the three products lines using:

- the framework and results as defined in Task 4.1 – further elaborated in draft publication
- data from Task 4.2 and Deliverable D4.2
- data from Deliverables D4.3 and D4.4

As well as cost-benefit estimates.

4. RESULTS

4.1.GOALS, FRAMEWORK AND RESULTS AS DEFINED IN TASK 4.1

The retrofit solutions proposed in AeroSolfd will directly contribute to some of the seventeen UN Sustainable Development Goals (SDG) which are presented below through their UN description; and with a graphical presentation (**Fehler! Verweisquelle konnte nicht gefunden werden.**) that includes the association with dimensions of sustainability impact of AeroSolfd. It was fund that the AeroSolfd retrofit solutions contribute to:

SDG 3 - Good Health and Well-Being (Ensure healthy lives and promote well-being for all at all ages)

SDG 6 - Clean Water and Sanitation (Ensure availability and sustainable management of water and sanitation for all)

SDG 8 - Decent Work and Economic Growth (Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all)

SDG 9 - Industry, Innovation and Infrastructure (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation)

SDG 11 - Sustainable Cities and Communities (Make cities and human settlements inclusive, safe, resilient and sustainable)

SDG 12 - Responsible Consumption and Production (Ensure sustainable consumption and production patterns)

SDG 13 – Climate Action (Take urgent action to combat climate change and its impacts)

SDG 14 - Life below Water (Conserve and sustainably use the oceans, seas and marine resources for sustainable development)

SDG 15 - Life on Land (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss)

SDG 17 - Partnerships for the Goals (Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development)

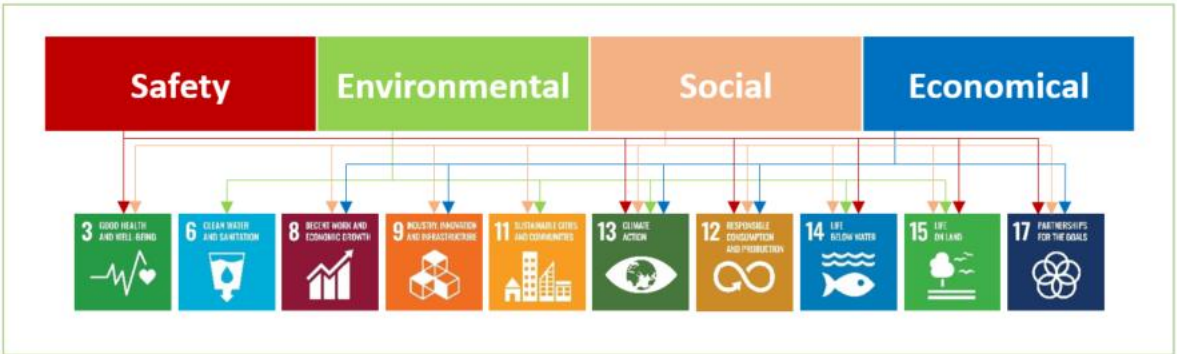

Figure 2. the sustainability impact dimension and UNSDGs in AeroSolfd

The framework was developed by starting from the expected outcomes—namely, the Sustainable Development Goals (SDGs) relevant to the AeroSolfd project—and working backward through the associated impact categories, methodological approaches and tools to identify the input data required for assessing the sustainability of AeroSolfd retrofit solutions, as defined in Task 4.1. The framework integrates Human and Environmental Risk Assessment, Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Economic Assessment (EA).

This comprehensive and interdisciplinary approach supports safety and sustainability evaluations across the full product life cycle. Key evaluation criteria include hazard avoidance, material efficiency, recyclability, and overall environmental and social performance.

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In the following sections, each AeroSolfd retrofit solution is presented along with a detailed description of the corresponding assessment results. This includes the definition of system boundaries and the SDG impact assessment across the life cycle of each solution. For each SDG, specific indicators were also identified for evaluation.

5. TAIL-PIPE FILTER FOR PETROL CARS

5.1. DESCRIPTION OF THE RETROFIT SOLUTION

A retrofit tailpipe filter device was developed, and its cost-effectiveness was demonstrated for European petrol direct injection vehicles. As illustrated in Figure 3, the device replaced the middle silencer and was made compatible with various engine and vehicle types across Europe.

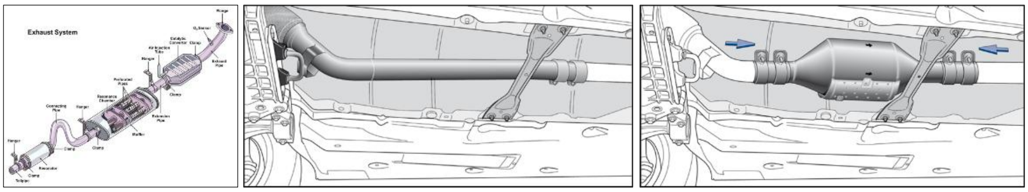

Figure 3. Integration of the retrofit tailpipe filter device replacing the middle silencer

Product descripton

The tailpipe filter consists of two main components: an **exhaust canning** and a **filter substrate**. The canning is constructed from stainless steel and incorporates an expanding fiber mat material. The filter substrate, which is uncoated, features a 300 cells-per-square-inch extruded honeycomb structure. It is highly porous (approximately 45%) and made from cordierite, an industrial mineral with the nominal chemical formula $Mg_2Al_4Si_5O_{18}$. Figure 4 illustrates the primary components of the retrofit tailpipe filter device.

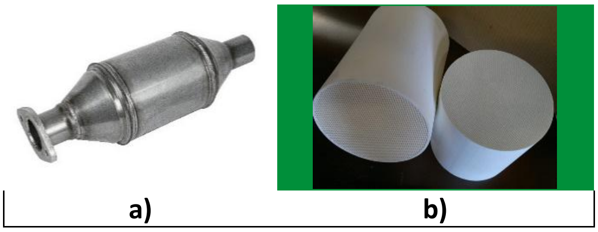

Figure 4. Components of the retrofit tailpipe filter: canning a) and filter substrate b).

5.2. SYSTEM BOUNDARIES OF OSA

[describe risk scoping and scenarios/LC to be assessed – see D4.2 and results from S+E-LCA].

A preliminary risk scoping analysis was conducted to support the implementation of the OSA framework, which helps to define risks scenarios, establish system boundaries, and identifying the most critical aspects to assess.

For AeroSolfd retrofit tailpipe filter product (P1), the system boundaries follow a partial life cycle approach (Cradle-to-Use). This includes Manufacturing phase (component manufacturing, and assembly) and the Use phase, while data for material extraction and processing and downstream activities (e.g., end-of-life/disposal or recycling) were assumed or derived from literature or LCA databases. A summary is provided in Table 3 below.

Table 2. Life cycle set up based on boundary system defined in AeroSolfd

LC-1	Raw-Material Extraction	Material Processing	Manufacturing		Use	Disposal
LC-2	Raw-Material Extraction	Material Processing	Component Manufacturing	Assembly	Use	End of Use/Life
P1	Assumed	Assumed				Assumed
P2	Assumed	Assumed				Assumed
P3	Assumed	Assumed				Assumed

LC-1: Simplified product's Life cycle stage based on ISO 14040; LC-2: Life cycle set up for AeroSolfd (Gate-to-Gate); P1: Tailpipe filter; P2: Passive brake dust particles filter; P3: Filter square.

5.3. SDG ASSESSMENT ALONG THE LIFE-CYCLE

The assessment of Sustainable Development Goals (SDGs) was performed using a comprehensive, interdisciplinary framework designed to evaluate safety and sustainability across the entire product life cycle—from raw material extraction to end-of-life. This approach integrates: Life Cycle Assessment (LCA); Social Life Cycle Assessment (S-LCA); Human and Environmental Risk Assessment (HERA) and Economic Assessment (EA). Together, these tools provide a holistic understanding of environmental, social, health, and economic impacts to guide sustainable innovation and informed decision-making.

Life Cycle Assessment (LCA) quantifies environmental impacts across all stages—extraction, production, transport, use, and end-of-life (e.g., recycling). It considers emissions such as greenhouse gases, toxic substances, and particulate matter, in line with ISO 14040/14044 standards. In the AeroSolfd project, LCA uses primary data when available, supported by GaBi databases (Sphera, n.d.) for consistency and data quality. Key phases include: Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation.

Social Life Cycle Assessment (S-LCA) evaluates social and socio-economic impacts throughout the life cycle, focusing on working conditions, health and safety, human rights, and community well-being. It follows UNEP/SETAC guidelines and complements environmental LCA by addressing stakeholder-related risks and opportunities.

Human and Environmental Risk Assessment (HERA) adds a hazard-based dimension by assessing: Occupational risks – Exposure of workers to hazardous substances or processes; General population risks – Exposure via air, water, or soil; Environmental risks – Potential harm to ecosystems.

Economic Assessment (EA) supports the framework by evaluating cost-effectiveness and economic feasibility. It helps balance environmental and social performance with financial viability, enabling sound investment and design decisions.

In the following sections, we present the impact results for each SDG to which the AeroSolfd project contributes, including the associated assessed indicators across each life cycle stage.

5.3.1. SDG3 - GOOD HEALTH AND WELL-BEING

Manufacturing

From RA

Occupational Exposure: Results from D4.2 shows that workers involved in producing the GFP may be exposed to metal dust and fumes, particularly when working with the stainless steel casing (laser cutting, bending, machining, and laser welding). These emissions likely contain Cr and Ni in the case of X5 CrNi 18-10 fumes. Potential exposures may also occur include airborne dust from cordierite and metal particles from welding and cutting processes during mounting, as well as a potential exposure to soot during installment. There are known occupational health risks associated with these industrial exposures. However, the exposures can be mitigated through appropriate encapsulation, local exhaust ventilation and the use of personal protective equipment. No new risks were observed and occupational risks are deemed manageable with no change in risk.

From LCA

As outlined in Deliverable D4.4, the assessment of SDG 3 (Good Health and Well-being) draws on a set of environmental indicators that reflect potential risks to human health. These include Human Toxicity (cancer and non-cancer), Photochemical Oxidant Formation (as a contributor to ground-level ozone), Fine Particulate Matter Formation, Ionising Radiation, and Ozone Depletion. Climate Change (Global Warming) is also considered, given its indirect links to the spread of disease and malnutrition through altered climatic conditions. Together, these indicators capture key pathways through which emissions may affect respiratory and cardiovascular health, contribute to certain cancers, and influence other health outcomes. The results are interpreted as potential, model-based impacts rather than measured health effects, providing a comparative understanding of the environmental burdens associated with each retrofit solution.

The manufacturing of the stainless-steel canning, cordierite substrate and insulation mat generates particulate and precursor emissions (e.g., NOx, SOx) in upstream supply chains. Although these burdens occur away from exposure hotspots, they contribute to background PM formation. The magnitude is proportional to material intensity and electricity mixes at suppliers. This phase accounts for the majority of resource consumption and environmental impacts. LCA mid-points show Human Toxicity (cancer 1×10^{-1} kg 14-DB eq; non-cancer 1.5 kg 14-DB eq) and Fine Particulate Matter Formation 1.4×10^{-2} kg $PM_{2.5}$ eq per unit. These arise from electricity-intensive sintering of the cordierite substrate and upstream steelmaking. Exposure occurs mainly off-site, under regulated conditions. As a result, the manufacturing stage is associated with a **medium-high negative impact** on SDG 3

From SLCA

Data not available; not assessed.

Use

From RA

The Risk Assessment (RA) of the impact on the SDG 3 was based on the indicators *Premature deaths due to exposure to fine particulate matter* (PM2.5) and *causes of death* (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease) as detailed in Deliverable 4.2.

The RA primarily relied on a literature review, as detailed in Deliverable 4.2. The authors identified that gasoline engine exhaust emissions share similar physio-chemical properties with diesel engine and jet engine exhaust particles. As a result, the assessment focused on their carcinogenic potential to humans.

Diesel engine emissions are classified as carcinogenic to humans. Epidemiological studies have shown that exposure to exhaust is associated with increased risks of lung cancer, ischemic heart disease, and other cardiovascular conditions. The results also indicated that reductions in PM2.5 and NO_2 levels were linked to improvements in mortality rates.

Therefore, this study suggests that the **implementation of retrofit tailpipe filter devices can contribute positively** to achieving SDG 3 (Good Health and Well-being).

From LCA

During operation, the retrofit GPF reduces tailpipe particulate number and particulate mass, which directly decreases near-road exposure, particularly relevant in urban microenvironments. Provided that the filter maintains low back-pressure and does not induce a notable fuel penalty, the avoided emissions dominate the health outcome over the life cycle. The retrofit GPF achieves > 95 % reduction of particulate number and proportionate mass, cutting near-road $PM_{2.5}$ exposure by around 10 µg m^{-3} in hotspot scenarios. DALY reduction of around 7.6×10^{-5} per functional unit. Avoided respiratory and cardiovascular outcomes far outweigh production burdens, although these were not closely evaluated by the environmental LCA and need further investigation and analysis. The assessment of the impact on SDG 3 indicates a reduction in human health and ecosystem burdens. As a result, the use stage can be associated with a **very high positive impact on SDG 3.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

Similar to the situation during manufacturing, exposure may occur to metal dust and fumes during the recycling phase. The emissions may contain Cr and Ni from the X5 CrNi 18-10 steel. Potential exposures may also occur include airborne dust from cordierite and metal particles during shredding and cutting processes. It is assumed that the exposures can be mitigated through appropriate encapsulation, local exhaust ventilation and the use of personal protective equipment. No new risks were observed and occupational risks are deemed manageable with no change in risk.

From LCA

At the End-of-Life, recycling of the metal can recovers part of the embedded upstream burdens and avoids primary steel production impacts that contribute to PM formation. The cordierite substrate typically lacks recycling routes and is landfilled or incinerated; its contribution to PM exposure is negligible due to landfilling and incineration activities taking place in controlled environments. It is currently assumed that no ceramic recovery occurs. Recycling credits from stainless steel recovery reduce Human Toxicity by around 5–10 %, offsetting landfill impacts of the inert cordierite. During the End-of-Life, the recycling of the steel offsets the energy demand and thus, has an overall **low positive impact on SDG 3.**

From SLCA

Data not available; not assessed.

5.3.2. SDG6 - CLEAN WATER AND SANITATION

Manufacturing

From RA

Data not available; not assessed.

From LCA

The assessment of the impact on SDG6 (Clean Water and Sanitation), as outlined in Deliverable D4.4, was based on several environmental indicators. These included: Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion, and Fossil Resource Depletion.

The manufacturing phase accounts for the majority of resource consumption and environmental impacts, primarily due to the extraction and processing of stainless steel and the sintering of the cordierite substrate—both of which are energy-intensive and emission-heavy processes.

Therefore, the manufacturing stage is associated with a **medium negative impact on SDG** 6.

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During the use phase, the device provides a low positive contribution to water quality through its indirect environmental benefits. By preventing the release and deposition of fine particles (including metals, soot, and other contaminants) into urban drainage systems, the filter reduces potential runoff contamination. This leads to a qualitative improvement in urban freshwater ecosystems, particularly in dense metropolitan areas where stormwater pollution is a persistent problem. While these gains are not easily quantifiable in life cycle terms, the environmental value of avoided contamination is notable. Thus, the use-phase stage is associated with a **low positive impact on SDG 6.**

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From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

The end-of-life stage offers a low positive outcome, largely due to the controlled recycling and inert disposal of components. Metals are assumed to be recovered efficiently through existing recycling channels, while remaining inert materials are safely landfilled with no leachate generation. This reduces the cumulative freshwater ecotoxicity impact by around 3 %, highlighting the value of responsible waste management practices. By closing material loops and preventing uncontrolled emissions, the end-of-life treatment contributes to a marginal but meaningful reduction in aquatic environmental burdens. The end-of-life phase stage is associated with a **low positive outcome on SDG6.**

From SLCA

The assessment based on indicators: Usefullness – How easy is to dispose the product components changed during maintenance, highlighted that products can be collected by usual recycling companies for free. By ensuring components are collected through formal recycling systems, the risk of plastics, metals, or hazardous debris entering waterways is minimized, potentially safeguarding marine ecosystems and the communities dependent on them. Proper recycling also contributes to the protection of terrestrial ecosystems and the livelihoods linked to them. Overall, it **contributes positively** to SDG 6

5.3.3. SDG8 - DECENT WORK AND ECONOMIC GROWTH

Manufacturing

From RA

Data not available; not assessed.

From LCA

The introduction of new production lines and assembly operations might generate additional skilled employment. These roles support economic activity within the manufacturing sector and encourage the development of technical expertise in sustainable technologies. Improvements in terms of economic growth and decent work are applicable when considering a closed-loop of raw materials, specially when working with steel; The assumed recycled inputs reduce upstream extraction pressures, thus, it contributes **medium positively to SDG8.**

From SLCA

The Social Life Cycle Assessment (S-LCA) of the impact on SDG 8 (Decent Work and Economic Growth) highlights the contribution to this goal by assessing relevant indicators related to local economic dynamics and workers well-being. These include: *The number of new employees hired for the development, production, or sale of the new product*; *Changes in occupational risk*; *Changes in employee satisfaction*; *Changes in working hours flexibility*; *Changes in work shifts*; *Changes in working hours*; *Salary comparison between product-specific workers and the local average*; *The intention to provide training opportunities to external organizations or the community*.

The assessment of these indicators demonstrate a positive contribution to SDG 8 (Decent Work and Economic Growth) by moderately increasing sales and income (15%–30%), supporting technological advancement, and promoting long-term sustainability through efficient cost management. Although innovation and job creation were limited, employee stability and satisfaction improved, supported by expanded social benefits and active participation in industry training.

Working conditions, hours, and flexibility remained stable, with no increase in risks or exposure to hazardous materials. Existing safety protocols and PPE remained effective, resulting in zero accidents and maintaining a safe, secure work environment. Overall, the initiative enhances economic activity, workforce well-being, and workplace safety, demonstrating a clear **positive impact on SDG 8**.

Use

From RA

Data not available; not assessed.

From LCA

During the use and service phase, the product provides a low positive impact by enhancing operational efficiency and reducing unnecessary labour time, as both installation and removal is quite fast. Its "fit-and-forget" design minimizes maintenance requirements, cutting down on exposure to mechanical risks and repetitive servicing tasks. This not only improves workforce productivity but also contributes to better job satisfaction and lower fatigue levels for technicians. The reduction in manual intervention aligns with the SDG 8 goal of promoting safe and efficient work practices, thus the use phase has a **low positive impact on SDG8.**

From SLCA

The Social Life Cycle Assessment (S-LCA) of the impact on SDG 8 (Decent Work and Economic Growth) is aligned with *use*, by highlighting on a positive note indicator such as: How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance; The answers given show the following: Very easy assembly and straightforward disposal reduce the physical demands on workers, while quick maintenance and low-frequency servicing minimise downtime and improve productivity. The availability of multiple suppliers for components ensures supply chain resilience, preventing work interruptions and safeguarding employment stability. There is a **positive contribution to SDG8**

End of life

From RA

Data not available; not assessed.

From LCA

At the end of life, the system continues to deliver a low positive benefit by supporting formal scrap-metal collection and regulated recycling activities. These processes ensure that recovery operations take place under fair labour conditions, providing steady employment in the recycling sector. By encouraging responsible material management and avoiding informal or unsafe waste practices, the end-of-life phase helps sustain decent jobs while reinforcing the circular economy's role in economic resilience. The End of Life stage is associated with a **low positive impact on SDG8.**

From SLCA

5.3.4. SDG9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

Manufacturing

From RA

Data not available; not assessed.

From LCA

The GPF demonstrates modular retrofitting, standardised canning, scalable across vehicle classes, enhancing EU industrial capability and circular infrastructure. Innovation from the LCA comes mainly from the decision to retrofit and from the material composition of the filter media, the latter having a **positive impact on SDG9.**

From SLCA

The S-LCA demonstrates a **moderately positive impact** on SDG 9 by driving technological advancement and supporting long-term sustainability. Efficient cost management and positive engagement in industry training have strengthened operational capabilities and encouraged gradual innovation. Production expenses were minimally affected, reflecting effective resource utilization and financial efficiency.

Use

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

The Social Life Cycle Assessment (S-LCA) of the impact on SDG 9 (Industry, Innovation and Infrastructure) is aligned with *use*, by highlighting on a positive note indicators such as: How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance; Very easy assembly, straightforward component replacement from multiple suppliers, and quick, low-frequency maintenance reduce downtime and optimise resource use. These characteristics support robust infrastructure by ensuring consistent performance and minimising operational disruptions. As such, it's a clear **positive contribution to SDG9**

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End of life

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

The product's components can be collected by standard recycling companies at no cost. Free collection by standard recycling companies ensures that components are channelled into formal, well-managed infrastructure, supporting the development and maintenance of efficient waste-processing networks. As such, the product makes a **positive impact on SDG9**

5.3.5. SDG11 - SUTAINABLE CITIES AND COMMUNITIES

Manufacturing

From RA

Data not available; not assessed.

From LCA

The manufacturing stage of the Gasoline Particulate Filter has a medium negative effect on SDG 11, as it occurs entirely off-site in specialized industrial facilities with minimal direct interaction with urban environments. While upstream activities such as material extraction and component fabrication may generate environmental impacts, these do not directly influence the sustainability or livability of cities and communities. The overall effect: **medium impact on SDG 11.**

From SLCA

Use

From RA

Data not available; not assessed.

From LCA

The results from the assessment in the use phase indicate that the GPF delivers a very high positive contribution to sustainable cities and communities by significantly improving urban air quality. Hsving a net $PM_{2.5}$ emission reduction exceeding 95 %, the directl benefits impact public health, particularly in dense traffic areas, leading to cleaner air, lower exposure to harmful pollutants, and measurable improvements in urban life expectancy and livability. From an LCA perspective, the avoided burdens in Human Health damage (around -3.5×10^{-7} DALY) substantially outweigh the upstream manufacturing footprint. In dense traffic environments, widespread GPF adoption would thus translate into tangible reductions in respiratory illness, hospital admissions, and premature deaths, thus imporving the livability and resilience of urban communities.The filter's role in mitigating vehicular air pollution makes it one of the most impactful interventions for achieving healthier and more sustainable cities. Thus the use phase stage is associated with a **very high positive impact on SDG11.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At the end-of-life stage, the GPF maintains a low positive influence by contributing to efficient material recovery and waste reduction. However, EoL occurs entirely off-site in specialized industrial facilities with minimal direct interaction with urban environments. Its simple recycling pathways, involving metal reclamation and inert disposal of ceramics, help reduce the load on municipal waste systems. This supports cleaner cities and lowers the environmental footprint of urban waste management infrastructure. Thus the EoL stage is associated with a **Low positive impact on SDG11 through reduced municipal waste burden and circular material flow.**

From SLCA

5.3.6. SDG12 - RESPONSIBLE CONSUMPTION AND PRODUCTIONS

Manufacturing

From RA

Data not available; not assessed.

From LCA

The manufacturing stage of the Gasoline Particulate Filter has a medium negative impact on SDG 12, mainly due to the extraction and processing of virgin raw materials. The Mineral and Fossil Resource Depletion potential reaches approximately 2.5 kg oil-eq per unit, showing the high energy demand of stainless steel fabrication and ceramic substrate sintering. These processes rely on non-renewable inputs and intensive heat treatments that contribute to upstream resource exhaustion. Although modern manufacturing practices improve efficiency and minimize waste, the dependency on virgin alloys and catalytic materials prevents this phase from being resource-neutral. New pathways for filter media recovery and use of recycled steel must be set in place to avoid these burdens, in addition, to the use of greener energy mixes. Thus the manufacturing stage is associated with a **negative impact on SDG12,** due to virgin material consumption and fossil dependency.

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During the use phase, the GPF exhibits a medium positive contribution to responsible consumption and production. Its long operational lifespan and no maintenance requirements improve resource efficiency by avoiding frequent replacements and spare part use. The filter's design ensures consistent performance without consumables. Although the device induces a minor fuel-penalty of around +0.5 %, the resulting environmental trade-off is marginal compared to the benefits of reduced particulate emissions and extended service life. Thus, the use phase is associated with a **positive impact on SDG12.**

As the avoided emissions outweigh the minor increase in fuel consumption, **the overall impact** on SDG 12 **during the use phase can be considered positive.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At the end-of-life stage, the GPF demonstrates a positive impact thanks to its strong recyclability and material recovery potential. Approximately 80 % of the total mass mainly the stainless steel housing and fittings can be recycled through conventional metal recovery systems. This recycling yields credits offsetting about 40 % of the manufacturing resource burden, effectively closing material loops and reducing demand for virgin metals. The inert ceramic substrate is safely disposed of, minimizing waste generation. As a result, the end-of-life management of the GPF actively supports circular economy principles, enhancing material efficiency and reducing environmental pressure across the product life cycle. However new recycling paths for the filter media should be set in place to avoid virgin material used for the manufacturing of new filters. The end of life stage is associated with a . **medium positive impact on SDG12.**

From SLCA

The S-LCA demonstrates a **moderately positive** impact on SDGs 12 (Responsible Consumption and Production) by enhancing the company's sustainability reputation and strengthening stakeholder trust and market positioning. The product's sustainability credentials, supported by recognized certifications, reinforce its environmental value and commitment to responsible production.

Maintenance is performed annually and is quick and efficient, minimizing downtime and optimizing resource use throughout the product's lifecycle. At end-of-life, products can be collected by existing recycling companies without additional cost, promoting resource efficiency, circularity, and cost-effective recycling practices.

5.3.7. SDG13 - CLIMATE ACTION

Manufacturing

From RA

Data not available; not assessed.

From LCA

The assessment of the impact on SDG 13 (Climate Action) in terms of ecosystem damage, thought the pathway of tropospheric ozone and damage to terrestrial species, as outlined in Deliverable D4.4, was based on several environmental indicators. These included: Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion, and Fossil Resource Depletion. The manufacturing phase accounts for the resource consumption and the majority of the environmental impacts, primarily due to the extraction and processing of stainless steel and the sintering of the cordierite substrate, both of which are energy-intensive and emission-heavy processes. Therefore, the manufacturing stage is associated with a **negative impact on SDG 13.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During the use phase, the GPF delivers a medium positive effect by substantially improving the environmental performance of the vehicle in operation. The filter's ability to capture particulate matter leads to reductions across several midpoint indicators, including Fine Particulate Matter Formation, Human Health damage, and Terrestrial and Freshwater Ecotoxicity. These improvements contribute to climate action by lowering pollutant loads that interact with atmospheric processes and by enhancing overall air-quality resilience. When considering the balance of all impact categories, the environmental gains during operation outweigh the upstream manufacturing burdens.The GPF however does not inherently reduce the CO2eq values, directly linked to climate change. Thus the use phase is associated with a **medium positive impact on SDG13** through reduced emissions (excluding CO2) and improved environmental performance during use.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

The assessment, based on indicators: Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion, and Fossil Resource Depletion, highlighted that a measurable credit is achieved by displacing virgin steel production. This recovery partially offsets the environmental impacts associated with the landfill disposal of the inert cordierite substrate. Thus, the End of Life stage is associated with a **low positive impact on SDG13.** The manufacturing as well as the end of life have a high dependency on the energy grid mix used, hence this offers a room for improvement.

From SLCA

The assessment based on indicators: Usefullness – How easy is to dispose the product components changed during maintenance, highlighted that products can be collected by usual recycling companies for free. By ensuring components are collected through formal recycling systems, the risk of plastics, metals, or hazardous debris entering waterways is minimized, potentially safeguarding marine ecosystems and the communities dependent on them. Proper recycling also contributes to the protection of terrestrial ecosystems and the livelihoods linked to them. Overall, it **contributes positively** to SDG6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water) and SDG 15 (Life on Land).

5.3.8. SDG14 - LIFE BELOW WATER

Manufacturing

From RA

Data not available; not assessed.

From LCA

The assessment of the impact on SDG 14 (Life Below Water) in terms of ecosystem damage, as outlined in Deliverable D4.4, was based on several environmental indicators. These included: Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion, and Fossil Resource Depletion. The Marine Eutrophication potential is approximately 1×10^{-6} kg P eq, while Marine Ecotoxicity reaches around 2.8×10^{-3} kg 14-DB eq per unit, both driven by industrial discharges and chemical processing during alloy and ceramic production. Wastewater from metal finishing operations introduces nutrients and trace metals that can affect aquatic ecosystems if untreated. Although these emissions are moderate, they represent the most relevant marine-related burdens in the life cycle of the filter. Thus, the manufacturing stage is associated with a . **medium negative impact on SDG14.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During the operational phase, the GPF delivers a low positive contribution to SDG 14 by indirectly reducing the pollutant load entering aquatic environments. The filter prevents accumulation of particles on road surfaces, which in turn lowers runoff contamination into nearby waterways during rainfall. This results in marginal but consistent improvements in water quality, particularly in urban settings where traffic-related runoff is a known contributor to marine and freshwater pollution.The extent of this was not analysed in the LCA, but supported via industry databases. The use phase is associated with a **low positive impact on** SDG14 through reduced pollutant runoff.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

The assessment, based on indicators: Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion, and Fossil Resource Depletion, highlighted that a measurable credit is achieved by displacing virgin steel production. This recovery partially offsets the environmental impacts associated with the landfill disposal of the inert cordierite substrate. Overall, it **contributes positively to SDG 14** .

From SLCA

The assessment based on indicators: Usefullness – How easy is to dispose the product components changed during maintenance, highlighted that products can be collected by usual recycling companies for free. By ensuring components are collected through formal recycling systems, the risk of plastics, metals, or hazardous debris entering waterways is minimized, potentially safeguarding marine ecosystems and the communities dependent on them. Proper recycling also contributes to the protection of terrestrial ecosystems and the livelihoods linked to them. Overall, it **contributes positively** to SDG 14 (Life Below Water).

5.3.9. SDG15 - LIFE ON LAND

Manufacturing

From RA

Data not available; not assessed.

From LCA

The manufacturing stage of the Gasoline Particulate Filter has a high negative impact on SDG 15 due to emissions and resource use linked to upstream industrial processes. The Terrestrial Ecotoxicity potential reaches approximately 2.3 × 10^{-7} species·yr, reflecting the effects of metal extraction, alloy production, and ceramic processing on soil and terrestrial ecosystems. Additional pressure comes from acidifying emissions (NO_x and SO_x) generated during energy-intensive stages such as sintering and metal treatment, which can contribute to soil acidification and biodiversity loss. Together, these effects make the manufacturing phase the most significant contributor to terrestrial impacts in the GPF life cycle. Thus, the manufacturing stage is associated with a **high negative impact on SDG 15.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During the use phase, the GPF provides a positive contribution to SDG 15 by preventing soil and vegetation contamination near roadways. By capturing PM and slightly reducing secondary emissions (PCDD,PCDF,PAH) emitted from gasoline exhaust, the filter helps reduce local deposition of substances on roadside soils and plants. This substantially reduces toxic stress on terrestrial organisms, improves soil health, and protects biodiversity in areas exposed to high traffic density. The operational benefits outweigh the manufacturing burdens, supporting ecosystem integrity in urban and peri-urban environments. No model was created to analyse particle deposition on the ground; industry databases were used to support conclusions. Main impact is on air, not on soil. Thus, the use phase is associated with a **positive impact on SDG 15.**

From SLCA

The assessment based on indicators: Usefullness - How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance; Cost of components to be replaced on maintenance, highlights efficient assembly, quick maintenance, and minimal downtime which reduces energy consumption and transport needs for repairs. Low-cost, easily replaceable components and fast maintenance reduce the risk of operational failures that could harm soil or terrestrial habitats. The ability to source parts quickly from multiple suppliers prevents prolonged equipment downtime that might lead to environmental degradation. Overall, it **contributes positively** to SDG 15 (Life on Land) by potentially protecting terrestrial ecosystems and the livelihoods linked to them during the product's operational phase.

End of life

From RA

Data not available; not assessed.

From LCA

At the end of its life cycle, the GPF maintains a low positive impact by contributing to reduced land disturbance through metal recovery. The recycling of stainless steel components decreases the need for virgin ore extraction, mitigating the ecological footprint of mining and associated habitat disruption. The inert ceramic substrate, which can be safely landfilled, adds no further terrestrial burden. No extra facilities are needed for the end of life of the GPF. Thus, the end of life stage is associated with a **low positive impact on SDG15,** mainly through avoided mining and reduced land use pressure.

From SLCA

The assessment based on indicators: Usefullness – How easy is to dispose the product components changed during maintenance, highlighted that products can be collected by usual recycling companies for free. By ensuring components are collected through formal recycling systems, the risk of plastics, metals, or hazardous debris entering waterways is minimized, potentially safeguarding marine ecosystems and the communities dependent on them. Proper recycling also contributes to the protection of terrestrial ecosystems and the livelihoods linked to them. Overall, it **contributes positively** to SDG 15 (Life on Land).

5.3.10. SDG17 - PARTNERSHIP FOR THE GOALS

Manufacturing

From RA

Data not available; not assessed.

From LCA

Collaborative R&D among manufacturers, research institutes, and policymakers under AeroSolfd builds enduring knowledge-sharing frameworks, training, and dissemination networks. Scalability was not analysed via the LCA.

From SLCA

Moderately Positive impact on SDG 17 (Partnerships for the Goals)

The S-LCA shows a moderately positive impact on SDG 17, although there has been minimal change in stakeholder diversity, indicating potential for broader engagement. The company actively shares product findings with industry partners, promoting wider industry learning and enhancing its reputation for transparency

Use

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

End of life

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

Data not available; not assessed.

5.4.SUMMARY TABLE

Table 3. Summary table with overall assessment for the GPF for each indicator group along the life-cycle.

SDGs	IMPACT	ASSESSMENT			
		LC STAGE	INDICATORS	APPROACHES	DATA
SDG 3	Negative (*quantitative*)	Manufacturing	Occupational exposure assessment Human Toxicity (Cancer and Non-Cancer) Photochemical Oxidant Formation Fine Particulate Matter Formation Ionising Radiation Ozone Depletion (in terms of increase in various type of cancer and increase in other diseases/causes). Climate Change — Global Warming (in terms of its contribution to the increase in other diseases, as well as malnutrition)	RA LCA	Primary and Secondary data
	Positive (*qualitative*)	Use	Premature deaths due to exposure to fine particulate matter (PM2.5) and causes of death (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease)	HRA (*currently limited to Hazard Assessment*)	Epidemiology studies
	Positive (*quantitative*)	Use	Exposure to fine particulate matter (PM2.5) + DALY	LCA	Primary and Secondary data
	Low Positive (*quantitative*)	End-of-Life	Exposure to fine particulate matter (PM2.5) + DALY	LCA	Secondary data
SDG 6	Negative (*quantitative*)	Manufacturing	Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion Fossil Resource Depletion	LCA	Primary and Secondary data
	Positive (*quantitative*)	Use	Freshwater ecotoxicity; Freshwater eutrophication; Water use	LCA	Primary-secondary data
	Positive (*quantitative*)	End-of-Life	Freshwater ecotoxicity; Freshwater eutrophication; Water use	LCA	Primary-secondary data

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	Positive (*qualitative*)	End-of-Life	How easy is to dispose the product components changed during maintenance	S-LCA	Secondary data
SDG 8	Positive (*quantitative*)	Manufacturing	Mineral Resource Depletion	LCA	Primary-secondary data
	Positive (*qualitative*)	Manufacturing	New employees hired for the development, production, or sale of the new product Changes in employee satisfaction Changes in working hours flexibility Changes in work shifts Changes in working hours Salary comparison between product-specific workers and the local average Intention to provide training opportunities to external organizations or the community.	S-LCA	Primary-secondary data
	Positive (*qualitative*)	Use	How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance	S-LCA	Primary data
	Positive (*quantitative*)	Use	How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance	LCA	Primary-secondary data
	Positive (*quantitative*)	End-of-Life	Steady employment in the recycling sector. Responsible material management Avoiding unsafe waste practices	LCA	Primary-secondary data
SDG 9	Positive (*quantitative*	Manufacturing	Enhancing EU industrial capability and circular infrastructure	LCA	Primary-secondary data
	Positive (*qualitative*)	Manufacturing	Driving technological advancement and supporting long-term sustainability	S-LCA	Primary data
	Positive (*qualitative*)	Use	How easy is it to assemble the components together; How easy is it to replace the components; How easy is to dispatch the product for different countries; How easy is the maintenance; Frequency of the maintenance	S-LCA	Primary data
	Positive (*qualitative*)	End-of-Life	Components collected by standard recycling companies Efficient waste-processing networks	S-LCA	Primary data

<table>
<tr><td rowspan="3">SDG 11</td><td>Positive (quantitative)</td><td>Manufacturing</td><td>Upstream activities do not directly influence the sustainability or livability of cities and communities.</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td>Positive (quantitative)</td><td>Use</td><td>very high positive contribution to sustainable cities and communities by significantly improving urban air quality</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td>Positive (quantitative)</td><td>End-of-Life</td><td>Reduced municipal waste burden and circular material flow.</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td rowspan="4">SDG 12</td><td>Negative (quantitative)</td><td>Manufacturing</td><td>Mineral Resource Depletion
Fossil Resource Depletion</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>Use</td><td>no maintenance requirements improve resource efficiency by avoiding frequent replacements and spare part use</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>End-of-Life</td><td>strong recyclability and material recovery potential</td><td>LCA</td><td>Primary-secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>End-of-Life</td><td>Components collected by standard recycling companies
Efficient waste-processing networks</td><td>S-LCA</td><td>Primary data</td></tr>
<tr><td rowspan="4">SDG 13</td><td>Negative (quantitative)</td><td>Manufacturing</td><td>Freshwater Ecotoxicity,
Freshwater Eutrophication,
Marine Eutrophication,
Freshwater Resource Depletion,
Terrestrial Ecotoxicity,
Terrestrial Acidification,
Mineral Resource Depletion
Fossil Resource Depletion</td><td>LCA</td><td>Primary and Secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>Use</td><td>Fine Particulate Matter Formation, Human Health damage, and Terrestrial and Freshwater Ecotoxicity.</td><td>LCA</td><td>Primary and Secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>End-of-Life</td><td>Freshwater Ecotoxicity,
Freshwater Eutrophication,
Marine Eutrophication,
Freshwater Resource Depletion,
Terrestrial Ecotoxicity,
Terrestrial Acidification,
Mineral Resource Depletion
Fossil Resource Depletion</td><td>LCA</td><td>Primary and Secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>End-of-Life</td><td>How easy is to dispose the product components changed during maintenance</td><td>S-LCA</td><td>Primary data</td></tr>
<tr><td rowspan="2">SDG 14</td><td>Negative (quantitative)</td><td>Manufacturing</td><td>Freshwater Ecotoxicity,
Freshwater Eutrophication,
Marine Eutrophication,
Freshwater Resource Depletion,
Terrestrial Ecotoxicity,
Terrestrial Acidification,
Mineral Resource Depletion
Fossil Resource Depletion</td><td>LCA</td><td>Primary and Secondary data</td></tr>
<tr><td>Positive (quantitative</td><td>Use</td><td>The filter prevents accumulation of particles on road surfaces, which in turn lowers runoff contamination into nearby waterways during rainfall.</td><td>LCA</td><td>Primary and Secondary data</td></tr>
</table>

	Positive (*quantitative*)	End-of-Life	Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion Fossil Resource Depletion	LCA	Primary and Secondary data
	Positive (*quantitative*)	End-of-Life	How easy is to dispose the product components changed during maintenance	LCA	Primary and Secondary data
SDG 15	Negative (*quantitative*)	Manufacturing	Terrestrial Ecotoxicity, Terrestrial Acidification,	LCA	Primary and Secondary data
	Positive (*quantitative*)	Use	Terrestrial Ecotoxicity, Terrestrial Acidification,	LCA	Primary and Secondary data
	Positive (*qualitative*)	Use	How easy is to dispose the product components changed during maintenance	S-LCA	Primary data
	Positive (*quantitative*)	End-of-Life	Mineral Resource Depletion	LCA	Primary and Secondary data
	Positive (*qualitative*)	End-of-Life	How easy is to dispose the product components changed during maintenance	LCA	Primary-secondary data
SDG 17	Positive (*qualitative*)	Manufacturing	Knowledge Sharing Enabled by the Product Intention to provide training opportunities to external organizations or the community	S-LCA	Primary data

5.5.OVERALL SUSTAINABILITY EVALUATION/IMPACT EVALUATION/EVALUATION

Table 4. Endpoint Impact Indicators, aggregated in DALY and species lost per year

UNIT	TOTAL BASELINE	TOTAL SOLUTION	% CHANGE	INTERPRETATION
DALY (Human Health)	8.82×10^{-5}	1.36×10^{-5}	↓ 84.6 %	Overall improvement for human health
Species·yr (Ecosystems)	1.14×10^{-7}	4.42×10^{-8}	↓ 61.2 %	Overall improvement for ecosystems

Table 5. Damage cost for the full Life Cycle

ENVIRONMENTAL IMPACT INDICATOR	BASELINE	SOLUTION	DAMAGE COST PER UNIT	DAMAGE COST BASELINE	DAMAGE COST SOLUTION
Climate change [kg CO2 eq.]	40,6296	12,05174	€ 0,13	€ 5,28	€ 1,57
Fine Particle Matter Formation [kg PM2.5 eq.]	0,08014	0,00653	€ 84,70	€ 6,79	€ 0,55
Fossil depletion [kg oil eq.]	0	1,030303	€ 0,03	€ 0,00	€ 0,03
Freshwater Consumption [m3]	0	0,023946	€ 0,41	€ 0,00	€ 0,01
Freshwater ecotoxicity [kg 1,4 DB eq.]	8,54E-08	0,002423	€ 0,02	€ 0,00	€ 0,00
Freshwater Eutrophication [kg P eq.]	0	0,000742	€ 14,25	€ 0,00	€ 0,01
Human toxicity, cancer [kg 1,4-DB eq.]	2,14E-05	0,069468	€ 3,99	€ 0,00	€ 0,28
Human toxicity, non-cancer [kg 1,4-DB eq.]	0	0,17384	€ 0,07	€ 0,00	€ 0,01
Ionizing Radiation [kBq Co-60 eq. to air]	0	0,048968	€ 0,00	€ 0,00	€ 0,00
Land use [Annual crop eq.·y]	0	0,089958	€ 0,10	€ 0,00	€ 0,01
Marine ecotoxicity [kg 1,4-DB eq.]	5,98E-06	0,018091	€ 0,00	€ 0,00	€ 0,00
Marine Eutrophication [kg N eq.]	0	4,45E-05	€ 14,25	€ 0,00	€ 0,00
Metal depletion [kg Cu eq.]	0	0,260366	€ 0,01	€ 0,00	€ 0,00
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	0	0,005002	€ 0,42	€ 0,00	€ 0,00
Photochemical Ozone Formation, Human Health [kg NOx eq.]	0	0,00497	€ 1,86	€ 0,00	€ 0,01
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0	5,74E-07	€ 29,10	€ 0,00	€ 0,00
Terrestrial Acidification [kg SO2 eq.]	0	0,018876	€ 5,28	€ 0,00	€ 0,10
Terrestrial ecotoxicity [kg 1,4-DB eq.]	1,71E-05	32,86133	€ 0,00	€ 0,00	€ 0,02
			TOTAL	**€ 17,35**	**€ 4,17**

Table 6. Eco-Costing for the full Life Cycle

ENVIRONMENTAL IMPACT INDICATOR	BASELINE	SOLUTION	ECO-COST PER UNIT	ECO-COST BASELINE	ECO-COST SOLUTION
Acidification [Mole of H+ eq.]	0	0,025602	€ 7,65	€ 0,00	€ 0,20
Climate Change - total [kg CO2 eq.]	33,63228	10,33807	€ 0,15	€ 5,04	€ 1,55
Climate Change, biogenic [kg CO2 eq.]	0	0,012374	€ 0,00	€ 0,00	€ 0,00
Climate Change, fossil [kg CO2 eq.]	33,63228	10,31962	€ 0,15	€ 5,04	€ 1,55
Climate Change, land use and land use change [kg CO2 eq.]	0	0,006074	€ 0,00	€ 0,00	€ 0,00
Ecotoxicity, freshwater - total [CTUe]	2,797713	30,32009	€ 0,00	€ 0,01	€ 0,09
Ecotoxicity, freshwater inorganics [CTUe]	2,436783	28,58762	€ 0,00	€ 0,01	€ 0,08
Ecotoxicity, freshwater organics [CTUe]	0,360929	1,73247	€ 0,00	€ 0,00	€ 0,01
Eutrophication, freshwater [kg P eq.]	0	3,59E-06	€ 16,46	€ 0,00	€ 0,00
Eutrophication, marine [kg N eq.]	0	0,002017	€ 23,89	€ 0,00	€ 0,05
Eutrophication, terrestrial [Mole of N eq.]	0	0,022328	€ 1,71	€ 0,00	€ 0,04
Human toxicity, cancer - total [CTUh]	8,49E-10	3,34E-09	€ 920,00	€ 0,00	€ 0,00
Human toxicity, cancer inorganics [CTUh]	0	2,45E-09	€ 0,00	€ 0,00	€ 0,00
Human toxicity, cancer organics [CTUh]	8,49E-10	8,94E-10	€ 0,00	€ 0,00	€ 0,00
Human toxicity, non-cancer - total [CTUh]	5,48E-08	3,63E-08	€ 216,00	€ 0,00	€ 0,00
Human toxicity, non-cancer inorganics [CTUh]	0	2,37E-08	€ 0,00	€ 0,00	€ 0,00

Human toxicity, non-cancer organics [CTUh]	5,48E-08	1,26E-08	€ 0,00	€ 0,00	€ 0,00
Ionising radiation, human health [kBq U235 eq.]	0	0,322704	€ 0,00	€ 0,00	€ 0,00
Land Use [Pt]	0	8,253284	€ 0,00	€ 0,00	€ 0,00
Ozone depletion [kg CFC-11 eq.]	0	2,18E-11	€ 0,00	€ 0,00	€ 0,00
Particle matter [Disease incidences]	1,91E-05	4,33E-07	€ 147,00	€ 0,00	€ 0,00
Photochemical ozone formation, human health [kg NMVOC eq.]	4,877922	1,004471	€ 6,12	€ 29,85	€ 6,15
Resource use, fossils [MJ]	0	44,93114	€ 0,00	€ 0,00	€ 0,00
Resource use, mineral and metals [kg Sb eq.]	0	0,000101	€ 0,00	€ 0,00	€ 0,00
Water use [m³ world equiv.]	0	0,750027	€ 0,00	€ 0,00	€ 0,00
			TOTAL	**€ 39,96**	**€ 9,70**

6. BRAKE DUST PARTICLE FILTER (BDPF)

6.1.DESCRIPTION OF THE RETROFIT SOLUTION

A passive brake dust particle filter (BDPF) device has been developed and is now ready for commercial deployment across various markets. Designed as a retrofit solution, the device can be mounted directly on the brake carrier, as illustrated in Figure 5

Figure 5: Illustration of the retrofit passive brake-wear filter mounted on the brake carrier.

Product descripton

The main components of the BDPF include brackets and frames made from formed sheet metal, flexible bellows folded and pleated for filtration, various sheet metal parts, and fastening elements such as weld nuts and screws. These are supported and connected by axial and radial cage assemblies that provide structural integrity. The materials used consist of corrosion-resistant CrNi steel for steel parts, screws, and bolts, as well as metal fibers for the filter cage.

6.2.SYSTEM BOUNDARIES OF OSA

[describe risk scoping and scenarios/LC to be assessed – see D4.2 and results from S+E-LCA].

A preliminary risk scoping analysis was conducted to support the implementation of the OSA framework, which helps to define risks scenarios, establish system boundaries, and identifying the most critical aspects to assess.

For AeroSolfd retrofit BDPF product (P2), the system boundaries follow a partial life cycle approach (Cradle-to-Use). This includes Manufacturing phase (component manufacturing, and assembly) and the Use phase, while excluding upstream activities (e.g., material extraction and processing) and downstream activities (e.g., end-of-life/disposal or recycling). Data for these excluded stages were assumed or derived from literature or LCA databases. A summary is provided in Table 7 below.

Table 7. Life cycle set up based on boundary system defined in AeroSolfd

LC-1	Raw-Material Extraction	Material Processing	Manufacturing		Use	Disposal
LC-2	Raw-Material Extraction	Material Processing	Component Manufacturing	Assembly	Use	End of Use/Life
P1	Assumed	Assumed				Assumed
P2	Assumed	Assumed				Assumed
P3	Assumed	Assumed				Assumed

LC-1: Simplified product's Life cycle stage based on ISO 14040; LC-2: Life cycle set up for AeroSolfd (Gate-to-Gate); P1: Tailpipe filter; P2: Brake dust particles filter; P3: Filter square.

6.3. SGD ASSESSMENT ALONG THE LIFE-CYCLE

6.3.1. SDG3 - GOOD HEALTH AND WELL-BEING

Manufacturing

From RA

Occupational Exposure: Occupational exposure is mainly associated with manufacturing and maintenance, particularly laser welding and handling during service, besides the steel manufacturing, which is outside of the scope for this analysis. No new exposure risks were identified and all exposure types are manageable. The risk of exposure to brake wear particles during service / filter change was not studied and remains a question. Nevertheless, exposure to this type of dust can be managed by the use of local exhaust ventilation during service and filter change. Professionals with high traffic-emission exposure will have reduced exposure to brake wear dust with implementation of BDPF. We conclude that there are no new risks that cannot be managed by appropriate exposure mitigation.

From LCA

LCA shows Fine Particulate Matter Formation at around 6×10^{-3} kg $PM_{2.5}$ eq and Human Toxicity (cancer around 0.06 kg 14-DB eq; non-cancer around 1.0 kg 14-DB eq) per unit. Burdens originate from alloy-steel melting, welding energy, and cutting oils. Occupational exposure is assumed to be well-controlled, however this fall beyond the scope of the environmental LCA. Although the burdens occur away from exposure hotspots, they contribute to background PM formation. The magnitude is proportional to material intensity and electricity mixes at suppliers. This phase accounts for the majority of resource consumption and environmental impacts. The manufacturing stage is associated with a **medium negative impact on SDG3.**

From SLCA

The S-LCA shows a positive impact on SDG 3 through high safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace. Regular assessments of health and safety practices help sustain strong performance and employee well-being. Additionally, reducing brake dust emissions improves air quality and supports environmental sustainability, contributing to both workforce health and broader sustainability goals.

Use

From RA

The Risk Assessment (RA) of the impact on the SDG3 also considered the indicators *Premature deaths due to exposure to fine particulate matter (PM2.5)* and *Causes of death* (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease) as detailed in Deliverable 4.2. The assessment of the toxicity of brake dust particles filters (BDPFs) was conducted through a literature review to identify inhalation studies related to brake wear particle exposure.

Brake dust particles filters were benchmarked against studded tire particles and diesel engine exhaust particles. The BDPFs studied exhibited varying levels of inflammatory potential, with the most inflammogenic types being comparable to diesel engine exhaust particles.

No intervention studies were identified in which brake wear emissions were actively reduced. Therefore, the authors chose to apply risk estimates from the RA on tailpipe filters for diesel engine exhaust (as described above) to approximate the potential health benefits of reducing brake wear emissions.

By drawing this association, i**t can be concluded that the implementation of retrofit partial brake dust particle filters (BDPF) could have a positive impact on achieving SDG 3** (Good Health and Well-being).

From LCA

During operation, the BDPF performs exactly as intended: capturing coarse and fine brake-wear particles at the source. Measured capture efficiencies of 38.5 % for PM_{10} and 27 % for $PM_{2.5}$ correspond to a 25–30 % reduction in fine-particulate matter formation compared with an unfiltered baseline (0.842 → 0.630 kg $PM_{2.5}$-eq). The benefits extend to toxicological categories: Human-toxicity, cancer and non-cancer indicators fall by around 56 %, due to the retention of metals such as copper, iron, zinc, and antimony that would otherwise enter the breathable air. When expressed in damage-cost terms, the avoided health burden is substantial: the combined cost of toxicity and particle-related disease decreases from € 350 per vehicle to € 165, a 53 % reduction in societal harm. Because the device is passive and draws no energy, these gains are not offset by operational emissions. The use phase therefore delivers a **highly positive contribution to SDG 3**

From SLCA

The S-LCA shows a **positive impact** on SDG 3 through high safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace. Regular assessments of health and safety practices help sustain strong performance and employee well-being. Additionally, reducing brake dust emissions improves air quality and supports environmental sustainability, contributing to both workforce health and broader sustainability goals.

End of life

From RA

Data not available; not assessed.

From LCA

Although the burdens occur away from exposure hotspots, they contribute to background PM formation. The magnitude is proportional to material intensity and electricity mixes at suppliers. At the end of its life, the BDPF's metal components are channelled into Europe's established recycling system. This offsets the upstream toxicity associated with virgin steelmaking, while the controlled disposal of spent fibre and trapped dust prevents uncontrolled worker or community exposure. The magnitude of improvement here is limited compared with the use phase but remains slightly positive, thus the edn of life stage is associated with a **low positive impact on SDG3.**

From SLCA

Data not available; not assessed.

6.3.2. SDG6 - CLEAN WATER AND SANITATION

Manufacturing

From RA

Data not available; not assessed.

From LCA

Water-related impacts in production are largely associated with upstream alloy manufacturing, which involves wastewater containing metal residues and process chemicals. The LCA results show a Freshwater Ecotoxicity of about 0.49 kg 1,4-DB eq, reduced to 0.19 kg 1,4-DB eq in the filtered scenario, 61 % improvement but still significant in absolute terms. Freshwater Eutrophication potential remains very low at 1.2×10^{-5} kg P eq, showing minimal nutrient discharge. Overall, the metal content processes during production keeps the manufacturing stage **medium negative for SDG 6.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

By capturing metallic brake dust before it disperses, the BDPF prevents the wash-off of iron, copper, zinc, and antimony particles into stormwater and groundwater. Although the LCA mainly focused on the air emissions and not the deposited one, the LCA this translates to a −21 % reduction in Freshwater Ecotoxicity. The filter thereby contributes **positively to SDG6** supporting cleaner water and healthier aquatic ecosystems.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At end-of-life, the assumed recycling path partially reduces the need for virgin steel production and its associated effluents. Spent filter media and trapped dust are handled through controlled disposal, eliminating uncontrolled leaching. This gives a small but positive contribution to water quality protection, thus the end of life is associated with a **low positive impact on SDG6.**

From SLCA

Data not available; not assessed.

6.3.3. SDG8 - DECENT WORK AND ECONOMIC GROWTH

Manufacturing

From RA

Data not available; not assessed.

From LCA

Production of the BDPF stimulates skilled employment in welding, assembly, and quality control without increasing accident risk. This is however beyond the scope of environmental LCA. Nevetheless, the creation of a retrofitting solution indicates a a **low-to-moderate positive impact on SDG 8.**

From SLCA

The S-LCA a moderately **positive impact** on SDG 8 by complying with stricter environmental standards and labour laws, thereby minimising social risks and ensuring fair working conditions. While innovation, local job creation, and new hires were limited, the company's focus on employee training reflects a continued investment in workforce development.

All employees receive minimum social security benefits, with additional support through paid sick leave, enabling staff to recover from illness without financial strain. This approach promotes a healthier and more secure workforce, contributing to overall employee well-being and organizational stability, even with limited economic expansion

Use

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Production of the BDPF stimulates skilled employment in disassembly, and quality control without increasing accident risk. This is however beyond the scope of environmental LCA. Nevetheless, the disassembly operations of a retrofitting solution indicates a a **low-to-moderate positive impact on SDG 8.**

From SLCA

Data not available; not assessed.

6.3.4. SDG9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

Manufacturing

From RA

Data not available; not assessed.

From LCA

The BDPF embodies industrial innovation within the existing vehicle fleet. Its modular, retrofit design allows rapid deployment without redesigning brake systems or vehicles, supporting sustainable industrialisation. Manufacturing advances such as laser-welding and use of the **DA-21-006** metal-fibre medium reflect process and material innovation. Overall, the manufacturing stage shows a **medium-to-high positive impact on SDG9.**

From SLCA

The initiative demonstrates a **positive impact** through multiple EU-level patents, highlighting strong innovation and future market potential. Product outcomes are shared with industry, academia, and policy networks, fostering social and technical innovation and supporting potential policy adoption. Active collaboration with industry partners promotes broader knowledge sharing and strengthens partnerships.

Use

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

Data not available; not assessed.

6.3.5. SDG11 - SUSTAINABLE CITIES AND COMMUNITIES

Manufacturing

From RA

Data not available; not assessed.

From LCA

Industrial production occurs away from cities. And while the net contribution to SDG 11 is dominated by the positive urban-air benefit during use, the manufacturing stage is indirectly associated with a **medium negative impact on SDG11.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

Urban air quality improves when brake-wear emissions are reduced. The filter lowers fine-particle formation by roughly 25–30 % ($PM_{2.5}$ eq 0.842 → 0.630 kg) and reduces the EF 3.1 "Particle matter [disease incidences]" indicator by −26.6 %. These gains directly advance SDG 11 target 11.6 on reducing the adverse environmental impact of cities. As braking events occur mostly in populated areas, the public-health benefit per vehicle is highest where it matters most. Exposure is beyond the scope of an environmental LCA and was thus not measured nor calculated. The use phase is associated with a **high positive impact on SDG11.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Industrial disposal occurs away from cities, and recycling prevents additional urban waste streams. Hence, the net contribution to SDG 11 is dominated by the positive urban-air benefit during use. The end of life stage is indirectly associated with a **medium positive impact on SDG11.**

From SLCA

Data not available; not assessed.

6.3.6. SDG12 - RESPONSIBLE CONSUMPTION AND PRODUCTIONS

Manufacturing

From RA

Data not available; not assessed.

From LCA

Material intensity drives most burdens. The ReCiPe Fossil Depletion (kg oil eq) and EF 3.1 Resource use – fossils (MJ) indicators show about 3.7 kg oil eq or 159 MJ per filter. Climate impacts of 11 kg CO_2 eq (EF 3.1 Climate Change – total) are linked to energy use in alloying and welding, giving the manufacturing stage a **medium negative impact on SDG12.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

The filter's passive nature (0 MJ during use) and long service life mean very low resource intensity per km driven. No consumables are required. Thus the use phase is associated with a **neutral impact on SDG12.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Recycling credits in ReCiPe Metal Depletion and EF 3.1 Resource use – minerals and metals, offsetting around 10–15 % of manufacturing burdens. Together these effects yield a **low positive impact SDG 12**.

From SLCA

Data not available; not assessed.

6.3.7. SDG 13 - CLIMATE ACTION

Manufacturing

From RA

Data not available; not assessed.

From LCA

At the manufacturing stage, assessment results demonstrate that the processes undertaken contribute predominantly to the overall environmental impacts, with moderate implications forSDG13 13. The production of stainless steel and fibre medium generates the bulk of climate impacts. The ReCiPe Climate Change (Human Health + Ecosystems) and EF 3.1 Climate Change – total indicators report around 11 kg CO_2 eq per unit. While this figure is modest compared with vehicle emissions, it is the main area where the retrofit adds new greenhouse-gas output. The impact assessment incorporates multiple environmental indicators, including *Climate Change*, *Freshwater Ecotoxicity*, *Freshwater Eutrophication*, *Marine Eutrophication*, *Freshwater Resource Depletion*, *Terrestrial Ecotoxicity*, Terrestrial Acidification, Mineral Resource depletion, and Fossil Resource depletion, to quantitatively evaluate damage to ecosystems and resource availability. For SDG 13 the most directly linked is Climate Change in terms of CO2 eq. As a result, the manufacturing stage is associated with **medium negative impacts on SDG 13.**

From SLCA

Data not available; not assessed.

Use

From RA

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Data not available; not assessed.

From LCA

Because the device has no power demand and negligible mass relative to the vehicle, and it is not meant to reduce CO2 footprint during use, the associated **impact on SDG13 is neutral.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At the end of life, the assessment results demonstrate that the processes undertaken contribute predominantly to the overall environmental impacts, with very minor implications for Sustainable SDG 13. While the production of stainless steel and fibre medium generates the bulk of climate impacts, during the end of life this is offset, since the recycling provides small CO_2 credits (1–2 kg eq), lowering the net climate burden. The result is a **neutral-to-slightly-positive contribution to SDG 13**, with clear potential for improvement through higher recycled-content steel or renewable electricity in fabrication and end of life. The impact assessment incorporates multiple environmental indicators, including *Climate Change*, *Freshwater Ecotoxicity*, *Freshwater Eutrophication*, *Marine Eutrophication*, *Freshwater Resource Depletion*, *Terrestrial Ecotoxicity*, Terrestrial Acidification, Mineral Resource depletion, and Fossil Resource depletion, to quantitatively evaluate damage to ecosystems and resource availability. For SDG 13 the most directly linked is Climate Change in terms of CO2 eq.

From SLCA

Data not available; not assessed.

6.3.8. SDG 14 - LIFE BELOW WATER

Manufacturing

From RA

Data not available; not assessed.

From LCA

The production of stainless-steel components and metal-fibre media introduces aquatic burdens linked to upstream mining and refining of chromium, nickel, and copper. According to the ReCiPe Marine Ecotoxicity and EF 3.1 Ecotoxicity, marine – total indicators, these activities account for approximately 14 kg 1,4-DB eq per unit. Although this is 61 % lower than the unfiltered baseline value of 36 kg 1,4-DB eq, the reduction arises from avoided brake-wear emissions rather than cleaner manufacturing. The residual 14 kg 1,4-DB eq still represents the inherent burden of material production and therefore constitutes a low negative impact within the manufacturing stage.As a result, the manufacturing stage is associated with **low negative impacts on SDG 14.**

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From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During operation, the BDPF directly prevents metallic particles from reaching road surfaces, thereby reducing the wash-off of Fe, Cu, Zn, and Sb to sewers and rivers. No model was used to calculate the washoff and conclusions are supported by industry data. This benefit is captured in both the ReCiPe Marine Eutrophication (kg N eq) and EF 3.1 Eutrophication, marine indicators, which show near-zero additional burden in the filtered scenario. Damage-cost results also demonstrate the gain: marine-ecotoxicity costs fall from € 0.12 → € 0.05 (−58 %). The use-phase effect on **SDG 14 is highly positive**.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At end-of-life, recycled steel avoids new ore extraction and related effluent discharges, while controlled treatment of the spent medium prevents marine contamination. With minimal transport and dismantling energy, the end-of-life phase adds only negligible waterborne impact and instead provides a small avoided-burden credit. Thus, the end of life has a **low positive impact on SDG14.**

From SLCA

Data not available; not assessed.

6.3.9. SDG 15 - LIFE ON LAND

Manufacturing

From RA

Data not available; not assessed.

From LCA

Terrestrial toxicity is the most significant environmental pressure in the product’s production phase. The ReCiPe Terrestrial Ecotoxicity (83 967 → 32 395 kg 1,4-DB eq) and EF 3.1 Ecotoxicity, terrestrial – total indicators show that alloy manufacturing and energy supply emit trace metals and acidic gases that stress soils and ecosystems. Even though the retrofit scenario halves this value relative to baseline, the absolute magnitude remains high, giving production a **high negative impact for SDG 15.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During use, toxic elements are captured before they can settle on roadside soils. The improvement appears in both ReCiPe Terrestrial Acidification (mol H^+ eq) and EF 3.1 Eutrophication, terrestrial (mol N eq) indicators, which decline in proportion to the particle-capture rate (PM_{10} 38.5 %, $PM_{2.5}$ 27 %). In practical terms, this reduces heavy-metal accumulation in urban greenspaces and farmland near major roads, protecting terrestrial biodiversity and soil fertility. No model was specifically followed to estimate the actual deposition of particles, as the study mainly focused on airborne particles. However, the overall behavoir of the BDPF during use is associated with a **high positive impact on SDG15.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Recycling of the stainless-steel housing offsets primary mining and reduces land disturbance, as seen in ReCiPe Land Use (0.38 Annual crop eq·yr) and EF 3.1 Land Use [Pt]. Controlled disposal of the fibre medium eliminates uncontrolled leaching. Thus, the end of life is associated with a **low positive impact on SDG15.**

From SLCA

Data not available; not assessed.

6.3.10. SDG 17 - PARTNERSHIP FOR THE GOALS

Manufacturing

From RA

Data not available; not assessed.

From LCA

The BDPF's development and assessment exemplify the cooperative framework promoted by SDG 17. Within AeroSolFDseveral partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a neutral **impact on SDG17.**

From SLCA

The initiative demonstrates a **positive impact** through multiple EU-level patents, highlighting strong innovation and future market potential. Product outcomes are shared with industry, academia, and policy networks, fostering social and technical innovation and supporting potential policy adoption. Active collaboration with industry partners promotes broader knowledge sharing and strengthens partnerships.

Use

From RA

Data not available; not assessed.

From LCA

The BDPF's development and assessment exemplify the cooperative framework promoted by SDG 17. Within AeroSolFD several partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a neutral **impact on SDG17.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

The BDPF's development and assessment exemplify the cooperative framework promoted by SDG 17. Within AeroSolFD several partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a neutral **impact on SDG17.**

From SLCA

Data not available; not assessed.

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6.4.SUMMARY TABLE

Table 8. Summary table with overall assessment for the BDPFfor each indicator group along the life-cycle.

SDGs	IMPACT	ASSESSMENT			
		LC STAGE	INDICATORS	APPROACHES	DATA
SDG 3	Negative (*quantitative*)	Manufacturing	Occupational exposure assessment Human Toxicity (Cancer and Non-Cancer) Photochemical Oxidant Formation Fine Particulate Matter Formation Ionising Radiation Ozone Depletion (in terms of increase in various type of cancer and increase in other diseases/causes). Climate Change — Global Warming (in terms of its contribution to the increase in other diseases, as well as malnutrition)	RA LCA	Primary and Secondary data
	Positive (*qualitative*)	Manufacturing	High safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace	S-LCA	Secondary data
	Positive (*qualitative*)	Use	Measured capture efficiencies of coarse and fine brake-wear particles at the source.	LCA	Primary and Secondary data
	Positive (*qualitative*)	Use	Premature deaths due to exposure to fine particulate matter (PM2.5) and causes of death (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease)	HRA (*currently limited to Hazard Assessment*)	Epidemiology studies
	Positive (*qualitative*)	Use	High safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace	S-LCA	Secondary data
	Positive (*qualitative*)	End-of-Life	Offsets the upstream toxicity associated with virgin steelmaking, while the controlled disposal of spent fibre and trapped dust prevents uncontrolled worker or community exposure	LCA	Primary and Secondary data
SDG 6	Negative (*quantitative*)	Manufacturing	Freshwater ecotoxicity; Freshwater eutrophication; Water use	LCA	Primary and Secondary data
	Positive (*qualitative*)	Use	Freshwater ecotoxicity; Freshwater eutrophication; Water use	LCA	Primary and Secondary data
	Positive (*qualitative*)	End-of-Life	Mineral Resource Depletion	LCA	Primary and Secondary data
SDG 8	Positive (*qualitative*)	Manufacturing	Skilled employment in welding, assembly, and quality control without increasing accident risk.	LCA	Primary data

	Positive (*qualitative*)	Manufacturing	Complying with stricter environmental standards and labour laws, thereby minimising social risks and ensuring fair working conditions	S-LCA	Primary data
	Positive (*qualitative*)	End-of-Life	Skilled employment in welding, assembly, and quality control without increasing accident risk.	LCA	Primary data
SDG 9	Positive (*qualitative*)	Manufacturing	Embodies industrial innovation within the existing vehicle fleet	LCA	Primary data
	Positive (*qualitative*)	Manufacturing	Impact through multiple EU-level patents, highlighting strong innovation and future market potential.	S-LCA	Primary data
SDG 11	Negative (*quantitative*)	Manufacturing	Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource Depletion Fossil Resource Depletion	LCA	Primary and Secondary data
	Positive (*qualitative*)	Use	Particle matter	LCA	Primary data
	Positive (*qualitative*)	End-of-Life	Industrial disposal occurs away from cities, and recycling prevents additional urban waste streams	LCA	Primary data
SDG 12	Negative (*quantitative*)	Manufacturing	Mineral Resource Fossil Resource	LCA	Primary and Secondary data
	No Change/neutral impact	Use	Mineral Resource Fossil Resource	LCA	Primary and Secondary data
	Positive	End-of-Life	Mineral Resource Minerals and metals, offsetting	LCA	Primary and Secondary data
SDG 13	Negative (*quantitative*)	Manufacturing	Climate Change, Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource depletion, and Fossil Resource depletion	LCA	Primary and Secondary data
	No Change/neutral impact	Use	No power demand and negligible mass relative to the vehicle, and it is not meant to reduce CO2 footprint during use	LCA	Primary and Secondary data
	Neutral-to-slightly-positive contribution	End-of-Life	Climate Change, Freshwater Ecotoxicity, Freshwater Eutrophication, Marine Eutrophication, Freshwater Resource Depletion, Terrestrial Ecotoxicity, Terrestrial Acidification, Mineral Resource depletion, and Fossil Resource depletion	LCA	Primary and Secondary data

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SDG 14	Negative (*quantitative*)	Manufacturing	Marine Ecotoxicity	LCA	Primary and Secondary data
	Positive (*quantitative*)	Use	Marine Eutrophication	LCA	Primary and Secondary data
	Positive (*quantitative*)	End-of-Life	Mineral Resource Fossil Resource Freshwater Resource Depletion	LCA	Primary and Secondary data
SDG 15	Negative (*quantitative*)	Manufacturing	Terrestrial Ecotoxicity	LCA	Primary and Secondary data
	Positive (*quantitative*)	Use	Terrestrial Acidification Eutrophication	LCA	Primary and Secondary data
	Positive	End-of-Life	Mineral Resource Fossil Resource Freshwater Resource Depletion	LCA	Primary and Secondary data
SDG 17	No Change/neutral impact	Use	No power demand and negligible mass relative to the vehicle, and it is not meant to reduce CO2 footprint during use	LCA	Primary and Secondary data

6.5. OVERALL SUSTAINABILTIY EVALUATION/IMPACT ASSEMENT EVALUATION

Table 9. Endpoint Impact Indicators, aggregated in DALY and species lost per year

UNIT	TOTAL BASELINE	TOTAL SOLUTION	% CHANGE	INTERPRETATION
DALY (Human Health)	7,37E-04	4,87E-04	↓ 33,88%	Overall improvement for human health
Species·yr (Ecosystems)	9,61E-07	4,19E-07	↓ 56,43%	Overall improvement for ecosystems

Table 10. Damage cost for entire Life Cycle

ENVIRONMENTAL IMPACT INDICATOR	BASELINE	SOLUTION	DAMAGE COST PER UNIT	DAMAGE COST BASELINE	DAMAGE COST SOLUTION
Climate change, default, excl biogenic carbon [kg CO2 eq.]	0	11,24512	€ 0,13	€ 0,00	€ 1,46
Climate change, incl biogenic carbon [kg CO2 eq.]	0	11,22514	€ 0,13	€ 0,00	€ 1,46
Fine Particle Matter Formation [kg PM2.5 eq.]	0,842	0,63011	€ 84,70	€ 71,32	€ 53,37
Fossil depletion [kg oil eq.]	0	3,72205	€ 0,03	€ 0,00	€ 0,10
Freshwater Consumption [m3]	0	0,054262	€ 0,41	€ 0,00	€ 0,02
Freshwater ecotoxicity [kg 1,4 DB eq.]	0,490215	0,194647	€ 0,02	€ 0,01	€ 0,00
Freshwater Eutrophication [kg P eq.]	0	1,23E-05	€ 14,25	€ 0,00	€ 0,00
Human toxicity, cancer [kg 1,4-DB eq.]	54,37986	21,09097	€ 3,99	€ 216,98	€ 84,15
Human toxicity, non-cancer [kg 1,4-DB eq.]	117,7815	45,79031	€ 0,07	€ 8,36	€ 3,25
Ionizing Radiation [kBq Co-60 eq. to air]	0	0,14912	€ 0,00	€ 0,00	€ 0,00
Land use [Annual crop eq.·y]	0	0,383718	€ 0,10	€ 0,00	€ 0,04
Marine ecotoxicity [kg 1,4-DB eq.]	36,43867	14,06607	€ 0,00	€ 0,12	€ 0,05
Marine Eutrophication [kg N eq.]	0	0,000141	€ 14,25	€ 0,00	€ 0,00
Metal depletion [kg Cu eq.]	0	0,523106	€ 0,01	€ 0,00	€ 0,01
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	0	0,016881	€ 0,42	€ 0,00	€ 0,01
Photochemical Ozone Formation, Human Health [kg NOx eq.]	0	0,016777	€ 1,86	€ 0,00	€ 0,03
Stratospheric Ozone Depletion [kg CFC-11 eq.]	0	2,30E-06	€ 29,10	€ 0,00	€ 0,00
Terrestrial Acidification [kg SO2 eq.]	0	0,04877	€ 5,28	€ 0,00	€ 0,26
Terrestrial ecotoxicity [kg 1,4-DB eq.]	83967,49	32394,54	€ 0,00	€ 53,74	€ 20,73
			TOTAL	**€ 350,52**	**€ 164,95**

Table 11. Eco-Costing for the Life Cycle

ENVIRONMENTAL IMPACT INDICATOR	BASELINE	SOLUTION	ECO-COST PER UNIT	ECO-COST BASELINE	ECO-COST SOLUTION
Acidification [Mole of H+ eq.]	0	0,068378416	7,65	0	0,523095
Climate Change - total [kg CO2 eq.]	0	11,08063761	0,15	0	1,662096
Climate Change, biogenic [kg CO2 eq.]	0	0,043019096	0	0	0
Climate Change, fossil [kg CO2 eq.]	0	11,02262597	0,15	0	1,653394
Climate Change, land use and land use change [kg CO2 eq.]	0	0,01499254	0	0	0
Ecotoxicity, freshwater - total [CTUe]	187,3008792	148,0069763	0,00289	0,5413	0,42774
Ecotoxicity, freshwater inorganics [CTUe]	187,3008792	143,4512607	0,00289	0,5413	0,414574
Ecotoxicity, freshwater organics [CTUe]	0	4,555715575	0,00289	0	0,013166

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State Secretariat for Education, Research and Innovation SERI

Eutrophication, freshwater [kg P eq.]	0	1,23E-05	16,46	0	0,000203
Eutrophication, marine [kg N eq.]	0	0,00688714	23,89	0	0,164534
Eutrophication, terrestrial [Mole of N eq.]	0	0,07594675 2	1,71	0	0,129869
Human toxicity, cancer - total [CTUh]	1,90E-07	8,25E-08	920	0,000175	7,59E-05
Human toxicity, cancer inorganics [CTUh]	1,90E-07	7,81E-08	0	0	0
Human toxicity, cancer organics [CTUh]	0	4,42E-09	0	0	0
Human toxicity, non-cancer - total [CTUh]	1,35E-06	5,94E-07	216	0,000291	0,000128
Human toxicity, non-cancer inorganics [CTUh]	1,35E-06	5,92E-07	0	0	0
Human toxicity, non-cancer organics [CTUh]	0	1,83E-09	0	0	0
Ionising radiation, human health [kBq U235 eq.]	0	0,86700906 7	0	0	0
Land Use [Pt]	0	33,8699431 1	0	0	0
Ozone depletion [kg CFC-11 eq.]	0	8,71E-11	0	0	0
Particle matter [Disease incidences]	0,00020081 4	0,00014731 8	147	0,02952	0,021656
Photochemical ozone formation, human health [kg NMVOC eq.]	0	0,02185645 4	6,12	0	0,133761
Resource use, fossils [MJ]	0	159,210985 3	0	0	0
Resource use, mineral and metals [kg Sb eq.]	0	0,00027152 8	0	0	0
Water use [m^3 world equiv.]	0	1,81206318 3	0	0	0
			TOTAL	**€ 0,57**	**€ 0,88**

7. FILTER SQUARES

7.1. DESCRIPTION OF THE RETROFIT SOLUTION

The design of an existing Filter Square air purifier was enhanced and field-tested as a retrofit solution to reduce particle exposure in enclosed environments such as bus stops, tunnels, and metro stations. Figure 6 illustrates the existing Filter Square air purifier.

Product descripton

The filter square's main component materials include **non-alloy** and **low carbon alloy steels**, used in structural parts like **sheet metal**, **cross bars**, **pipes**, and **studs**. Fasteners such as **rivets**, **screws**, **bolts**, and **nuts** are made from both standard and **stainless steel** for strength and corrosion resistance. **Washers** in steel and stainless steel complete the assembly, ensuring durability and reliable performance in demanding environments.

The Filter Square assembly includes key structural parts like the support plate, support bracket, and sheet metal housing for stability and protection. Airflow is managed by a flow grid, while electrical connectivity is provided through sockets, plugs, cable brackets, and organized wire and cable harnesses. Integrated sensors, including a pressure sensor and contact switch, enable system monitoring. A control panel allows user interaction, and a mounting foot ensures secure installation.

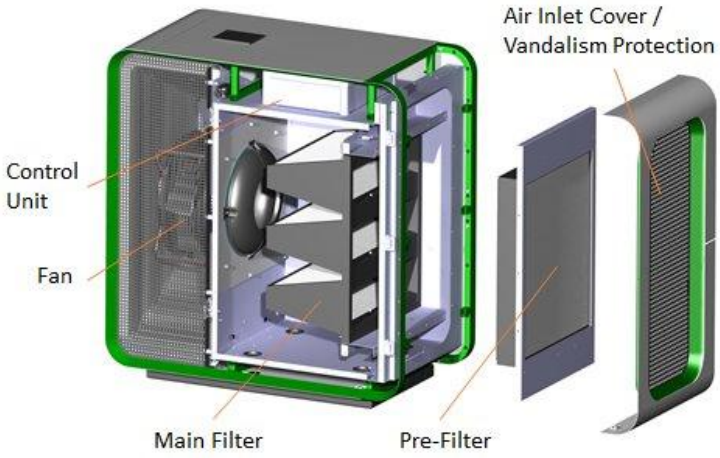

Figure 6. Filter Square air purifier unit

The Filter Square are manufactured through processes such as laser cutting, extrusion, machining, bending, and forming to shape structural components. Assembly uses welding, fastening, and riveting to ensure a secure build. Key structural elements like the frame, inlet and outlet grids, and covers are mounted early in the process.

Functional parts, including the fan, acoustic foam, edge protection, and intake port (with grounding strap and sticker), are then installed. Sensors such as differential pressure sensors and the smoke detector are mounted, along with the switch cabinet and door switch.

Cable routing is performed for both left and right versions, including fan wiring, followed by grounding of the frame and door. The process concludes with the installation of labels, outlet grid, and final covers, completing the assembly.

7.2.SYSTEM BOUNDARIES OF OSA

A preliminary risk scoping analysis was conducted to support the implementation of the OSA framework, which helps to define risks scenarios, establish system boundaries, and identifying the most critical aspects to assess.

For AeroSolfd retrofit Filter Squares product (P3), the system boundaries follow a partial life cycle approach (Cradle-to-Use). This includes Manufacturing phase (component manufacturing, and assembly) and the Use phase, while excluding upstream activities (e.g., material extraction and processing) and downstream activities (e.g., end-of-life/disposal or recycling). Data for these excluded stages were assumed or derived from literature or LCA databases. A summary is provided in Table 12 below.

Table 12. Life cycle set up based on boundary system defined in AeroSolfd

LC-1	Raw-Material Extraction	Material Processing	Manufacturing		Use	Disposal
LC-2	Raw-Material Extraction	Material Processing	Component Manufacturing	Assembly	Use	End of Use/Life
P1	Assumed	Assumed				Assumed
P2	Assumed	Assumed				Assumed
P3	Assumed	Assumed				Assumed

LC-1: Simplified product's Life cycle stage based on ISO 14040; LC-2: Life cycle set up for AeroSolfd (Gate-to-Gate); P1: Tailpipe filter; P2: Passive brake dust particles filter; P3: Filter square.

7.3.SGD ASSESSMENT ALONG THE LIFE-CYCLE

7.3.1. SDG3 - GOOD HEALTH AND WELL-BEING

Manufacturing

From RA

Occupational exposure: Workers involved in producing the Filter Square may be exposed to metal dust and welding fumes, particularly when working with stainless steel components through processes like cutting, bending, machining, and welding. These emissions may contain Cr, Ni, Mn and in the case of DX51D+Z, Zn fumes, which can pose inhalation risks without proper exposure mitigation. The use of acoustic foam and any adhesives or coatings introduces the potential for volatile organic compound (VOC) exposure, especially during application or curing. Additionally, there are ergonomic risks from handling heavy or sharp structural parts, as well as the potential for injury during welding, riveting, or fastening. Assembly of electrical parts, such as sensors and control panels, carries the risk of electrical shock or burns if safety procedures are not strictly followed.

From LCA

Although the burdens occur away from exposure hotspots, they contribute to background PM formation. The magnitude is proportional to material intensity and electricity mixes at suppliers. This phase accounts for the majority of resource consumption and environmental impacts. The Filter Square's production stage adds health-related burdens mainly through metal refining, polymer processing, and electronics assembly. According to ReCiPe 2016, Human toxicity (cancer) reaches 4.02 kg 1,4-DB eq, while Human toxicity (non-cancer) is 3.02 kg 1,4-DB eq, reflecting upstream releases of nickel, chromium, and solvent emissions. In EF 3.1, these equate to 9.9 × 10^{-7} CTUh (cancer) and 5.24 × 10^{-7} CTUh (non-cancer). Fine-particulate emissions from manufacturing are minimal (0.077 kg $PM_{2.5}$-eq) but present. These burdens are associated with a **medium negative impact on SDG3.**

From SLCA

The S-LCA shows a **positive impact** on SDG 3 through high safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace. Regular assessments of health and safety practices help sustain strong performance and employee well-being. Additionally, workers are provided with PPE and the company implemented new safety protocols, further ensuring no increased risks from hazardous materials. Finally, M+H guarantees that all employees receive legally mandated social security benefits, along with additional support on Sickness Leave, allowing workers to recover without financial strain, and reducing the risk of infection spread.

Use

From RA

Occupational exposure: During maintenance or repair of the Filter Squares, technicians may be exposed to worn or degraded materials, such as acoustic foam, which may release particulates or trace chemicals over time. Electrical components can also pose hazards if accessed without proper insulation.

Exchange filters is also known to be associated with risk of exposure to dust and volatiles captured on the filter. The risk of this exposure depends entirely on the service environment. Specific procedures may be established to exchange filters directly into filter waste-bags. Alternatively, PPE should be used if filter change is conducted.

The Hazard Assessment (HA) for the Filter Square was also conducted through a literature review, focusing on the indicators *Premature deaths due to exposure to fine particulate matter* (PM2.5) and *Causes of death* (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease), as detailed in Deliverable 4.2.

Four intervention studies were identified where ambient air particulate levels were reduced. These included: a natural intervention study of the health effects of reducing black smoke (approximately equivalent to PM_{10}) following a coal-burning ban; health outcomes of individuals relocating to areas with lower $PM_{2.5}$ levels; a quasi-experimental study of the health effects of a diesel emission control ordinance lowering diesel engine exhaust emissions, and health effects of the temporary shutdown of a steel mill, reducing PM_{10} exposure.

The first study showed that banning coal burning significantly reduced black smoke concentrations, which was associated with a decline in mortality, in particular cardiovascular mortality. Similarly, the second study indicated that individuals who moved from areas with high to moderate pollution experienced reduced mortality rates. The third study also demonstrated lower mortality following the lowering of diesel engine exhaust emission levels. The fourth intervention also demonstrated lowered mortality during the steel mill's temporary closure. Based on these intervention studies, it is estimated that total mortality is reduced by 0.16-0.21% per ug PM10 or 0.10-0.11% per ug PM2.5.

Based on these findings, **it can be assumed that the Filter Square could have a positive impact on achieving SDG 3** (Good Health and Well-being) by contributing to reduced air pollution and related health risks.

From LCA

During operation, the Filter Square substantially reduces indoor exposure to PM in metro environments. Field measurements in Lisbon showed average reductions of 18–25 %, with peak efficiencies up to 77 % when HVAC systems were off and eight units operated at full flow. The LCA parameterisation (best-case, 2 h/day, 77 % efficiency, CADR = 5 544 $m^3 h^{-1}$, f = 0.585) yields an effective removal of ≈ 174 mg $PM_{2.5}$ per kWh. These performance gains translate into large avoided health damages: in the damage-costing results, Human toxicity, cancer drops by −130.5 kg 1,4-DB eq (−€ 520.73) and Human toxicity, non-cancer by −55.5 kg 1,4-DB eq (−€ 3.94), clearly outweighing the small added burden from electricity use (8.65 kg CO_2-eq yr^{-1}). Indoor fine-particle exposure reduction therefore provides a **high positive impact to SDG 3**

From SLCA

The S-LCA shows a **potentially negative** impact due to moderate difficulty in assembly and repetitive tasks that may lead to fatigue and ergonomic strain.

End of life

From RA

Data not available; not assessed.

From LCA

Although the burdens occur away from exposure hotspots, they contribute to background PM formation. The magnitude is proportional to material intensity and electricity mixes at suppliers. This phase accounts for the majority of resource consumption and environmental impacts. At end-of-life, the product is dismantled under the WEEE framework. Metal recycling avoids further toxicity from primary mining, recorded as small negative values in both indicator sets (Human toxicity, cancer −0.099 kg 1,4-DB eq; Fine PM −0.0137 kg $PM_{2.5}$-eq). Thus this is associated with a **low positive impact on SDG3.**

From SLCA

Data not available; not assessed.

7.3.2. SDG6 - CLEAN WATER AND SANITATION

Manufacturing

From RA

Data not available; not assessed.

From LCA

Upstream material production introduces aquatic toxicity and water use. ReCiPe Freshwater ecotoxicity is +0.0166 kg 1,4-DB eq, and Freshwater eutrophication is 9.0×10^{-5} kg P eq. EF 3.1 Ecotoxicity, freshwater – total records 222 CTUe, while Water use equals 2.39 m^3 world eq. These indicate moderate, material-driven burdens from refining and chemical processing. Thus, the manufacturing phase is associated with a **medium negative impact on SDG6.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

In service, less particulate and metallic dust settles and is washed into drains, reducing the pollutant load entering sewer systems. Although this micro-environmental benefit is not credited in ReCiPe or EF 3.1, it aligns with a reduction in local ecotoxic stress. Thus, the use phase is associated with a low-to-medium positive impact on SDG6.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At end-of-life, the assumed recycling path partially reduces the need for virgin steel production and its associated effluents. Spent filter media and trapped dust are handled through controlled disposal, eliminating uncontrolled leaching. With correct disposal of electric and electronic equipment, it is possible to have a a small but positive contribution to water quality protection, thus the end of life is associated with a **low positive impact on SDG6.**

From SLCA

Data not available; not assessed.

7.3.3. SDG8 - DECENT WORK AND ECONOMIC GROWTH

Manufacturing

From RA

Data not available; not assessed.

From LCA

Production of the Filter Square stimulates skilled employment in welding, assembly, and quality control without increasing accident risk. This is however beyond the scope of environmental LCA. Nevetheless, the creation of a retrofitting solution indicates a **low-to-medium positive impact on SDG 8.**

From SLCA

The S-LCA shows a moderately positive impact on SDG 8, mainly through compliance with strong environmental standards and labour laws, reducing socials risks while maintain responsible production practices. The inclusion of CSR clauses in contracts and timely supplier payments further support ethical business conduct. The company's focus on staff training indicates a continuous commitment in workforce development, even while innovation, local job creation, and new hires were scarce. Employees receive minimum social security benefits and paid sick leave, enabling them to recover without financial strain, and promoting a healthier and secure workforce.

There is room for improvement as demonstrated through the absence of supplier audits for prototype suppliers and absence of salary audits to identify and address pay discrepancies.

Use

From RA

Data not available; not assessed.

From LCA

Yearly cartridge replacement and standard electrical inspection sustain stable maintenance activity without excessive labour. However this falls beyond the scope of environmental LCA. The use phase is then associated with a neutral-to-low-postive impact on SDG8

From SLCA

The S-LCA shows a potentially **negative impact** on SDG 8 due to the dependence on a single supplier which may lead to unforeseen delays, potentially contributing to users' dissatisfaction, putting pressure and stress on workers, and creating reputational problems. The large dimensions of the product may also present challenges to clients when storing and transporting it, however, the maintenance of the product, albeit time-consuming, is straightforward with the support of the manual.

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End of life

From RA

Data not available; not assessed.

From LCA

Treatment of spent cartridges, disassembly of electrical and electronic components, as well as recycling of metal parts sustain stable activity without excessive labour. However this falls beyond the scope of environmental LCA. The end of life phase is then associated with a neutral-to-low-postive impact on SDG8.

From SLCA

Data not available; not assessed.

7.3.4. SDG9 - INDUSTRY, INNOVATION AND INFRASTRUCTURE

Manufacturing

From RA

Data not available; not assessed.

From LCA

The Filter Square exemplifies the integration of sensor-based operation, modular fan units, and data-driven optimisation without rebuilding HVAC systems.Thus, although FALLING beyond the scope of an environmental LCA, it the Filter Sqaure during manufacturing has a medium positive impact on SDG9.

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Data not available; not assessed.

From SLCA

Data not available; not assessed.

7.3.5. SDG11 - SUSTAINABLE CITIES AND COMMUNITIES

Manufacturing

From RA

Data not available; not assessed.

From LCA

The manufacturing stage of the Filter Square has a medium negative on SDG 11, as it occurs entirely off-site in specialized industrial facilities with minimal direct interaction with urban environments. While upstream activities such as material extraction and component fabrication may generate environmental impacts, these do not directly influence the sustainability or livability of cities and communities. The overall effect: **medium impact on SDG 11.**

From SLCA
Data not available; not assessed.

Use
From RA
Data not available; not assessed.

From LCA
In metro stations, the Filter Square's core purpose is to improve air quality for the public. Field data show $PM_{2.5}$ reductions 18–25 % (daily) and up to 77 % locally. ReCiPe Fine Particulate Matter Formation (0.0579 kg $PM_{2.5}$-eq) records the minor system burden, while EF 3.1 Particle matter [disease incidences] = 3.49×10^{-6} confirms negligible added exposure. In contrast, the actual indoor concentrations fall markedly—an effect captured in your performance metric (174 mg removed per kWh). Operated strategically, it supports healthier, more sustainable public-transport facilities. Thus this is associated with a **high positive impact on SDG11.**
From SLCA
Data not available; not assessed.

End of life
From RA
Data not available; not assessed.

From LCA
Industrial disposal occurs away from cities, and recycling prevents additional urban waste streams. Hence, the net contribution to SDG 11 is dominated by the positive urban-air benefit during use. The end of life stage is indirectly associated with a **medium positive impact on SDG11.**

From SLCA
Data not available; not assessed.

7.3.6. SDG12 - RESPONSIBLE CONSUMPTION AND PRODUCTIONS

Manufacturing
From RA
Data not available; not assessed.

From LCA
Production drives Climate change = 90.55 kg CO_2-eq, Fossil depletion = 24.57 kg oil-eq, Metal depletion = 2.96 kg Cu-eq, and Resource use – fossils = 1 055 MJ. These values define the initial consumption footprint. The assessment considered relevant indicators related to damage to ecosystems and resource availability, including *Mineral Resource Depletion*, *Fossil Resource Depletion*, and *Freshwater Resource Depletion*. As a result, the manufacturing phase of the Filter Square demonstrates **a medium negative impact on SDG 12.**
From SLCA
The S-LCA demonstrates a **moderately positive** impact on SDGs 12 by sourcing from Germany that apply strict labour laws and environmental standards, and through the inclusion of CSR clauses in

contracts and internal CSR policies reflecting alignment with ethical practices. Though, the lack of supplier audits for prototype suppliers presents uncertainty and highlights the need for improved evaluation

Use

From RA

Data not available; not assessed.

From LCA

Operational energy consumption emerged as a significant contributor to these impacts, as the Filter Square is an active system that requires continuous fan and control operation. No consumables apart from filters, and an energy use 335.8 kWh yr^{-1} delivers significant health benefit. Operating during peak exposure rather than continuously exemplifies responsible use of resources. As a result, the use phase of the Filter Square demonstrates a **low positive impact on SDG 12.**

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

Recycling credits in ReCiPe Metal Depletion and EF 3.1 Resource use – minerals and metals, offsetting part of manufacturing burdens. Together these effects yield a **low positive impact SDG 12**.

From SLCA

The S-LCA demonstrates a **neutral impact** on SDGs 12, however, special collection and disposal is required for replaced components which leads to extra costs.

7.3.7. SDG 13 - CLIMATE ACTION

Manufacturing

From RA

Data not available; not assessed.

From LCA

Production adds 90.55 kg CO_2-eq. Electricity use during operation adds 8.65 kg CO_2-eq yr^{-1}, while recycling yields −16.98 kg CO_2-eq. The net total (82 kg CO_2-eq → € 10.7 damage cost) defines the device's climate footprint, thus having a medium to high negative impact on SDG13. Climate result is dominated by electricity + production, and never fully offset by the device. Therefore, there is a need to decarbonise power and to reduce metal mass/increase recycled content, and keep targeted operation.

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

Because Portugal's grid is around 70% renewables (2023), the 8.66 kg CO_2-eq/yr energy burden is modest; on dirtier grids it would grow. While the use phase of the Filter Square allows for particles to be capture,s the climate change impact indicators, measured in CO2 eq does not get offset in any way. Thus, the use phae is associated with a neutral impact on SDG13.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

At end-of-life, the assumed recycling path partially reduces the need for virgin steel production and its associated effluents. Spent filter media and trapped dust are handled through controlled disposal, eliminating uncontrolled leaching. With correct disposal of electric and electronic equipment, it is possible to have a small but positive contribution to water quality protection, thus the end of life is associated with **a neutral to low positive impact on SDG13.**

From SLCA

Data not available; not assessed.

7.3.8. SDG 14 – LIFE BELOW WATER

Manufacturing

From RA

Data not available; not assessed.

From LCA

Upstream alloy production contributes small marine toxicity (0.056 kg 1,4-DB eq) and eutrophication (0.00225 kg N eq), totalling € 0.03 damage cost. This is then associated with a low negative impact on SDG14.

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

Once operating, the Filter Square intercepts fine airborne particles that would otherwise settle on station floors and be washed into drainage networks. The captured mass over its 10-year lifetime ($PM_{2.5}$-equivalent, including Fe, Cu, Mn, Cr, Zn, and Pb) represents several grams per day of metal that no longer reaches surface water via runoff. This function is not fully captured by standard LCIA models because indoor removal is not treated as an emission reduction, but conceptually it avoids downstream aquatic toxicity. If we compare damage-cost values, the marine ecotoxicity category switches from a positive € 0.12 (baseline) to a slight benefit (−€ 0.01) in the full life-cycle balance, evidencing that capture outweighs the small manufacturing footprint.
In coastal cities where stormwater discharges directly into marine basins, this reduction contributes

directly to SDG14 which aim to reduce marine pollution from land-based sources. It can be concluded that it has a medium positive effect on SDG14.

From SLCA

Data not available; not assessed.

End of life

From RA

Data not available; not assessed.

From LCA

The end-of-life model (shredding, sorting, melting) recovers steel, aluminium, and copper, displacing virgin smelting operations that are among the most polluting industrial activities for aquatic ecosystems. The credit appears as negative marine-toxicity values in both ReCiPe and EF 3.1 (EoL = −0.033 kg 1,4-DB eq). Polymer and electronic residues are incinerated with energy recovery, with negligible influence on marine compartments, thus having a **low positive impact on SDG14.**

From SLCA

Data not available; not assessed.

7.3.9. SDG 15 – LIFE ON LAND

Manufacturing

From RA

Data not available; not assessed.

From LCA

Among all categories, terrestrial ecotoxicity is the largest contributor in the Filter Square life cycle. In ReCiPe 2016, production reaches 58.9 kg 1,4-DB eq, while the broader EF 3.1 Ecotoxicity, terrestrial – total category records 433 Pt, both tied to mining and alloy production of stainless steel and copper. Accompanying categories (Terrestrial acidification (0.173 kg SO_2-eq) and Land use (3.65 Annual-crop eq·yr)) add smaller contributions but reinforce that extraction and refining remain the main environmental cost. This gives manufacturing a **high negative rating for SDG 15.**

From SLCA

Data not available; not assessed.

Use

From RA

Data not available; not assessed.

From LCA

During operation, the Filter Square captures PM containing substantial fractions of Fe (366 g), Cu (259 g), Mn (283 g), Cr (587 g), and Zn (391 g) Refer to D4.4 for more information. Without the device, these metals would settle on surfaces, ballast, or soil near metro tracks, contributing to long-term accumulation and toxicity for soil microorganisms and plants. This avoided deposition explains the negative terrestrial-ecotoxicity result in the damage-cost table (overall −5 783 kg 1,4-DB eq → −€ 3.7). It also improves EF 3.1 Eutrophication, terrestrial (0.541 mol N eq) and Acidification (0.26 mol H^+ eq), showing reduced nutrient and acid stress. In ecological terms, this equates to fewer soil-quality degradations and lower bioaccumulation in urban fauna, having a **high positive impact on SDG 15.**

From SLCA

Data not available; not assessed.

End of life

From RA
Data not available; not assessed.
From LCA
The ReCiPe and EF3.1 Land-use indicator showed that, while still material-intensive, recovered metals substantially lower the need for new extraction sites and a controlled WEEE handling prevents soil contamination by residues. Thus, this has an associated **low positive impact on SDG15.**

From SLCA
Data not available; not assessed.

7.3.10. SDG 17 – PARTNERSHIP FOR THE GOALS

Manufacturing

From RA
Data not available; not assessed.
From LCA
Within AeroSolFDseveral partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a **neutral impact on SDG17.**
From SLCA
Data not available; not assessed.

Use

From RA
Data not available; not assessed.
From LCA
Within AeroSolFDseveral partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a **neutral impact on SDG17.**
From SLCA
Data not available; not assessed.

End of life

From RA
Data not available; not assessed.
From LCA
Within AeroSolFDseveral partners participated in integrated design, testing, and life-cycle modelling under shared data protocols. This collaboration produced a harmonised understanding of environmental and social performance that can be transferred to policy and standardisation bodies. This however is beyond the scope of an environmental LCA and thus the manufacturing, use phase and end of life is associated with a **neutral impact on SDG17.**
From SLCA
The S-LCA shows a **moderately positive impact** on SDG 17 with the sharing of knowledge to industry partners, promoting innovation and possible future policy adoption, however, there is room for

broader engagement since there is minimal increase in stakeholder diversity when the new product was introduced.

7.4.SUMMARY TABLE

Table 13. Summary table with overall assessment for the Filter Squares for each indicator group along the life-cycle.

SDGs	IMPACT	ASSESSMENT			
		LC STAGE	INDICATORS	APPROACHES	DATA
SDG 3	Negative (quantitative)	Manufacturing	Occupational exposure Human Toxicity (cancer and non-cancer) Fine Particulate Matter Formation Photochemical Ozone Formation (HH)	RA LCA	Primary & Secondary (LCA databases, BoM averages)
	Positive (qualitative)	Manufacturing	high safety standards, comprehensive training, and continuous incident monitoring, ensuring a safe and healthy workplace	S-LCA	Primary data
	Positive (quantitative)	Use	Occupational exposure Fine Particulate Matter Formation Human Toxicity (cancer and non-cancer) Photochemical Ozone Formation Health damage (DALY)	RA LCA	Primary (Field measurements, operational data) + Secondary (LCA databases)
	Positive (qualitative)	Use	Premature deaths due to exposure to fine particulate matter (PM2.5) and Causes of death (e.g.: Asthma, Chronic obstructive pulmonary disease, Lung cancer, Diabetes Mellitus, Stroke, Ischemic heart disease	HRA (*currently limited to Hazard Assessment*)	Epidemiology studies
	Negative (qualitative)	Use	Difficulty in assembly and repetitive tasks that may lead to fatigue and ergonomic strain.	S-LCA	Primary data
	Slight Positive (quantitative)	End-of-Life	Human Toxicity Fine Particulate Matter Formation	LCA	Secondary (WEEE treatment data)
SDG 6	Negative (quantitative)	Manufacturing	Freshwater Ecotoxicity Freshwater Eutrophication Water Use	LCA	Secondary (Material and process inventories)
	Positive (quantitative)	Use	Reduced aquatic emissions from metal/particle run-off	LCA	Primary and Secondary data

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	Slight Positive (quantitative)	End-of-Life	Freshwater Ecotoxicity Resource Use (Water)	LCA	Secondary (EoL datasets)
SDG 8	Positive (qualitative)	Manufacturing	Resource Use (Fossils) Land Use Infrastructure and Energy Inputs	LCA	Secondary (Industrial averages)
	Positive (qualitative)	Manufacturing	compliance with strong environmental standards and labour laws, reducing socials risks while maintain responsible production practices.	S-LCA	Primary data
	Positive (qualitative)	Use	Operational maintenance requirements Energy Efficiency	LCA	Primary (Partner inputs)
	Negative (qualitative)	Use	single supplier which may lead to unforeseen delays, potentially contributing to users' dissatisfaction, putting pressure and stress on workers, and creating reputational problems	S-LCA	Primary data
	Positive	End-of-Life	WEEE Management Recycling Processes	LCA	Secondary (Regulatory datasets)
SDG 9	Positive (qualitative)	Manufacturing	Metal Depletion Resource Use (Minerals and Metals) Climate Change	LCA	Primary (Design BoM) + Secondary (LCA datasets)
SDG 11	Negative (quantitative)	Manufacturing	Climate Change Fine Particulate Matter Formation Human Toxicity (cancer and non-cancer) Resource Use (Fossils)	LCA	Primary and Secondary (LCA databases)
	Positive (quantitative)	Use	Fine Particulate Matter Formation Photochemical Ozone Formation (HH) Human Toxicity (cancer and non-cancer) Climate Change (energy use)	LCA	Primary (Field measurements) + Secondary (LCA databases)
	Positive (quantitative)	End-of-Life	Resource Use (Minerals and Metals) Metal Depletion	LCA	Secondary (EoL recycling data)
SDG 12	Negative (qualitative)	Manufacturing	Climate Change Fossil Depletion Metal Depletion Resource Use (Fossils) Land Use	LCA	Primary and Secondary (LCA databases)
	Positive	Manufacturing	strict labour laws and environmental standards	S-LCA	Primary data
	Positive (quantitative)	Use	Energy Use Operational Efficiency Fine Particulate Matter Formation	LCA	Primary (Operational data)

	Positive (quantitative)	End-of-Life	Mineral Fossil and Freshwater Resource Depletion	LCA	Secondary (EoL datasets)
SDG 13	Negative (quantitative)	Manufacturing	Climate Change (total, fossil, land-use) Photochemical Ozone Formation (HH and Ecosystems)	LCA	Primary and Secondary (LCA databases)
	Negative (quantitative)	Use	Climate Change (total CO_2-eq) Resource Use (Fossils)	LCA	Primary (Operational energy) + Secondary (Grid mix)
	Positive (quantitative)	End-of-Life	Climate Change credits from recycling Resource Use (Fossils)	LCA	Secondary (EoL datasets)
SDG 14	Negative (quantitative)	Manufacturing	Marine Ecotoxicity Marine Eutrophication Water Use	LCA	Primary and Secondary (LCA databases)
	Positive (quantitative)	Use	Reduction of metal and particulate run-off to aquatic systems	LCA	Primary and Secondary data
	Positive (quantitative)	End-of-Life	Marine Ecotoxicity Resource Use (Water)	LCA	Secondary (EoL data)
SDG 15	Negative (quantitative)	Manufacturing	Terrestrial Ecotoxicity Acidification Land Use Resource Use (Minerals and Metals)	LCA	Secondary (LCA databases)
	Positive (quantitative)	Use	Terrestrial Ecotoxicity Acidification Eutrophication (Terrestrial) Fine Particulate Matter Formation	LCA	Primary and Secondary (LCA databases)
	Positive (quantitative)	End-of-Life	Land Use Metal Depletion	LCA	Secondary (EoL datasets)
SDG 17	Positive (qualitative)	Cross-stage	Partnership Data Sharing	Project Governance	Primary (Project partner datasets) + Secondary (LCA method frameworks)
	Positive (qualitative)	Cross-stage	sharing of knowledge to industry partners, promoting innovation and possible future policy adoption	S-LCA	Primary data

7.5.OVERALL SUSTAINABILITY EVALUATION

Table 14. Endpoint Impact Indicators, aggregated in DALY and species lost per year

UNIT	TOTAL SOLUTION	INTERPRETATION
DALY (Human Health)	-0,000281	Overall improvement for human health
Species·yr (Ecosystems)	0,000000482	Slight burden for ecosystems

The use phase of the Filter Square device involves both environmental burdens and benefits that occur in different locations and therefore must be interpreted carefully. The primary burden is associated with the device's electricity consumption during operation. These impacts are not generated within the metro station itself but rather off-site, at the level of the national or regional power system that supplies the electricity. In contrast, the primary benefit (the capture of particulate matter) occurs on-site, directly within the metro station environment where passengers and staff are exposed.

This creates a spatial mismatch between the origin of environmental burdens and the location of the environmental and health benefits. While electricity-related impacts represent a distributed, system-level pressure on the environment, the captured particles represent a localized improvement in air quality. As such, the comparison between the two should be viewed as an environmental trade-off between off-site energy impacts and on-site air quality gains.

It is also important to note that the assessment compares the midpoint indicators associated with electricity use and particle capture. No exposure modelling or health endpoint translation has been applied, as the intention is to maintain a consistent system boundary focused on emissions and resource use. Consequently, results should be interpreted as a balance between environmental pressures rather than as direct quantifications of health benefits. Future analyses could include sensitivity testing with different electricity mixes or explicit exposure-based characterisation to further refine the interpretation of the use-phase impacts.

Table 15. Damage cost for the full Life Cycle for the Filter Square

	PRODUCTION	EOL	USE PHASE BURDEN (ENERGY DEMAND)	USE PHASE BENEFIT (CAPTURED PARTICLES)	OVERALL	DAMAGE COSTING PER UNIT	TOTAL DAMAGE COST
Climate change, default, excl biogenic carbon [kg CO2 eq.]	90,54843	-16,9796	8,659101	0	82,22793	€ 0,13	€ 10,69

Climate change, incl biogenic carbon [kg CO2 eq.]	90,14955	-16,9598	8,651202	0	81,84097	€ 0,13	€ 10,64
Fine Particle Matter Formation [kg PM2.5 eq.]	0,077047	-0,01376	0,003125	0,008458	0,057953	€ 84,70	€ 4,91
Fossil depletion [kg oil eq.]	24,5698	-2,51414	2,712399	0	24,76806	€ 0,03	€ 0,69
Freshwater Consumption [m3]	0,171009	0,487655	0,316178	0	0,974842	€ 0,41	€ 0,40
Freshwater ecotoxicity [kg 1,4 DB eq.]	0,016598	-0,00288	0,000687	0,092398	-0,078	€ 0,02	€ 0,00
Freshwater Eutrophication [kg P eq.]	7,39E-05	-1,02E-06	1,75E-05	0	9,04E-05	€ 14,25	€ 0,00
Human toxicity, cancer [kg 1,4-DB eq.]	4,015781	-0,09925	0,031249	134,456	-130,508	€ 3,99	-€ 520,73
Human toxicity, non-cancer [kg 1,4-DB eq.]	3,019495	-1,54966	0,141381	57,11051	-55,4993	€ 0,07	-€ 3,94
Ionizing Radiation [kBq Co-60 eq. to air]	0,379107	-0,21026	0,003129	0	0,171977	€ 0,00	€ 0,00
Land use [Annual crop eq.·y]	1,94972	0,318316	1,379422	0	3,647458	€ 0,10	€ 0,36
Marine ecotoxicity [kg 1,4-DB eq.]	0,056494	-0,03307	0,001858	3,017318	-2,99203	€ 0,00	-€ 0,01
Marine Eutrophication [kg N eq.]	0,000615	0,001352	0,000281	0	0,002248	€ 14,25	€ 0,03
Metal depletion [kg Cu eq.]	2,96459	-1,1268	0,011881	0	1,849667	€ 0,01	€ 0,03
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	0,136229	-0,02583	0,012554	0	0,122957	€ 0,42	€ 0,05
Photochemical Ozone	0,135328	-0,0258	0,012373	0	0,1219	€ 1,86	€ 0,23

Formation, Human Health [kg NOx eq.]							
Stratospheric Ozone Depletion [kg CFC-11 eq.]	1,24E-05	1,39E-06	4,96E-06	0	1,88E-05	€ 29,10	€ 0,00
Terrestrial Acidification [kg SO2 eq.]	0,202333	-0,03964	0,010314	0	0,17301	€ 5,28	€ 0,91
Terrestrial ecotoxicity [kg 1,4-DB eq.]	58,88488	-62,2783	1,371584	5781,631	-5783,65	€ 0,00	-€ 3,70
						TOTAL	-€ 499,44

Table 16. Eco Costing Life Cycle Filter Square

	PRODUCTION	EOL	USE PHASE BURDEN (ENERGY DEMAND)	USE PHASE BENEFIT (CAPTURED PARTICLES)	OVERALL	ECO-COST PER UNIT	ECO COST TOTAL
Acidification [Mole of H+ eq.]	0,301681	-0,0586	0,017153	0	0,260232	7,65	1,990775
Climate Change - total [kg CO2 eq.]	89,55543	-16,9539	8,521948	0	81,12348	€ 0,15	12,16852
Climate Change, biogenic [kg CO2 eq.]	0,154112	-0,03647	0,070523	0	0,188168	€ 0,00	0
Climate Change, fossil [kg CO2 eq.]	89,29567	-16,8961	8,343643	0	80,74319	€ 0,15	12,11148
Climate Change, land use and land use change [kg CO2 eq.]	0,105653	-0,02131	0,107781	0	0,192128	€ 0,00	0
Ecotoxicity, freshwater - total [CTUe]	222,4668	-23,4032	18,5607	49,18167	168,4427	2,89E-03	0,486799
Ecotoxicity, freshwater inorganics [CTUe]	211,1515	-20,785	15,93015	49,18167	157,115	2,89E-03	0,454062
Ecotoxicity, freshwater organics [CTUe]	11,31527	-2,61816	2,630551	0	11,32766	2,89E-03	0,032737
Eutrophication, freshwater [kg P eq.]	7,41E-05	-9,65E-07	1,76E-05	0	9,07E-05	€ 16,46	0,001493
Eutrophication, marine [kg N eq.]	0,053664	-0,00561	0,005593	0	0,053643	€ 23,89	1,281531
Eutrophication, terrestrial [Mole of N eq.]	0,580521	-0,10269	0,06342	0	0,54125	€ 1,71	0,925538
Human toxicity, cancer - total [CTUh]	9,90E-07	-3,41E-08	6,33E-09	4,90E-07	4,72E-07	€ 920,00	0,000434
Human toxicity, cancer inorganics [CTUh]	2,17E-08	-4,39E-10	5,73E-10	4,90E-07	-4,70E-07		0

Human toxicity, cancer organics [CTUh]	9,68E-07	-3,36E-08	5,75E-09	0	9,40E-07		0
Human toxicity, non-cancer - total [CTUh]	5,24E-07	-6,38E-08	5,02E-08	6,83E-07	-1,70E-07	€ 216,00	-3,7E-05
Human toxicity, non-cancer inorganics [CTUh]	5,15E-07	-6,41E-08	4,80E-08	6,83E-07	-1,80E-07		0
Human toxicity, non-cancer organics [CTUh]	9,83E-09	2,42E-10	2,19E-09	0	1,23E-08		0
Ionising radiation, human health [kBq U235 eq.]	2,290355	-1,38893	0,020198	0	0,921623		0
Land Use [Pt]	114,969	129,6131	189,3356	0	433,9177		0
Ozone depletion [kg CFC-11 eq.]	1,88E-09	1,75E-08	1,57E-10	0	1,95E-08	€ 0	0
Particle matter [Disease incidences]	6,33E-06	-9,87E-07	1,57E-07	2,02E-06	3,49E-06	€ 147,00	0,000513
Photochemical ozone formation, human health [kg NMVOC eq.]	0,181933	-0,03696	0,015688	0	0,160662	€ 6,12	0,983251
Resource use, fossils [MJ]	1060,88	-118,013	112,8304	0	1055,697		0
Resource use, mineral and metals [kg Sb eq.]	0,000322	-0,00059	2,45E-06	0	-0,00026		0
Water use [m^3 world equiv.]	2,389618	9,167823	15,4323	0	26,98974		0
						TOTAL	30,4371

8. DEVIATIONS FROM THE PLAN

The completion and submission of D4.5 experienced a delay compared with the initial plan.This adjustment was mainly the result of extended data-collection and validation activities across the project. Since many of the performance and operational parameters were being refined in parallel with the assessment work, the analysis phase was postponed so that all inputs were consistent and scientifically sound.

The decision to extend the schedule was taken to prioritise the representativeness of the environmental and socio-economic assessments. Rather than relying on preliminary data, the consortium collectively agreed that integrating verified results would enhance the quality and credibility of the findings.

WP4 activities are inherently connected with data and insights generated throughout the project. This iterative nature of development meant that updates in material composition, energy consumption, and operational behaviour were continuously incorporated into the life-cycle models.

While this created a dynamic workflow, WP coordination and data harmonisation became essential steps before finalising the deliverables, slightly extending the timeline but improving coherence and internal consistency.

To manage this, interim datasets and assumptions were initially used to maintain modelling progress. Regular technical meetings and shared data templates helped align partners, reduce uncertainty, and obtain updates. The timeline adjustment had no adverse impact on the project outcomes.

9. LINKS WITH OTHER WPS

There are no deliverables depending on this deliverable.

10. CONCLUSIONS AND RECOMMENDATIONS

The sustainability assessment conducted within WP4 of the AeroSolfd project evaluated the retrofit solutions developed and tested under the project, with the primary objective of assessing the environmental, social, and economic sustainability of technologies designed to reduce human exposure and environmental impacts from traffic-related emissions.

The assessment employed a comprehensive and integrative approach, combining Life Cycle Assessment (LCA), Risk Assessment (RA), Social Life Cycle Assessment (S-LCA), and Economic Assessment (EA). This multi-dimensional methodology enabled the simultaneous evaluation of environmental performance, human and ecosystem health risks, socio-economic implications, and overall viability of retrofit technologies. The assessment explicitly aligns with several Sustainable Development Goals (SDGs)—notably SDG 3 (Good Health and Well-Being), SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production)—thereby linking project outcomes to broader European and global sustainability objectives.

The assessment demonstrated that the AeroSolfd retrofit solutions can effectively reduce traffic-related emissions while providing additional social and economic benefits, including improved occupational safety and potential resource savings. At the same time, the work identified key methodological challenges, such as harmonizing diverse assessment approaches and handling limited or sensitive data. Differences in data requirements and output metrics between LCA and RA, as well as varying stakeholder perspectives, highlighted the need for ongoing collaboration and refinement of the assessment framework.

Overall, the WP4 work concludes that AeroSolfd contributes not only to the development of effective retrofit solutions for reducing traffic-related emissions but also to advancing systemic sustainability assessment methodologies that support evidence-based decision-making for cleaner and healthier urban environments

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